Preface

The last century witnessed many changes in the practice of medicine. As we move into the 21st century, we will see more and more procedures performed with minimally invasive, image-guided techniques. At the forefront of this revolution is the specialty of interventional radiology. Interventional radiology traditionally involves the treatment of vascular disease, but has grown to include nonvascular intervention and, recently, the treatment of spinal disorders.

The objective of *Interventional Radiology of the Spine: Image-Guided Pain Therapy* is to provide the practicing interventional radiologist with a single source for evaluating and treating the patient with back pain. This includes discussion of interventional spinal procedures, spinal imaging, and the clinical evaluation of the spine patient. The practicing pain specialist will also find this work useful because radiological spinal imaging is included, a topic most pain management textbooks lack. Imaging has become an essential element in the evaluation of patients with back pain.

The book is divided into two sections: Part I: Spinal Anatomy, Imaging, and Clinical Evaluation; and Part II: Interventional Spinal Procedures. Topics in Part I include basic spinal anatomy, CT, MRI, and nuclear medicine of the spine, and the clinical evaluation of the spine patient. Topics in Part II include discussion of the history of spinal procedures, review of the pharmacology of medications used in injection procedures, selective nerve root blocks, epidural injections, facet injections, sacroiliac joint injections, discography, treatment of discogenic back pain, spinal biopsy techniques, percutaneous vertebroplasty, and transcatheter therapy for tumors of the spine.

The topics covered in this book should provide the reader with a useful, comprehensive, state-of-the-art reference on minimally invasive, image-guided spinal procedures, as well as a review of anatomy and imaging findings in spinal disorders. The hope is that *Interventional Radiology of the Spine: Image-Guided Pain Therapy* will allow more interventionalists to fully employ the skill and expertise that they possess to the evaluation and treatment of patients with back pain.

J. Kevin McGraw, *MD*

2 Computed Tomography of the Spine

Stephen Futterer, MD

INTRODUCTION

Computed tomography (CT) and magnetic resonance imaging (MRI) have dramatically changed the way that diseases of the spine are diagnosed and treated. Indeed it is difficult to envision the practice of medicine without these advanced imaging techniques, although their widespread use spans only the last 25 yr. These modalities are best regarded as complementary, rather than as redundant, because each gives different and useful information. As an example, consider the evaluation of a patient with acute cervical spine trauma. Plain film radiography is generally the initial step in the evaluation of these patients. However, plain films are limited in their ability to detect nondisplaced fractures, to characterize complex fractures/dislocations optimally, or to evaluate fully injury at the cervicothoracic junction. In the severely injured patient, plain film evaluation is often hindered by difficulties with patient positioning and cooperation. Overlying material, such as a cervical collar or endotracheal tube, obscures bony detail and further limits the examination.

CT is definitely more sensitive to fractures when compared to plain radiographs. CT is also able to depict more precisely the degree of retropulsion and the relative position of the fracture fragments. Recent advances in CT technology include subsecond spiral imaging and multislice acquisition, which have enabled increasingly rapid imaging of larger body segments and with less image degradation. This is perhaps most evident in the improved quality of the postprocessed images. The ability to represent data accurately in multiple planes has significantly improved the diagnostic capability of CT *(1)*. A fracture in the scan plane, such as a subtle vertebral compression fracture, is easily missed on standard axial CT images while plainly visible on the sagittal reformations.

CT does have its limitations. CT is very insensitive in the detection of spinal cord abnormalities and does not play a role in the evaluation of ligamentous injury. While CT can detect an acute traumatic disc extrusion or epidural hematoma, MRI is considered superior. MRI is clearly indicated for the trauma patient with an acute neurologic deficit to assess both for epidural pathology and cord contusion. Short tau inversion recovery (STIR) images on MRI are useful to assess for ligamentous injury in the uncooperative or obtunded patient, for whom flexion and extension views may be unsafe. The sensitivity of this technique for edema is exemplified by the depiction of increased marrow signal in vertebral bodies that have no loss of height or demonstrable fracture by CT. This phenomenon is commonly seen at multiple levels adjacent to an obvious spinal fracture.

CT does have some distinct advantages over MRI. The most obvious are the immediate accessibility (without the need for screening), shorter imaging time, and the far less frequent problem with claustrophobia. The result is fewer studies limited by motion artifact. Monitoring of critically ill patients is also easier in the CT setting. Several specific problems are best evaluated with CT. The high spatial resolution makes CT optimal for detection of acute fractures and pars interarticularis defects *(2)*. CT more accurately reveals the relationship of surgical hardware to the adjacent bony structures as well as the integrity of the surgical construct. CT detection of pathologic mineralization is also superior to MRI, which lacks both sensitivity and specificity. Calcification may not be evident, even in retrospect, on MR images. When seen, it usually is of low signal intensity on all pulse sequences but can cause

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T1 shortening. Furthermore, blood products and gas can mimic mineralization on MRI. The detection and characterization of pathologic mineralization, as well as the distinction from hemorrhage or gas, has important diagnostic and therapeutic implications. Specific examples include the distinction between osteophyte and disc material, the evaluation of tumor matrix (chondroid or osteoid), the detection of ligamentous ossification (e.g., ossification of the posterior longitudinal ligament [OPLL] or diffuse ideopathic skeletal hyperostosis [DISH]), and the identification of mural calcification in a synovial cyst. There are other applications of CT worth noting. Volumetric data acquisition has also enabled its use for surgical planning and stereotactic intraoperative localization. CT also is invaluable in guiding biopsy procedures. Recent advances in slip-ring technology have allowed the development of CT fluoroscopy. This technique gives nearly real-time feedback of needle position and allows for biopsy of smaller lesions and those subject to motion, particularly in the diaphragmatic region.

As initially stated, CT and MRI should be viewed as complementary, with each having its strengths and weaknesses. In addition to it benefits in the trauma setting, MRI has other advantages over CT in evaluation of spine disorders. The higher contrast resolution of MRI makes it more sensitive to infiltrative marrow disorders, leptomeningeal disease, and intrinsic spinal cord pathology (tumors, demyelinating disease, or syrinx). MRI can also provide physiologic data, as with diffusion-weighted imaging and cerebrospinal fluid (CSF) flow techniques. In the current climate of financial austerity, there is a tendency for insurers and referring physicians to take a “single best test” approach. Although it is ideal to seek conclusive diagnostic information using the fewest and least invasive tests available, there are clearly situations that call for multiple modalities to provide a definitive diagnosis and to optimize treatment planning. Spinal disease is quite complex, and the various clinical presentations lack specificity. This makes it difficult to apply rigidly an algorithm for workup and management. Ultimately the approach must be flexible and take into account both the clinical scenario and the findings on initial imaging evaluation.

CT TECHNIQUE

Advances in CT technology have led to a current generation of CT scanners that boast faster acquisition, increased anatomic coverage, and higher spatial resolution. The result has been an increase in productivity as well as improvement in diagnostic accuracy. Rapid, thin section multidetector volumetric acquisition enables a wide array of postprocessing capabilities, such as high-resolution two-dimensional reformation, three-dimensional volume rendering, and surface shading techniques. This has dramatically enhanced the ability of CT, an inherently two-dimensional modality, to depict three-dimensional structures. The gains are perhaps best exemplified by the surge in applications of CT angiography and in the detailed multiplanar reformations in spine imaging. Surgical procedures involving the brain, sinonasal cavity, and spine are increasingly performed with the assistance of stereotactic imaging guidance using CT data. In addition, the advent of CT fluoro-scopy has enabled almost real-time guidance of interventional procedures. To be sure, the future holds new advances, which will further broaden the diagnostic limits of CT.

CT imaging protocols inevitably vary between institutions depending on the specific capabilities of the scanner, physician preferences, and the clinical indications for evaluation of the spine. At our institution, the CT protocols are based on multidetector (MDCT) scanners. The scan parameters for imaging of the cervical, thoracic, and lumbar spine are very similar. The protocol described in the following is representative. CT data are acquired helically in high-speed mode with a slice thickness of 2.5 mm, a rotation time of 1 s, and a table speed of 7.5 mm per rotation. No gantry tilt is used. Tube voltage is 140 kV and the tube current time product is 300 mAs. The base data are then reconstructed with a bone and soft tissue algorithm to 1.25 mm slice thickness at 1.25-mm slice intervals. For image analysis, sagittal and coronal reformations are obtained with a slice thickness of 2.5 mm based on the reconstructed data. The cervical and lumbar spine studies are performed with quiet respiration while the thoracic studies are acquired during suspended respiration. The studies are usually performed without administration of intravenous contrast. Infrequently a patient presents with a clear indication for contrast, such as the evaluation of possible discitis, but for whom MRI is contraindicated (e.g., the presence of a pacemaker).

DEGENERATIVE SPONDYLOSIS

OVERVIEW

By far the most common indication for spine imaging is to evaluate for degenerative spondylosis as a cause of acute or chronic neck pain, back pain, or symptoms of radiculopathy. For the purposes of this chapter, the discussion on degenerative disease is limited to the lumbar spine. There are innumerable articles and texts on the subject and yet there is no consensus as to the appropriate workup and management of these pain syndromes. Complicating the matter is the relatively high incidence of spinal imaging abnormalities in healthy volunteers. A well known study by Jensen et al. evaluated 98 asymptomatic individuals for abnormalities on lumbar spine MRI. The age of the subjects ranged from 20 to 80 yr and there were nearly equal numbers of men and women. There was a high prevalence of imaging pathology, with only 36% of subjects having a normal disc at all levels. Fifty-two percent of the subjects had a disc bulge at one level or more and 27% had a disc protrusion. Notably disc extrusion was seen in only 1%. Other findings included Schmorl's node (19%), annular tear (14%), and facet arthropathy (8%) *(3)*. Autopsy studies as well as other imaging based studies utilizing myelography, CT, and MRI have found similar results *(4,5)*. This underscores the need for careful correlation of the imaging findings with the clinical presentation, particularly if surgical intervention is considered.

Plain film radiography is often the initial study obtained in the evaluation of symptoms referable to the spine. Radiographs allow for assessment of spine alignment, bone density, vertebral body height, disc height, endplate sclerosis, and osteophyte formation. The advantages of low cost and ready availability of plain radiography are, however, offset by limited soft tissue contrast, structural overlap, and relatively high radiation exposure *(6,7)*. The cross-sectional nature of CT greatly improves the ability to resolve structures of similar density because of the lack of overlap. MRI has the additional advantages over CT of superior contrast resolution, a direct multiplanar imaging capability, and the lack of ionizing radiation. Still there are practical drawbacks to MRI related to availability, expense, length of examination, and patient claustrophobia.

