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Spinal instability and deformity due to neoplastic conditions

Daryl R. Fourney, M.D., F.R.C.S.(C), and Ziya L. Gokaslan, M.D.

Division of Neurosurgery, Royal University Hospital, University of Saskatchewan, Saskatoon, Saskatchewan, Canada; and Department of Neurosurgery, Johns Hopkins University, Baltimore, Maryland

In addition to tumor resection, a major goal of spine surgery involving tumors is the preservation or achievement of spinal stability. The criteria defining stability, originally developed for use in trauma, are not directly applicable in the setting of neoplasia. The authors discuss the most common patterns of tumor-related instability and deformity at all levels of the spinal column and review the surgical options for treatment.

Key Words • **tumor excision** • **metastasis** • **spinal deformity** • **spinal stabilization**

Restoration or maintenance of spinal stability is an important objective in the surgical management of patients with spinal neoplasms. Of the various destructive spinal tumors, metastases are the most common and axial or mechanical pain is a significant cause of morbidity in this patient population.[7] Although the most frequently cited role for surgery in the setting of metastatic spinal disease has been the relief of epidural compression, one of the most rewarding clinical scenarios for the spinal surgeon is successful palliation in cases of tumor-related instability and deformity, which is achieved using the current generation of fixation devices.

Effective methods for the reconstruction and stabilization of all regions of the spinal column have evolved; however, there are relatively little data with regard to the use of these procedures in patients with spinal tumors. The purpose of this article is to discuss the patterns of spine-related instability and deformity that occur in neoplastic disease and to review the options for surgical management. The unique anatomical and biomechanical features of the different regions of the spine will also be considered.

CRITERIA FOR SPINAL STABILITY AND TIMING OF STABILIZATION

The definition, and therefore the management, of spinal instability in the setting of neoplasia is controversial.[28] Various criteria have been proposed to define stability, but none is directly applicable for spinal tumors. The three-column concept of the spine introduced by Denis[4] is widely accepted as the mechanical model for thoracolumbar fractures. Generally accepted criteria for spinal instability secondary to trauma include: 1) at least two-column injury; 2) greater than 50% collapse of VB height; 3) greater than 20 to 30° of kyphotic angulation; or 4) involvement of the same column in two or more adjacent levels.[15] These concepts may not always be applicable in cases involving neoplastic destruction of the spine because the pattern of disruption of the bone, discs, and ligaments differs significantly from that in trauma. Additionally, the quality of the surrounding stock of bone and the ability of the spine to heal are often poor in patients with malignant disease.

Tumorous involvement of the cancellous core of the VB with preservation of the cortical bone support may not result in spinal instability. Likewise, instability does not usually occur when this involvement is limited solely to the anterior column. Involvement of the posterior half of the VB (that is, the middle column) including the cortical bone, however, may result in pathological compression fracture. Kyphosis, as well as extrusion of tumor, bone, or disc into the spinal canal, may result in neurological compromise (Fig. 1). Shearing deformity with antero- or posterolisthesis may also be produced.

In the absence of obvious VB collapse or deformity, segmental instability is presumed when the clinical syndrome of axial or mechanical pain is present. This pain is characteristically aggravated by movements and relieved by recumbency.

Thus, neuroimaging studies are only one component of

Abbreviations used in this paper: BMD = bone mineral density; CT = computerized tomography; MR = magnetic resonance imaging; PMMA = polymethylmethacrylate; VB = vertebral body; VSI = vertebral strength index.

Fig. 1. Sagittal T_1-weighted MR image obtained in a patient with lung cancer metastatic to C6–7, demonstrating VB collapse, kyphotic deformity, retropulsed tumor/bone fragments, and severe cord compression.

a systematic approach to determining the clinical instability of the spine, which includes anatomical, biomechanical, clinical, and therapeutic considerations. Clinical instability has been defined as "loss of the ability of the spine under physiologic loads to maintain relationships between vertebrae in such a way that there is either damage or subsequent irritation to the spinal cord or nerve roots, and in addition there is development of incapacitating deformity or pain due to structural changes."[26] Therefore, symptoms and signs, in addition to radiological criteria, should direct the therapeutic approach.