Several published studies have evaluated the relative accuracy of MRI, CT, and CT myelography in the diagnosis of lumbar disc herniation. The results demonstrated that the three examinations were essentially equal in diagnostic ability. Jackson et al. prospectively studied 59 symptomatic patients with low back pain and radiculopathy. Each patient was imaged using all three techniques and every patient underwent surgical exploration (total of 120 disc sites). Accuracy results were as follows: MRI (76.5%), CT myelography (76%), and CT (73.6%). The authors concluded that MRI should be the study of choice in the diagnosis of lumbar disc herniation because of its noninvasive nature and the lack of ionizing radiation *(4)*. Similar results were reported in a cohort of 95 patients by Thornbury et al., who also found no statistical difference in accuracy between the three examinations. They concluded that MRI should replace CT myelography but not CT because the latter is equally accurate but less costly *(5)*. Despite the passage of time, there remains considerable variation in the referral patterns for spine imaging. In some centers, CT myelography surprisingly enjoys continued popularity. Suffice it to say that both CT (with or without myelography) and MRI provide excellent information about spinal anatomy and pathologic derangement, which sometimes is additive. As CT technology continues to improve and with the ever-present issue of cost-effectiveness, it is likely that CT will continue to play a prominent role in the diagnosis of degenerative diseases of the spine.

INTERVERTEBRAL DISC DEGENERATION

CT is relatively limited in the direct evaluation of intervertebral disc pathology. The vacuum disc phenomenon is easily seen on CT although it is a late manifestation of disc degeneration. Loss of disc height can be appreciated on sagittal reformations. CT does readily detect secondary findings of disc degeneration, such as endplate sclerosis or osteophyte formation *(8)*. Clearly MRI affords better delineation of both disc structure and internal derangement. The T2-weighted images alone provide information concerning disc height, disc hydration, the presence or absence of annular tears, and diffuse or focal abnormalities in disc contour *(9)*. As stated earlier, both CT and MRI are accurate in the detection of disc contour abnormalities including diffuse bulge, focal protrusion, and disc extrusion. It could be argued that the diagnostic yield of the additional disc-related findings on MRI is blunted due to their relatively frequent occurrence in the asymptomatic population.

One interesting caveat is the occasionally troublesome appearance of high T2 signal in the disc space in an otherwise degenerative appearing spine. In extreme cases, the findings can be easily confused with discitis, in that the adjacent marrow may demonstrate edema and the disc and endplates may enhance following gadolinium administration. As always, the imaging findings must be put into clinical context. However, it is not unusual for a patient with discitis, particularly if elderly, to have scant clinical evidence of infection. There are several possible explanations for fluid in the disc space in the setting of disc degeneration without infection. The first relates to the vacuum phenomenon. It is theorized that during the course of the MRI examination, gas within a vacuum disc can be replaced by fluid, resulting in high T2 signal within the disc space. Schweitzer and El-Noueam noted the presence of fluid signal within the disc space on T2-weighted MR images in 12 of 100 (12%) patients known to have the vacuum disc phenomenon. In the other 88 subjects, the gas cleft was of low signal intensity on both T1- and T2-weighted images *(10)*. The fluid usually takes a fusiform or linear shape and has a central location within the disc, much like the corresponding gas cleft on plain radiographs *(10)*. Plain films and/or CT will usually confirm the presence of gas in such cases. Awareness of the variable appearance of the vacuum disc on MRI will help avert unnecessary investigations for infectious discitis (Fig. 1). There are other less common disease processes that can

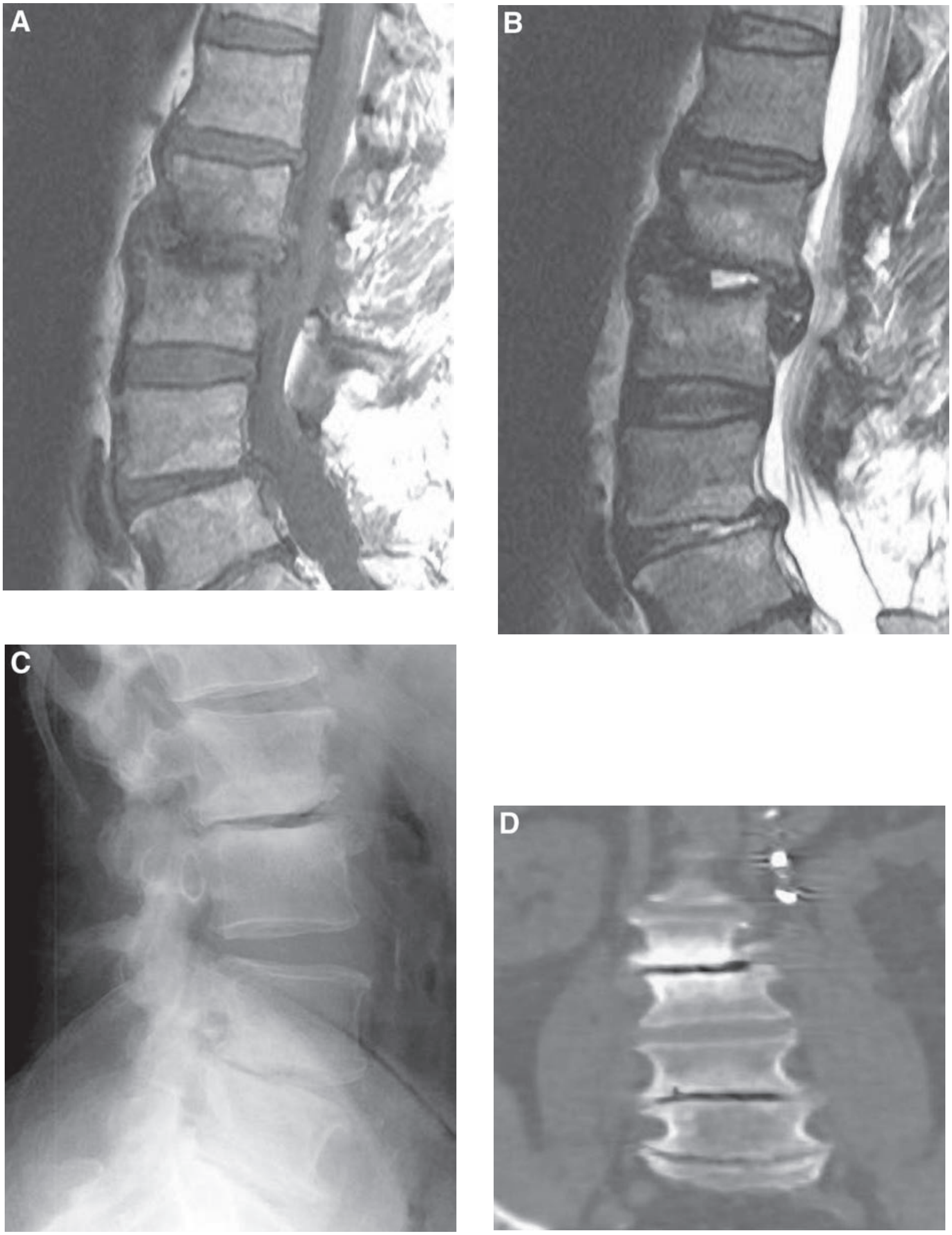

Fig. 1. Sagittal T1- **(A)** and sagittal T2-weighted images **(B)** demonstrate endplate edema and fluid in the disc space at L2–3, findings usually associated with discitis. Note the relative preservation of the vertebral endplates and the similar changes at L4–5. A large disc extrusion is also present at L2–3. **(C)** Lateral radiograph reveals degenerative endplate sclerosis, osteophytes, and an intervertebral vacuum disc at L2–3, which virtually excludes the presence of discitis. **(D)** Coronal CT reformation is derived from a routine abdominal CT performed for an unrelated reason. It shows the remarkable resolution that is attainable with MPRs, even from a nondedicated exam. Also note the vacuum cleft at the L4–5 space.

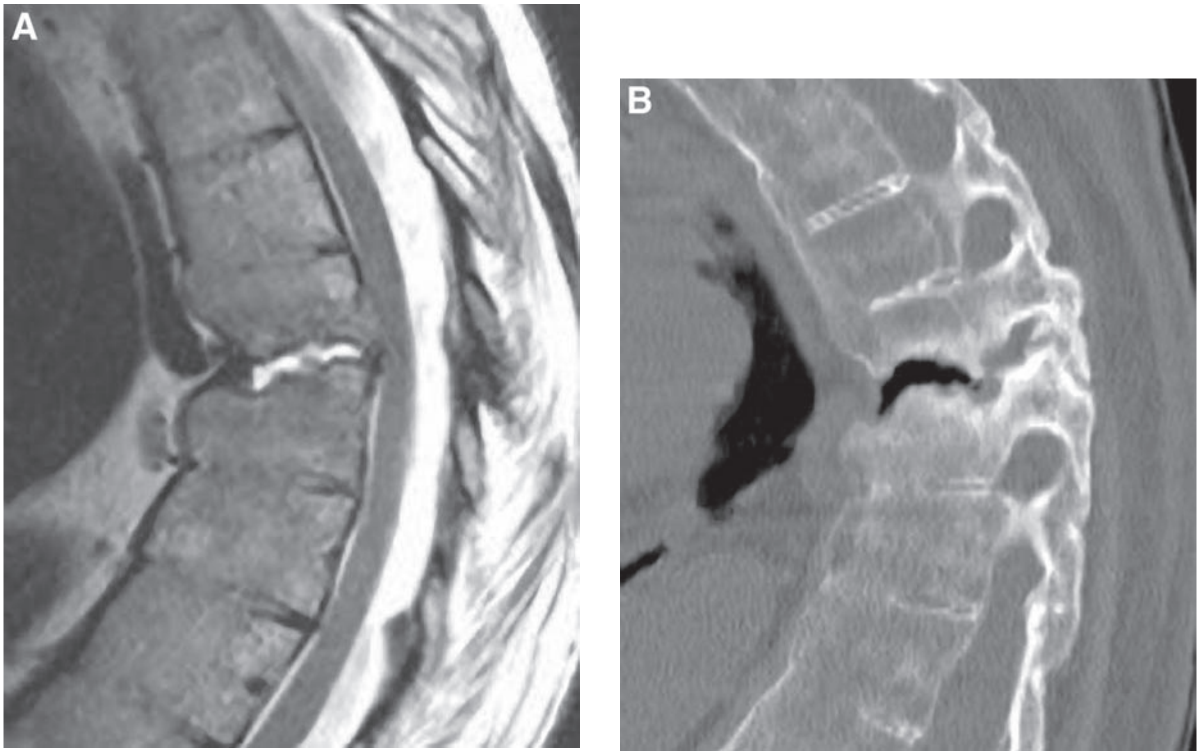

Fig. 2. (A) Sagittal T2-weighted image demonstrates fluid in the expected location of the T8–9 disc space with associated endplate erosion. This appearance could be misconstrued as indicative of discitis. **(B)** Sagittal CT reformation more clearly shows the bony fusion characteristic of ankylosing spondylitis, which in this case is complicated by fracture and pseudoarthrosis. Patients with DISH are at risk for similar injuries. Note again the association of a vacuum cleft with high T2 signal on MR.

also present with high T2 signal in the disc space. One such scenario occurs when there is complete loss of disc height at a given disc level associated with segmental instability, which results in a pseudoarthrosis of the adjoining endplates. The result is similar to the Baastrup's phenomenon, in which fluid is noted at the friction point between adjacent spinous processes. Other causes of pseudoarthrosis, such as when an unstable fracture complicates ankylosing spondylitis or spinal fusion, can also simulate infectious discitis (Fig. 2). Additional rare mimics include neuropathic (Charcot) spine and dialysis-related spondyloarthropathy *(11)*. In some cases, disc biopsy is needed to exclude infection, which can be performed using either fluoroscopic or CT guidance.

Although unrelated, a vacuum cleft also occurs within a collapsed vertebral body in the setting of avascular necrosis (Kummell's disease) (Fig. 3). It is worth mentioning in the context of the vacuum disc phenomenon because of the similar imaging findings. The intravertebral vacuum cleft (within the vertebral body) is virtually always an indicator of benign disease, and its recognition should prevent unnecessary workup and intervention driven by a suspicion of underlying malignancy or infection. On plain radiographs and CT, the collapsed vertebral body is noted to contain a horizontal linear band of gaslike radiolucency. This phenomenon is dynamic, however, and it is dependent on both patient position and the time spent in that position. Malghem et al. found that on serial T2-weighted MR images (over an approx 1-h period), the cleft gradually changed from a signal void (gas) to a band of high signal intensity, suggesting that the gas had been replaced with fluid. Furthermore, the vacuum cleft was most visible on supine and extension stress radiographs and was shown to disappear on standing and flexion views. The authors stressed that when a band of high T2 signal is observed within a collapsed vertebral body, the presence of a vacuum cleft should be confirmed with the appropriate radiographic views or repeat T2-weighted images after prolonged sitting or standing *(12)*.

FACET JOINT DEGENERATION

Low back pain is extremely common and is one of the leading causes of disability in North America. It is the second leading cause of physician visits in the United States. In a substantial percentage of cases in the adult population, there is at least some minor abnormality of disc, endplate, or facet joints. However, the correlation between the specific symptoms and diagnostic testing is often less than gratifying, even when the imaging findings are quite striking. The explanation for this lack of correlation relates, in part, to the numerous potential etiologies for such pain syndromes. Causes include annular tear,

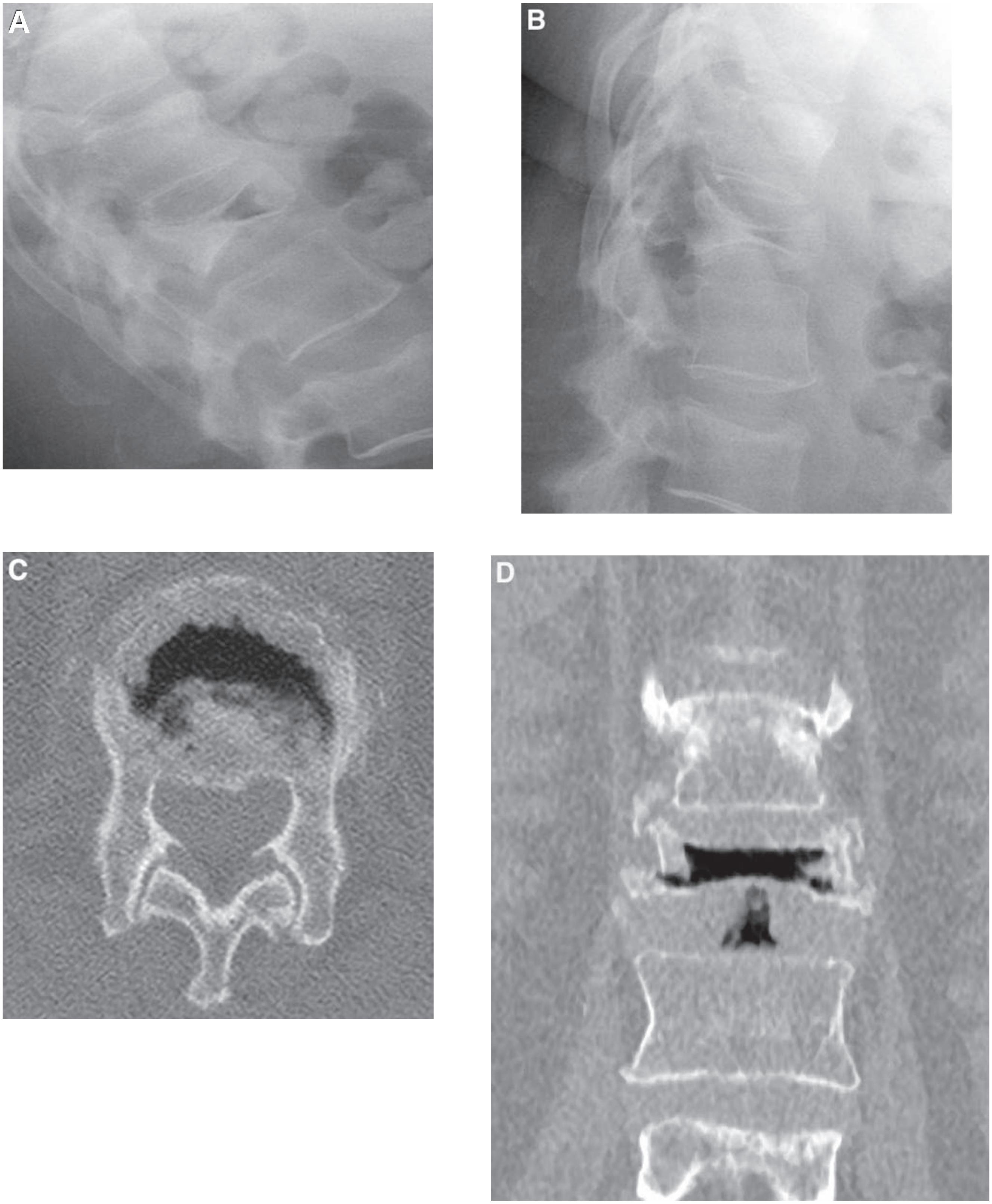

Fig. 3. (A,B) Plain radiographs obtained in extension and flexion reveal vertebral collapse and an intravertebral vacuum cleft, which are characteristic of Kummell's disease (vertebral avascular necrosis). Note the positional change of vertebral height and size of the the vacuum cleft. Axial CT **(C)** and coronal CT reformation **(D)** confirm the presence of intravertebral gas. Note also that the axial CT image more accurately quantifies the degree of retropulsion as compared with the plain radiographs. **(E)** Sagittal STIR demonstrates high T2 signal fluid that has

Fig. 3. (*continued*)
replaced the gas within a vertebral vacuum cleft due to prolonged supine positioning. This MR appearance should prompt correlation with plain radiographs or CT to confirm the diagnosis of Kummell's disease.

disc protrusion/extrusion (which may have both a mechanical and chemical irritation effect), spinal stenosis, facet arthropathy, osteophytic nerve root compression, spondylolysis (with or without spondylolisthesis), vertebral compression fracture, sacral insufficiency fracture, discitis/osteomyelitis, spinal tumor (either primary or metastatic), arachnoiditis, and postoperative scar. The clinical differential diagnosis may also include causes of back pain unrelated to the spine, such as abdominal aortic aneurysm, retroperitoneal lymphadenopathy, or renal colic. A detailed discussion of the neurophysiologic basis of back pain and radiculopathy is beyond the scope of this text. The reader is referred to an excellent review of the complex relationship between the somatic and autonomic nervous system and the nature of referred pain by Jinkins et al. *(13)*.

Facet arthropathy is one of the many causes of back pain with or without radiculopathy. Facet disease degeneration can result in nerve root compression due to stenosis of the central spinal canal, lateral recess, or neural foramen. This may result from osteophyte formation, hypertrophy/redundancy of the ligamentum flavum, or the formation of a synovial cyst (Fig. 4). Again the precise mechanism of pain development is not well understood, but it is likely related to both mechanical and inflammatory factors. Support for an inflammatory component lies in the relief of symptoms with injection of corticosteroid and local anesthetic into the facet joint. In this way, a facet joint injection acts as both a diagnostic test and a therapeutic intervention. Similarly, a synovial cyst may be aspirated under image guidance and may even resolve with injection of the adjacent joint.

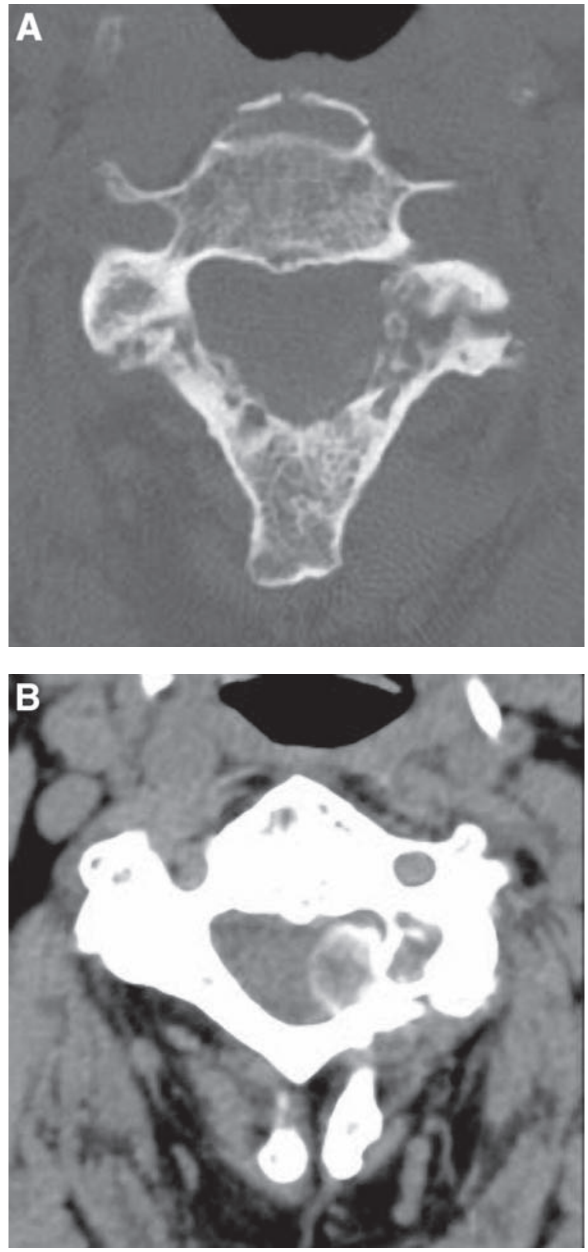

Fig. 4. (A) Axial CT filmed on bone windows demonstrates prominent left-sided facet joint degeneration at C2–3. **(B)** Soft tissue windows is just caudal to image **(A)** at the C3 level. It reveals an extradural mass with mural calcification that causes moderate spinal canal stenosis. The findings are typical for a synovial cyst. This case was confirmed surgically.