The biomechanical effects of spinal metastases and the mechanisms of neoplastic VB collapse remain poorly defined. There are no clear standards for predicting the risk of pathological fracture, even when lesions have been identified and characterized on bone scans, CT scans, or MR images. Theoretically, VB collapse may be prevented by administering radiotherapy if the metastatic tumor is radiosensitive and its growth (and thus lytic destruction of the vertebra) can be inhibited. Once the tumor reaches a critical size, which can be defined as "impending collapse," only prophylactic surgical stabilization (or perhaps vertebroplasty[9]) can prevent fracture. Therefore, some reliable method to predict impending VB collapse would be extremely beneficial.

In the few experimental studies in which authors have addressed this issue, limited success has been achieved in developing an adequate model of osteolytic disease and in the mechanisms by which to generate VB collapse.[11,18,20]

Taneichi, et al.,[25] have analyzed radiological and clinical data obtained in 53 patients with 100 thoracic or lumbar metastases by using a multivariate logistic regression model in an attempt to identify the probability of collapse under various states of metastatic vertebral involvement. They found distinct differences in the timing and occurrence of VB collapse in the thoracic spine compared with thoracolumbar or lumbar regions. In the thoracic spine, destruction of the costovertebral joint was a more important risk factor for collapse than the size of the metastatic lesion within the VB. This phenomenon was attributed to the loss of stiffness and strength normally provided by the rib cage. In the thoracolumbar and lumbar spine, the most important collapse-related factor was the size of the VB defect. In addition, metastatic involvement of the pedicle had a much greater influence on VB collapse in the thoracolumbar and lumbar spine than in the thoracic spine. A major limitation of this study was that only tumor size and the location of defects within the vertebrae were considered; other important factors such as age, sex, and bone density were not analyzed.

The combined effects of BMD and vertebral defects were demonstrated in an experimental study of thoracic cadaveric vertebrae subjected to compressive loads after drilling of the centrum to simulate lytic metastases.[5] Interestingly, defect size alone did not reliably predict the fracture threshold, and BMD was found to be an equally, if not more important predictive variable. When defect size was considered with BMD, a more accurate predictive factor—the VSI—was established. The VSI is the product of the cross-sectional area of the remaining intact VB and the BMD. The VSI can be measured in vivo by using CT scans. The authors suggested the use of the VSI as an objective measure of pathological fracture risk that could be used with clinical criteria in the decision-making process regarding surgical stabilization.

Iatrogenic instability is another important issue. Spinal instability may be caused or worsened by the approach to, or resection of, spinal tumors. For example, a laminectomy in the presence of neoplastic involvement of the anterior or middle columns may result in instability. By definition, a two-column defect is created by a vertebrectomy, regardless of the state of the posterior columns. In both of these cases spinal instrumentation may be required for stabilization, although in selected cases, reconstruction of the vertebrectomy defect alone (without additional fixation) may provide satisfactory support. It remains unclear, however, what extent of osseous destruction requires anterior reconstruction (with or without supplementary anterior plate fixation) compared with combined anterior–posterior stabilization. In a recent biomechanical analysis of various stages of tumor lesions in human cadaveric specimens, investigators found that anterior reconstruction provided stiffness equivalent to circumferential reconstruction, provided that only corpectomy or subtotal spondylectomy had been conducted. Total spondylectomy significantly reduced the stiffness conferred by the anterior reconstruction, suggesting the need for combined anterior–posterior procedures.[14]