One advantage of CT over MRI is the ability readily to distinguish soft tissue structures from bone or osteophyte. CT accurately characterizes facet joint degeneration with

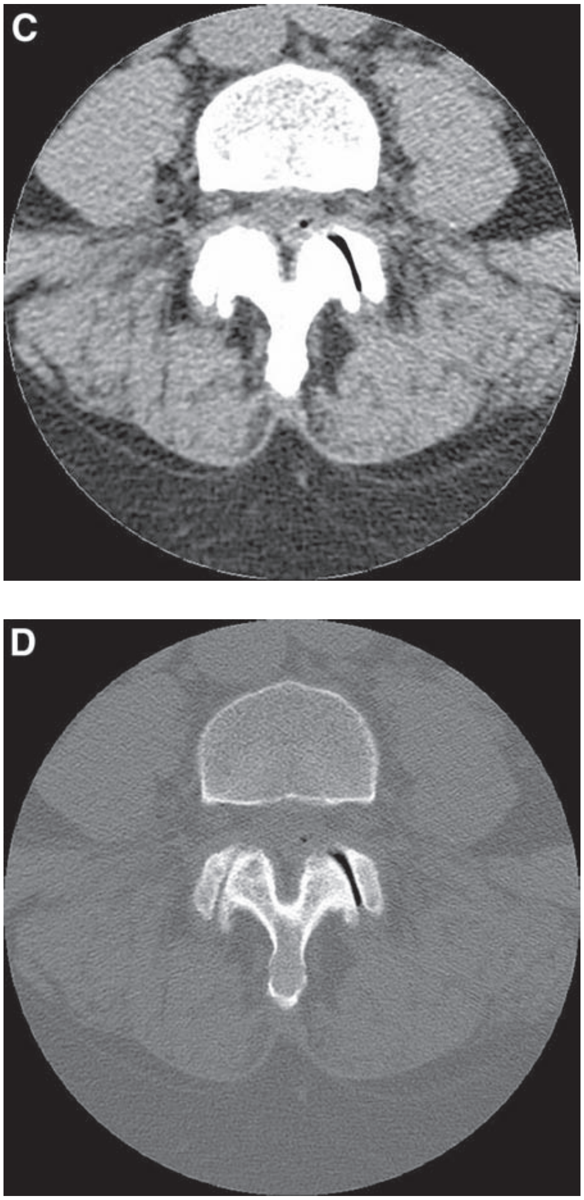

Fig. 4. (*continued*)
(C, D) Axial CT scans from a different patient demonstrate gas within a synovial cyst, indicating communication with the adjacent facet joint.

its accompanying joint misalignment, bony overgrowth, sclerosis, and subchondral cyst formation. CT also readily detects soft tissue mineralization, which can be found in the ligamentum flavum, posterior longitudinal ligament, the wall of a synovial cyst, or in the thecal sac in the rare case of arachnoiditis ossificans. Sagittal reformations are very useful in the assessment of neural foraminal stenosis. CT accurately characterizes spondylolisthesis, which may be secondary to facet joint degeneration or spondylolysis. The ability to detect central canal and lateral recess stenosis is comparable to that of MRI. The high spatial resolution also extends to evaluation of surgical hardware. CT, often following an initial plain film evaluation, is the preferred method for evaluating the integrity of a surgical construct, which may be diminished by hardware malposition or fracture *(14)*.

SPINAL CANAL STENOSIS

Central spinal canal stenosis may be developmental, acquired, or a combination of the two. Developmental stenosis is relatively uncommon and is estimated to account for approx 15% of all cases of spinal stenosis. It may be idiopathic or related to a more generalized disorder affecting the skeletal system, as in the case of the mucopolysaccharidoses or Down's syndrome. The idiopathic variant may selectively involve the lumbar region or may be generalized. It results from the formation of short pedicles with a resulting decrease in the cross-sectional diameter of the central canal. In isolation, this abnormality is generally not symptomatic but renders the patient more susceptible to relatively mild derangements of the disc or posterior elements. Acquired central spinal stenosis may be caused by various abnormalities related to degeneration of the intervertebral disc (vertebral osteophyte, circumferential disc bulge, focal disc protrusion or extrusion), facet joints (osteophyte, synovial cyst, or spondylolisthesis), and hypertrophy of the ligamentum flavum. Clinical presentation is nonspecific and includes back pain and radiculopathy that despite impressive imaging findings may be asymptomatic. The clinical consequence of more severe stenosis is a syndrome of neurogenic or spinal claudication, related to compression of the nerve roots of the cauda equina. The symptoms are typically bilateral and include back pain, sciatica, lower extremity parasthesias, and motor weakness, which tend to be exacerbated on standing or walking and improved with lying flat or sitting, particularly with flexion. The straight leg raise sign is frequently absent and sensory changes are often nondermatomal owing to the typically diffuse nature of disease. Bowel, bladder, and sexual dysfunction are late manifestations. Axial T2-weighted MR images are the best noninvasive way to evaluate the degree of central canal stenosis. CT and CT myelography are comparable techniques *(14)*.

SYNOVIAL CYSTS

Juxtaarticular or synovial cysts are synovium-lined cystic masses that arise adjacent to degenerated facet joints and usually communicate with the joint space. Synovial cysts are most common in the middle and lower lumbar regions, with cervical lesions being relatively uncommon. The result is an extradural mass that lies posterior or posterolateral to the thecal sac within the spinal canal. Cyst contents are variable and include serous fluid, more viscous gelatinous material, hemorrhage, or gas.

This accounts for the varied appearance of synovial cysts on imaging studies. On CT, cysts range from hypodense to hyperdense (the latter indicating hemorrhage or protein-rich fluid), and the cyst wall may be calcified (Fig. 4). The lesions may be difficult to detect on CT or, when of soft tissue attenuation, may be misinterpreted as a free disc fragment. The MR appearance on T2-weighted images is usually characteristic, with a low signal intensity rim and high signal centrally. A fluid level may be present within the cyst cavity. The capsule may enhance following contrast administration. On injection of the adjacent facet joint, the cyst will often fill with contrast, indicating communication with the joint space. For that reason, one of the management strategies for symptomatic synovial cysts is corticosteroid injection into the affected joint. Others have advocated percutaneous drainage under image guidance, with or without the instillation of steroids. Surgical removal via laminectomy is generally reserved for large lesions with significant mass effect.

PARS INTERARTICULARIS DEFECTS (SPONDYLOLYSIS)

Spondylolysis represents a unilateral or bilateral defect in the pars interarticularis of the vertebra. Alignment may be normal or there may be accompanying spondylolisthesis. The etiology of spondylolysis has long been debated. Current consensus would favor that the lesion is an acquired fatigue fracture secondary to repetitive stress rather than congenital. The recognized spike in incidence in school-age children would support that perception. It is thought to be present in as many as 3–7% of the population, with a male predominance. The lower lumbar region is most commonly affected with involvement at the L5 level in two thirds of cases. The incidence decreases at each ascending level in the lumbar spine. Involvement of the cervical spine is uncommon.

When plain radiography is used, pars defects are most clearly visible on oblique projections. A radiolucent cleft is identified through the neck of the “Scottie dog,” which describes the appearance of the pedicle, facet joint, and lamina in that imaging plane. Plain films may be nondiagnostic owing to poor technique, improper positioning, or if there is superimposed facet osteophyte and sclerosis. CT is more definitive and will clearly demonstrate a break through the region of the pars interarticularis (Fig. 5). In the axial plane, contiguous images will fail to demonstrate a complete ring at the affected level. The appearance on sagittal reformations mimics that of the oblique radiograph. In the unusual situation of a unilateral pars defect, hypertrophy and sclerosis of the contralateral pedicle and lamina will be seen, related to asymmetric loading stress. The findings may lead to an erroneous diagnosis of osteoid osteoma. Similar changes can result from congenital absence of a pedicle, lamina, or articular facet. MRI is frequently diagnostic in the setting of pars defects, with CT being confirmatory in equivocal cases. All of the standard imaging modalities will depict spondylolisthesis associated with spondylolysis, although CT and MRI have the added advantage of quantifying the degree of secondary central canal and neural foraminal stenosis. Increased activity on bone scan in the region of the spondylolysis has been correlated with clinical activity.

SPINAL TRAUMA

The balance between the use of plain film radiography and CT in the evaluation of acutely injured patient continues to evolve. The debate over the appropriate triage algorithm considers such factors as time, cost, and diagnostic accuracy. In reality, other factors such as clinical judgment, regional practice variations, and the possibility of litigation also affect the utilization of resources. The issue boils down to two considerations. First, who should be imaged? Second, how should they be imaged? A complete discussion of all of these issues is beyond the scope of this chapter, but a few background points are worth noting. The National Emergency X-Radiography Utilization Study (NEXUS) was a large, multicenter prospective study that evaluated 34,069 patients with neck trauma in an attempt to determine criteria for classifying patients with an extremely low likelihood of clinically significant injury. The goal was to define a subset of patients for whom imaging would not be necessary. Five criteria had to be satisfied in order to be considered for the low probability category. These consisted of the absence of midline cervical tenderness, the lack of a focal neurologic deficit, a normal level of consciousness, the absence of intoxication, and the lack of a distracting painful injury. This clinical tool identified 99% (missing 8 of 818 fractures) of the clinically significant injuries. Further investigation revealed that only two of the eight missed fractures were believed to be clinically significant, and in one of those two the criteria had not been correctly applied. Their conclusion was that clinical indicators accurately predict the likelihood of significant cervical spine injury *(15)*. The result would be improved diagnostic yield and cost-effectiveness for imaging studies.

As to the question of how best to image the patient suspected of cervical injury, there is to date no consensus. There appears to be a trend toward the use of CT earlier in the investigation, usually following a series of plain radiographs including anteroposterior, lateral, and odontoid views. In the severely injured patient, obtaining adequate plain films is difficult and time consuming, often requiring multiple repeat images. This can lead to a costly delay in the management of other potentially life-

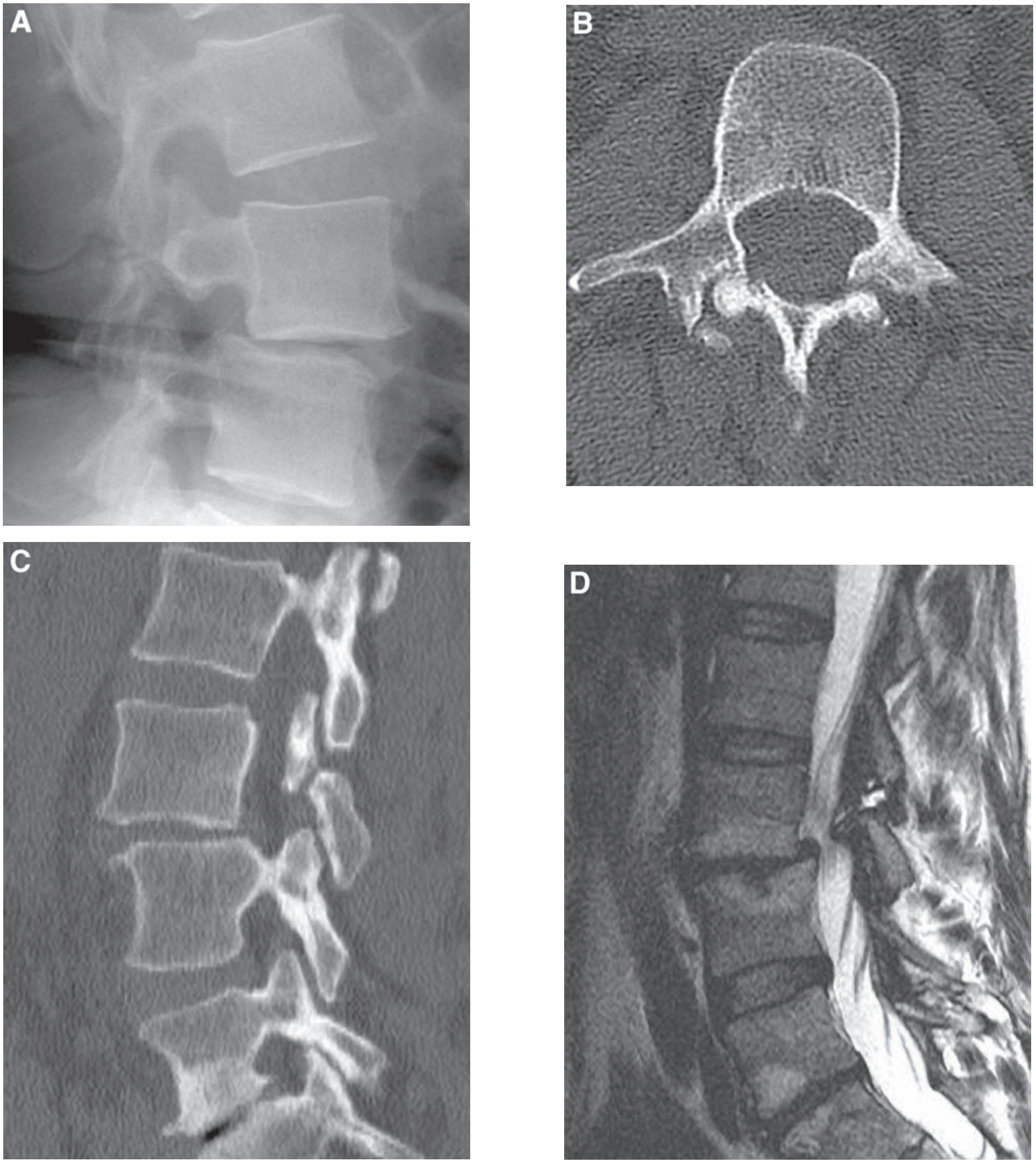

Fig. 5. Lateral radiograph **(A)** and axial CT **(B)** reveal obvious interruption of the pars interarticularis at L3 bilaterally. There is associated disc degeneration at L3–4 with grade 1 spondylolisthesis. **(C)** Sagittal CT reformation again demonstrates the spondylolysis. The actual bony defect may be difficult to detect on MR images, as in this case. **(D)** Sagittal T2 shows reactive edema, which is indirect evidence of instability at that level.

threatening injuries. The cervicothoracic junction is often poorly imaged in the severe trauma patient. The odontoid process is frequently obscured by overlapping bony structures or by the presence of an endotracheal tube. This has led some to advocate the use of CT to clear the cervical spine routinely in the setting of an inadequate initial plain film evaluation (Fig. 6) *(1)*. Others have further proposed that CT should be the initial study in severely injured patients who have already been triaged to CT for evaluation of other critical injuries, such as to the head or viscera *(16)*. Several studies support this proposal. Blacksin and Lee studied routine use of CT of the craniocervical junc-

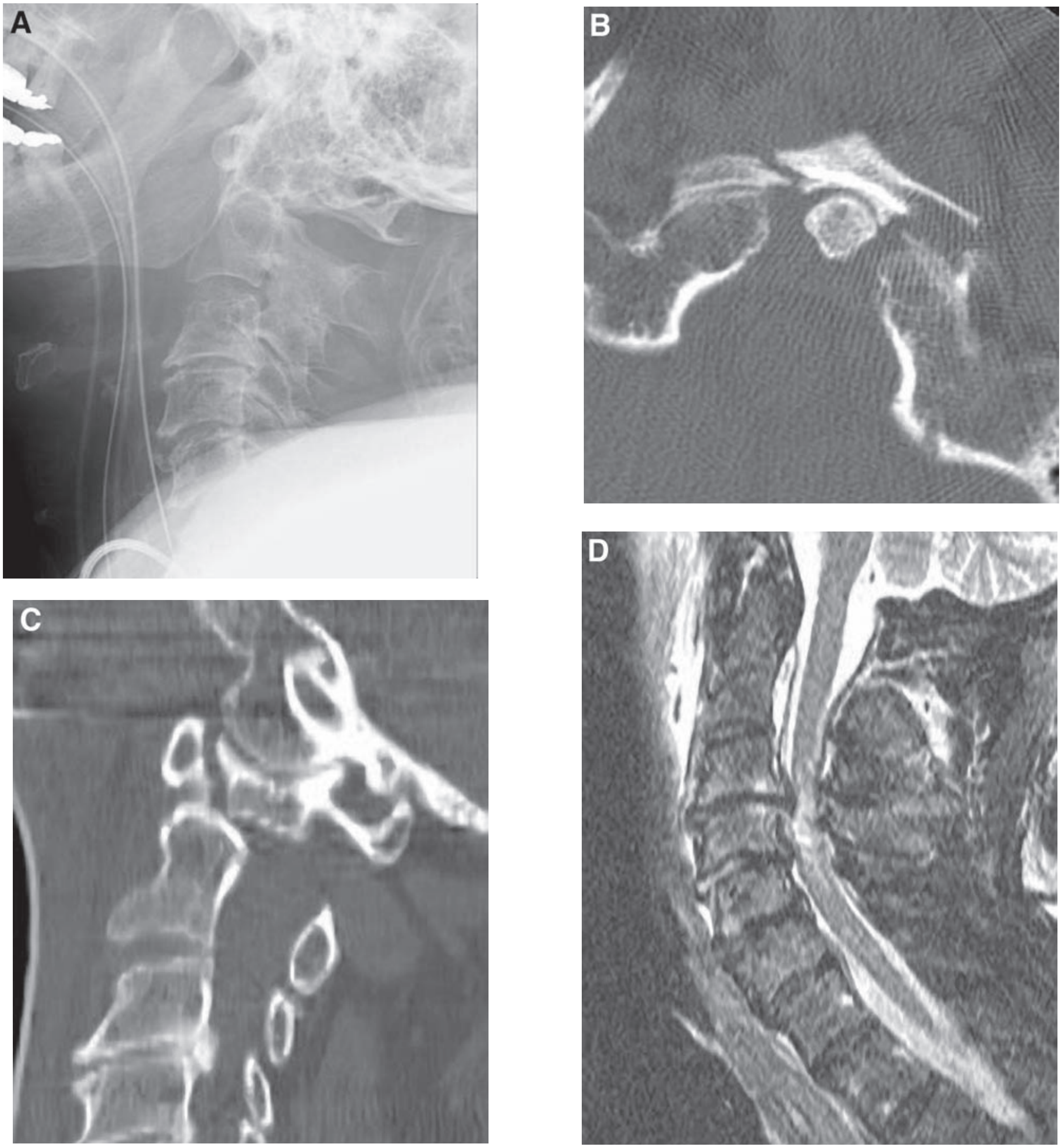

Fig. 6. (A) Lateral radiograph was obtained following trauma in a patient with acute quadriparesis. The endotracheal tube precluded obtaining a satisfactory odontoid view. The lateral view was initially interpreted as showing no fracture. Axial CT **(B)** and sagittal CT reformation **(C)** demonstrate minimally displaced fractures of the anterior arch of C1, which extended into the C1 lateral mass bilaterally. **(D)** Sagittal STIR reveals spinal cord edema at the C3–4 level, which is not directly related to the fractures. The likely mechanism is a hyperextension injury in the setting of degenerative spinal stenosis. Note the dorsal osteophyte complex at C3–4 on the sagittal CT image. This example underscores the complementary nature of CT and MRI in the trauma setting.

tion in 100 patients at high risk for cervical spine injury. They found eight fractures (8%) that were not directly identified on plain radiographs although prevertebral soft tissue swelling was seen in three of those patients *(17)*. Berne et al. studied 58 patients with severe, blunt trauma who had multiple injuries and were clinically unevaluable for cervical spine injury (due to head injury, shock, intoxication, pharmacologic sedation, or paralysis). All patients were evaluated with standard cervical spine radiographs and all underwent complete cervical spine helical CT studies. Twenty patients (34.4%) had cervical spine fractures. Plain radiography failed to detect eight fractures, three of which were deemed unstable. Two fractures were missed on CT although both were considered stable. The authors concluded that a protocol of initial complete cervical spine CT combined with cervical radiography would lead to more rapid and accurate diagnosis of cervical fractures in high-risk patients *(1)*. Undoubtedly, management algorithms will continue to be modified and imaging protocols will vary between institutions. Other factors such as expense and scanner availability will inevitably factor into the equation. As CT technology continues to improve and scan times decrease, the use of CT in the evaluation of cervical spine injury will likely increase.

Careful attention to technique is critical to maximize both sensitivity and specificity of spine CT in the setting of trauma. Thin-section helical axial CT images are acquired through the region of interest with both sagittal and coronal reformations performed in all cases. The latter are critical to the evaluation of fractures in the axial plane, such as a nondisplaced odontoid fracture. Compression fractures may also be quite subtle on axial images but are readily seen on sagittal reformations. The sagittal plane is also best for characterizing abnormalities of alignment, particularly of the facet joints. Such reformatted images easily distinguish a high riding facet from one that is either perched or completely jumped. Facet fractures are best confirmed in the axial plane since those images have the highest spatial resolution. At our institution, helical (MDCT) 2.5-mm axial unenhanced CT images are obtained from the skull base through the upper thoracic spine. The base data are then reconstructed to 1.25 mm slice thickness at 1.25-mm intervals and then reformatted as 2.5-mm slices in the sagittal and coronal planes. The images are reconstructed in both soft tissue and bone algorithm.

Image interpretation should utilize both bone and soft tissue windows. Close inspection of the latter may reveal a disc extrusion or epidural hematoma, which may be unsuspected in a severely injured patient. Such a finding should prompt evaluation with MRI to confirm the abnormality and to assess for accompanying spinal cord injury, which is not possible on CT. MRI has the added advantage of detecting ligamentous injury in the acute phase without the need for flexion and extension of a potentially unstable spine. The sensitivity of MRI for soft tissue injury diminishes with time, and thus flexion–extension views are still of use in looking for delayed instability. They are also indicated in the acute setting for cooperative patients who have been cleared of fracture by previous imaging.

The principles for imaging the thoracic and lumbar spine are the same as in the cervical spine. Generally speaking, the force required to produce a fracture in the thoracic region is higher than in the cervical or lumbar spine because of the stabilizing effect of the thoracic cage. For that reason, thoracic spine injuries are less common but tend to be more severe. There is a high incidence of associated neurologic deficit, occurring in approx 50% of cases. Comorbid visceral injury is another important factor in these patients. Thoracic spine fractures may be associated with cardiac contusion, pulmonary contusion or laceration, tracheobronchial rupture, pneumothorax, and aortic rupture. With lumbar fractures, potential concurrent injury to the solid organs or hollow viscera in the abdomen necessitates efficient evaluation of the spine. The obvious goal of imaging is accurate and rapid diagnosis while allowing for continued monitoring and resuscitation efforts. Although it is beyond the scope of this chapter to examine these visceral injuries, suffice to say that CT plays a vital and ever increasing role in their evaluation.

The mechanism of injury to the thoracolumbar spine is usually related to axial loading and flexion and results in a predictable array of fracture patterns, including compression fracture, burst fracture, flexion–distraction (Chance fracture), and fracture–dislocation. Over the years, many schemes have been proposed for the classification of injuries to the thoracic and lumbar spine. One of the most commonly utilized is the three-column system devised by Denis, who divided the spine into anterior, middle, and posterior components in an attempt to categorize fractures on the basis of mechanism and to make predictions regarding vertebral stability. The anterior column consists of the anterior longitudinal ligament, the ventral half of the vertebral body, and the corresponding intervertebral disc. The middle column is composed of the posterior half of the vertebral body, the corresponding disc segment, and the posterior longitudinal ligament. The posterior column is made up of the bony posterior elements and the supporting ligaments, including the ligamentum flavum and interspinous ligaments. Denis asserted that spinal instability would ensue if any two of these columns were disrupted *(18)*. Simple compression fractures, because they involve only the anterior column, are considered stable. Burst-type fractures, which by definition involve the middle column, are by this system always classified as unstable (Fig. 7). Fracture–dislocation (dislocation is usually anterior or lateral) and flexion–distraction injuries involve all three columns and are obviously unstable *(18)*. Regardless of the classification system used, imaging remains the fundamental basis for the diagnosis and thus the management of patients with spinal injury.

With few exceptions, the modality initially employed in the investigation of spinal trauma is plain film radiography. It has the advantages of rapid acquisition and low cost, and it also provides an easy basis for comparison in

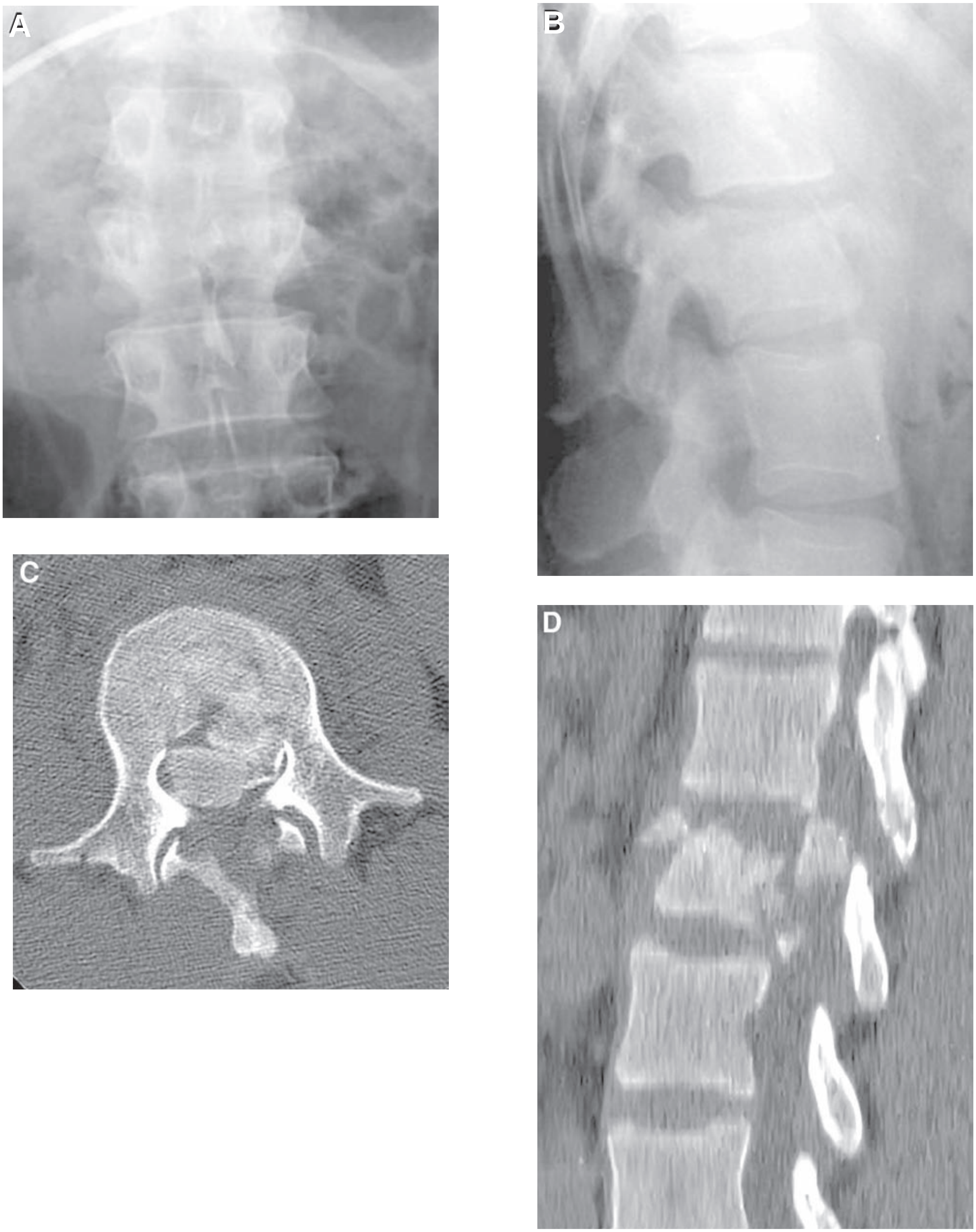

Fig. 7. (A, B) AP and lateral radiographs demonstrate the classic findings of a burst fracture at the L2 level. There is vertebral collapse, retropulsion, and widening of the interpedicular distance. Axial CT **(C)** and sagittal CT reformation **(D)** show to better advantage the distribution of fracture fragments and the degree of retropulsion. **(E)** Sagittal STIR reveals ligamentous disruption posteriorly. Notice also edema

Fig. 7. (*continued*)
in the adjacent L1 and L3 vertebral bodies despite a normal appearance on CT. This points to the sensitivity of STIR images in detecting marrow and soft tissue edema. **(F)** Sagittal T1 reveals a moderate ventral epidural hematoma.

the anticipation of serial exams *(6)*. There are, however, limitations. Because of the overlapping soft tissues of the shoulder girdle, the upper thoracic spine is often poorly evaluated on plain X-ray images. Respiratory motion, external radiopaque material overlying the spine, and localized differences in beam penetration (most commonly related to the diaphragm) often result in suboptimal radiographs in the severely injured patient. Even high-quality images fail to detect subtle fractures and tend to underestimate the degree of retropulsion. Taking the case of a fracture–dislocation, CT more accurately depicts the extent of the fractures (especially with regard to the posterior elements), the relationship of the bone fragments, and the degree of retropulsion. The sagittal and coronal reformations clearly demonstrate loss of vertebral body height, vertebral subluxation, and abnormal alignment of the facet joints. This has obvious implications in terms of fracture classification and the assessment of stability. MRI adds important information for patients with complex spine fractures and those with neurologic deficits. Spinal cord contusion, epidural hematoma, disc extrusion, and ligamentous disruption are all best evaluated with MRI. This modality also is ideal for detecting delayed complications of spinal trauma such as myelomalacia, cord atrophy, and syrinx formation.

SPINE TUMORS

Primary tumors of the spine are far less common than spinal involvement with metastatic disease, multiple myeloma, or lymphoproliferative disorders. The presence of multiple lesions suggests the latter diagnoses although some primary lesions can also be multiple, as with multifocal hemangiomas or enostoses, which might create diagnostic confusion. Because of higher contrast resolution, spinal involvement with disseminated malignancy (metastic disease or multiple myeloma) is best investigated with MRI. Most lesions in this setting will be of low signal intensity on T1-weighted images and high signal intensity on T2 and STIR images. Purely sclerotic lesions can be problematic on MRI because of a lack of increased T2 signal. In this setting, the areas of sclerosis may be more conspicuous on CT. Until recently, it was not practical to study the entire spine with CT. The ability of bone scan and MRI to image the spine effectively still today relegates CT to an adjunctive role. CT does have its uses, however. It can distinguish an atypical hemangioma (those that lack T1 shortening precontrast) from a malignant lesion seen on MRI (*see* later). CT also plays an obvious role in the evaluation of patients for whom MRI is contraindicated, albeit with some loss of sensitivity *(19)*.

With localized disease of the spine, both benign and malignant primary spinal tumors enter the differential diagnosis. This covers a broad spectrum of lesions ranging from a benign enostosis (bone island) to a highly aggressive sarcoma. In such cases, CT can add valuable information about the etiology and biological activity of the lesion. For example, an expansile lesion with multiple cystic areas that contain fluid–fluid levels is characteristic of an aneurysmal bone cyst. The presence of mineralized matrix would suggest a tumor of osteoid or cartilagenous origin (osteosarcoma or chondrosarcoma). Indicators of a more aggressive lesion include poorly defined margins (wide zone of transition), bone destruction, associated soft tissue mass, and invasion of adjacent structures *(19,20)*.

BENIGN TUMORS

On the benign end of the tumor spectrum, there are several lesions whose appearance is usually diagnostic, including enostosis, osteoid osteoma, hemangioma, and osteochondroma. Enostoses, or bone islands, are benign incidental lesions detected on imaging, which occasionally are mistaken for sclerotic metastases. They are classically round to oval in shape, sharply defined, and have characteristic spiculated margins. Most lesions do not demonstrate activity on bone scintigraphy although giant bone islands (>2 cm) may show increased uptake. On rare occasions, interval growth will prompt biopsy to prove its benign etiology.

Osteoid osteoma is a lesion of young patients, usually between the ages of 10 and 20 yr, with a male predominance (3:1). It should be noted that only 10% of osteoid osteomas involve the axial skeleton. The classic clinical history in such cases is painful scoliosis, but it may also present with localized pain, radiculopathy, or gait disturbance. The pain tends to be worse at night and is typically relieved with aspirin or nonsteroidal antiinflammatory drugs (NSAIDs). Spinal lesions tend to involve the posterior elements (75%) and involvement of the lumbar spine is most frequent (59%), followed by the cervical (27%), thoracic (12%), and sacral (2%) regions. On CT, the lesion is round to oval with a central radiolucent nidus that is surrounded by a variable extent of reactive sclerosis. The central nidus is usually <1.5 cm in diameter and may contain a focus of calcification. Although the lesion may heal spontaneously, complete surgical resection of the nidus is often needed for cure. CT-guided percutaneous excision or ablation of the nidus has also been described *(19)*.

A vertebral hemangioma is a very common incidental finding on spine imaging studies (Fig. 8). On MRI, the lesions are usually of high signal intensity on both T1- and T2-weighted images with a subtly variegated internal architecture. Hemangiomas are most frequently found in the vertebral body although extension into the pedicles and laminae is well described. Isolated involvement of the posterior elements is uncommon. Rarely there is a soft tissue component with extension into the paraspinal soft tissues or spinal canal. The CT appearance is virtually pathognomonic and is characterized by a geographic zone of radiolucency that contains an internal scaffold of coarse vertical trabeculae, the so-called "corduroy" pattern. CT is very useful for confirming the diagnosis of hemangioma when the MRI appearance is atypical.

Spinal osteochondromas are uncommon tumors that can be seen sporadically as solitary lesions or in the setting of hereditary multiple exostoses. Patients are young, usually in the third or fourth decade, and there is a male predominance. Any part of the spine may be affected but the cervical region is most often involved. Myelopathy is a frequent presenting manifestation although trauma may uncover an otherwise asymptomatic lesion. Osteochondromas that project anteriorly may cause dysphagia, vocal cord dysfunction, or vascular compromise. The lesion may be sessile or pedunculated. As with exostoses in the appendicular skeleton, the characteristic finding is lesion continuity with the underlying vertebral cortex and marrow, which is well depicted by CT. Both CT and MRI are well suited to demonstrate the degree of accompanying spinal canal stenosis or mass effect on paravertebral structures. Osteochondromas rarely undergo malignant transformation into a secondary chondrosarcoma *(19)*.

There are three primary spinal tumors that are considered pathologically benign but that may have aggressive clinical features on the basis of size and an expansile growth pattern. These are the aneurysmal bone cyst, osteoblastoma, and giant cell tumor. All three lesions tend to occur in younger patients. Although histologically benign, these tumors have substantial recurrence rates if not completely resected. Complete resection of large lesions is often impossible in the spine as a result of the associated morbidity.

Aneurysmal bone cyst (ABC) in the spine most often involves the thoracic region. Involvement of the sacrum, unlike giant cell tumor, is rare. Pathologically, the lesion is characterized by multiple blood-filled cystic spaces. On CT and MRI, a multicystic mass with expansile remodeling is found with characteristic fluid–fluid levels, indi-

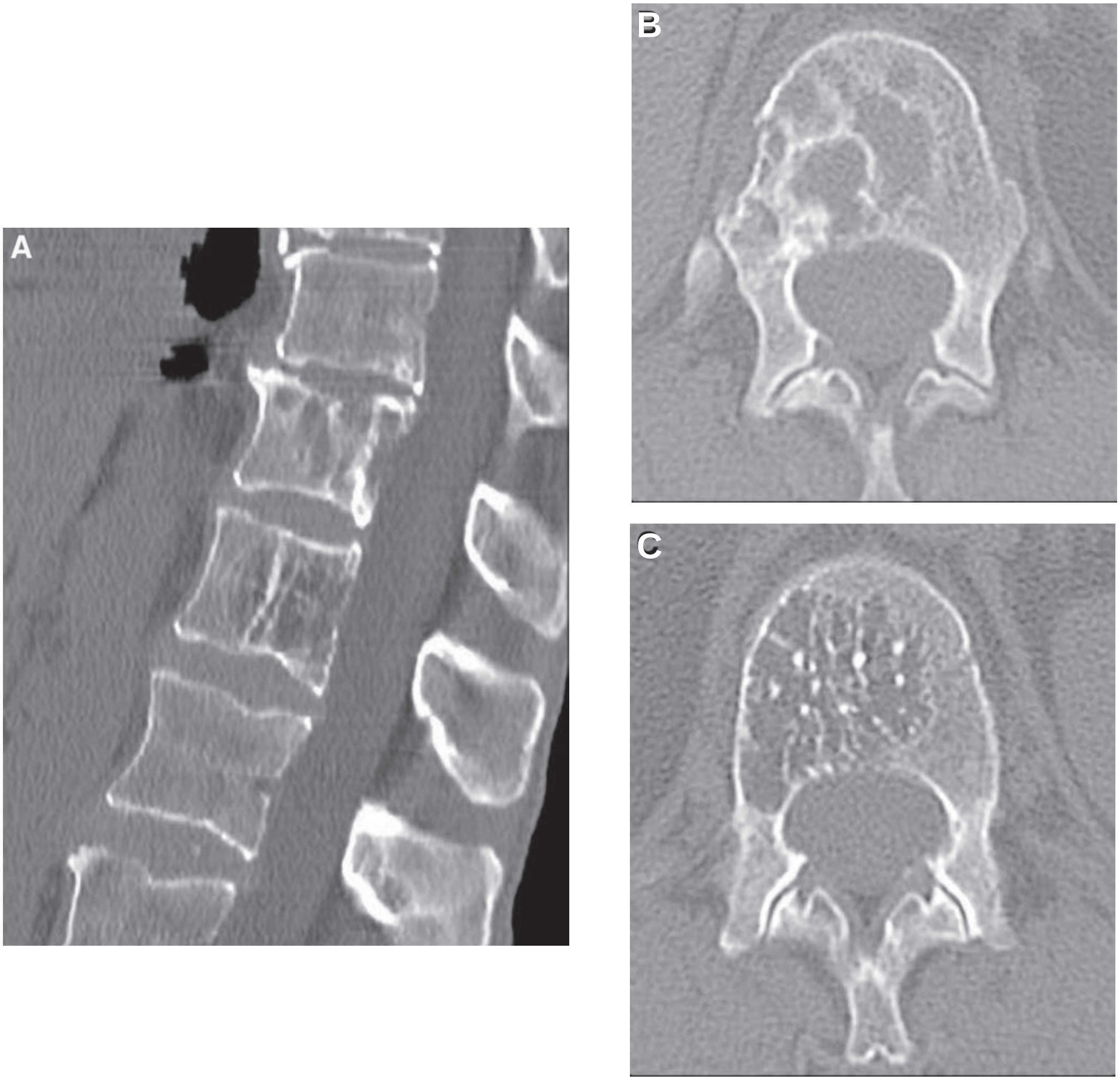

Fig. 8. (A) Sagittal CT reformation reveals predominately osteolytic foci involving both the L1 and L2 vertebrae in a patient with suspected metastatic breast carcinoma. **(B)** Axial CT at the L1 level shows irregular areas of lytic bone destruction with a small break in the cortex laterally. This proved to be metastatic disease. **(C)** Axial CT at the L2 level demonstrates the classic "corduroy" appearance of a vertebral hemangioma. Note the prominent vertically oriented trabeculae on both the axial and sagittal images.

cating the presence of hemorrhage. A thin outer rim of preserved periosteum is typical although it may be interrupted. The lesion is usually centered on the posterior elements although involvement of the vertebral body is common (75–90%). Direct extension to involve adjacent ribs and vertebral bodies has been described (Fig. 9). ABCs are vascular lesions and embolization can be performed as a primary treatment or preoperatively to minimize blood loss at surgery. ABCs are also radiosensitive *(19)*.

Like ABC, osteoblastoma of the spine most often localizes to the posterior elements with extension into the vertebral body being fairly common (42%). Smaller lesions have an appearance very similar to osteoid osteoma with a central lucent region surrounded by reactive sclerosis. With this type of osteoblastoma, the only distinction from osteoid osteoma is based on size (>1.5 cm). At the other end of the spectrum is an aggressive, expansile mass with bone destruction, paraspinal soft tissue infiltration, and multifocal mineralization that may resemble chondroid

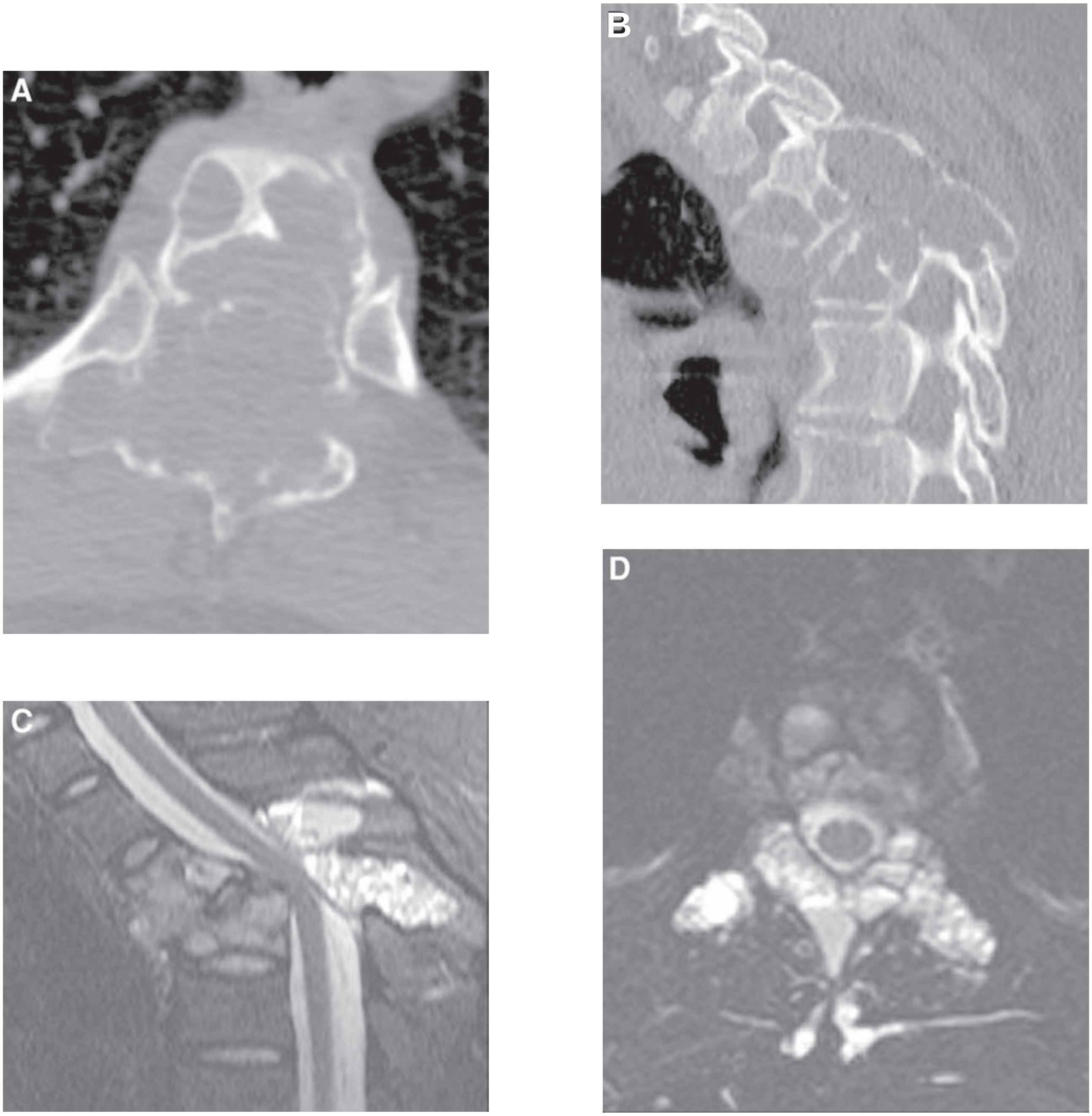

Fig. 9. Axial CT **(A)** and sagittal CT reformation **(B)** demonstrate expansile, destructive lytic lesions involving both the T2 and T3 vertebral levels. There is involvement of the anterior and posterior elements with vertebral collapse and accompanying kyphosis. Differential considerations would include primary and secondary spinal malignancies (metastatic disease, multiple myeloma, or lymphoma) as well as benign aggressive lesions such as aneurysmal bone cyst (ABC) or osteoblastoma. **(C, D)** Sagittal and axial STIR demonstrate a characteristic multiloculated, cystic appearance with fluid–fluid levels (indicating hemorrhage). Although not entirely specific, this pattern strongly suggests the diagnosis of ABC, which was confirmed surgically.

matrix (rings and arcs). Treatment is surgical resection. The recurrence rate for the aggressive form is approx 50% vs 10–15% for the more indolent subtype. Malignant transformation is rare but has been reported.

Giant cell tumors (GCTs) differ from the other two lesions in that the most arise in the sacrum. In addition, involvement of the spine usually localizes to the vertebral body rather than the posterior elements. Necrosis and hemorrhage within a GCT may create an appearance similar to an ABC. Unlike GCTs of the long bones, lesions of the sacrum and spine have a tendency to spread across natural boundaries, such as the intervertebral disc space and sacroiliac joint. This finding may lead to a misdiagnosis of infection. Treatment for GCTs is surgical resec-

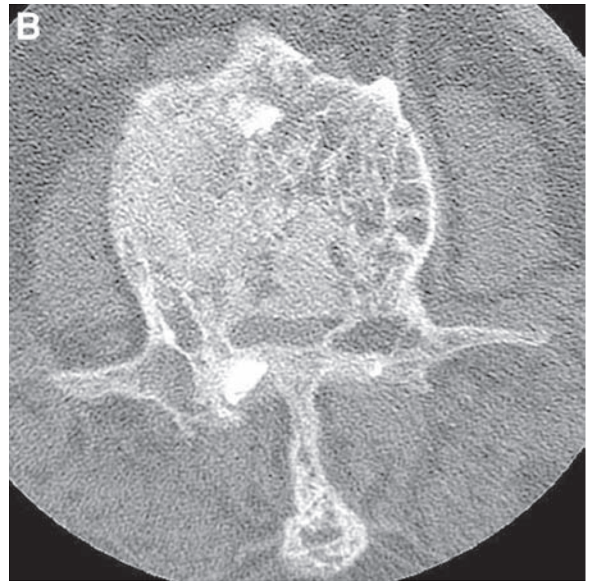

Fig. 10. Lateral radiograph **(A)** displays a relatively lucent appearance of the L2 vertebral body with loss of height and some widening in the anteroposterior dimension. Axial CT **(B)** shows the characteristic features of Paget's disease with a coarse trabecular pattern and osseous expansion, which results in severe spinal canal stenosis.

tion. Incompletely resected tumors are treated with radiation. The prognosis of GCT of the spine is less favorable than for the other benign tumors. Recurrence is expected in 40–60% of cases. Malignant transformation of GCTs is described in 10–15% of cases although there is speculation that the majority of these may actually represent radiation–induced sarcomas *(19)*.

MALIGNANT TUMORS

Nonlymphoproliferative primary malignant tumors of the spine in adults include chordoma, chondrosarcoma, and osteosarcoma. In the pediatric population, Ewing's sarcoma and primitive neuroectodermal (PNET) tumors predominate, although with these tumors metastatic disease to the spine is more common than a primary lesion. All of these tumors share an aggressive imaging appearance with frequent bone destruction, paraspinal soft tissue mass, and invasion of adjacent structures, most notably the spinal canal. Large size at presentation often precludes complete surgical resection and patients usually succumb to their disease *(19)*.

Chordoma is a tumor of notochordal remnants that can arise anywhere between the skull base and the coccyx. It is the most common malignant primary spinal tumor in adults, excluding lymphoproliferative disorders. In descending order of frequency, chordomas arise from the sacrococcygeal region (50%), clivus (30–35%), and the remaining spinal regions (15%). Of the latter, the cervical region is most often involved (particularly C2), followed by the lumbar spine. The imaging hallmark is an enhancing, destructive midline mass that demonstrates very high signal intensity on T2-weighted images. Amorphous calcification is frequently seen on CT, particularly in the sacrococcygeal lesions. This pattern is suggestive of the diagnosis but overlaps the appearance of chondrosarcoma, a tumor that also has a predilection for the skull base and the sacrum/pelvis. Not suprisingly, the variant chondroid chordoma shares several histopathologic features with chondosarcoma. Prognosis depends on the extent of resection. Tumors in the saccro-coccygeal region tend to fare better, with a mean survival in the 8- to 10-yr range.

The second most common primary malignancy of the spine is chondrosarcoma. Most lesions arise *de novo*, with only a small percentage resulting from malignant transformation of an osteochondroma. The thoracic spine is the most common location for spinal chondrosarcoma. As stated previously, the imaging appearance is very similar to that of a chordoma. Mineralization with chondroid matrix is typically evident on CT. The tumors are usually low grade and pulmonary metastases, frequently seen with peripheral lesions, are relatively uncommon. Mean survival is approx 6 yr.

Osteosarcomas of the spine are rare. The mean age at onset is in the fourth decade, about 10 yr older than for conventional osteosarcoma of the extremities. These tumors show variable differentiation and can produce osseous matrix, chondroid martix, or may be entirely lytic. This results in a variety of imaging appearances although densely mineralized matrix is the norm. Osteosarcoma is also one of the causes of a so-called "ivory vertebral body." Secondary osteosarcomas may result from prior radiation therapy (latency period 5–20 yr) or underlying Paget's disease (Fig. 10). Prognosis of spinal osteosarcoma is extremely poor, with death usually occurring in less than 1 yr.

CONCLUSION

In this chapter, I have tried to present an overview of the many uses of CT in the evaluation of spine disorders. Wherever possible, I have compared the strengths and weaknesses of CT and MRI. There are some instances in which these modalities should be viewed as complementary rather than competing because each provides important and significantly different information. It is clear that advances in CT technology have led to a resurgence of CT imaging applications including detailed two- and three-dimensional representations of the spine, CT angiography, CT brain perfusion mapping, stereotactic surgical guidance, and near real-time guidance of interventional procedures. Information that was once the domain of conventional angiography or MRI is now attainable with CT, which has the inherent advantages of wide availability, rapid acquisition, and relatively low cost. Further increases in speed and image quality are forthcoming as multislice volumetric CT scanners continue to improve. This will lead to novel CT applications as well as even greater productivity. CT, it seems, is here to stay. As my friend and fellow radiologist Dr. John Nicotra once said, "CT is good at showing you stuff." To me, that says it all.

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