PATTERNS OF INSTABILITY AND TECHNIQUES FOR STABILIZATION

Currently available techniques of spinal stabilization may be broadly categorized as anterior or posterior, and they may be subclassified with regard to spinal level (Table 1). A number of advancements have occurred in recent years. In cases requiring posterior stabilization, wire-secured devices were previously popular; howev-

TABLE 1
*Modern methods of spinal stabilization in cases involving neoplasms, stratified by spinal region**

Region	Anterior Approach	Posterior Approach
occipitocervical	NA	occipitocervical plate or contoured rod w/ screws or wires
cervical		
C1–2	transodontoid screws	C1–2 transarticular screws &/or sublaminar wiring
C3–7	cervical locking plate & screws	lat mass screws & rods
cervicothoracic	cervical locking plate & screws	lat mass screws & pedicle screws w/ rods
thoracic		
T1–6	cervical locking plate & screws	pedicle screws or hooks & rods
T7–12	TL locking plate & screws	pedicle screws or hooks & rods
TL	TL locking plate & screws	pedicle screws & rods
L1–4	TL locking plate & screws	pedicle screws & rods
lumbosacral	NA	pedicle screws & rods
lumbopelvic	NA	Galveston rod or iliac screws/rods

* NA = not available; TL = thoracolumbar.

er, current techniques generally involve screw- or hook-based systems secured to either rods or plates. Not only are these systems more rigid, but they may be used at levels where laminectomy or facet removal has been performed. When applying pedicle screws, segmental distraction, compression, lordotic, rotation, and antero- or retrolisthetic forces can be applied, depending on the clinical situation. The pedicle screw fixation–induced rigidity may allow for relatively short-segment constructs.

Metastatic disease most commonly involves the VB, and postvertebrectomy reconstruction is required for stability. The VB may be replaced with various materials, including autograft or allograft bone, PMMA, or spacers.[28] Recently, distractible or telescoping cages (Synex Cage; Synthes Spine, West Chester, PA) have become available. A bone graft is often recommended in patients with a life expectancy beyond 6 months; however, PMMA-assisted reconstruction is probably the best option for most cancer patients. Because PMMA accomplishes immediate stabilization after radical tumor resection, patients can ambulate without the use of external orthoses and can undergo radiotherapy without delay.

A number of methods for the use of PMMA in the VB have been described. Of these, the chest tube technique[6] has been used most extensively with excellent results, even in patients who have survived beyond 3 years posttreatment.[10] A modification of this technique involving coaxial chest tubes has been described for use in the cervical and upper thoracic spine.[19] Although PMMA is very stable in compression mode, we advocate the additional use of anterior fixation devices, such as a locking plate and screws, to prevent distraction failure and to provide increased rigidity (Table 1).

Craniovertebral Junction

Metastatic tumors involving the atlas and axis are distinct from those occurring throughout the rest of the spine because of 1) the anatomical and biomechanical characteristics of the craniovertebral articulation and 2) the critical functions of the spinal cord near the cervicomedullary junction. In a review of atlantoaxial metastases, the most frequent location of disease was at the junction between the dens and the axial body.[21] Many patients harbored pathological C-2 fractures associated with translational deformities. Rotatory atlantoaxial subluxation was also demonstrated in patients with disease involving the occipitocervical articulation.

A low incidence of neurological deficits in patients with atlantoaxial metastases may be explained by the increased size of the upper cervical canal compared with other spinal levels. The most common clinical presentation is severe neck pain due to spinal instability.[24] As a result, anterior tumor resection (via a trans- or extraoral approach) is rarely indicated, and our surgical management strategy has focused on posterior spinal stabilization.

A long segmental stabilization (that is, occipitocervical fixation) is justified because it protects the patient against the potential loss of stability due to progression of the destructive process, although it reduces the range of neck movements. In our experience, a patient's degree of pain relief is so valued that he or she does not consider the loss of mobility, which can often be significantly compensated for, to be detrimental to his well-being. Our goal is to provide a solid construct at the time of surgery so that the use of any cumbersome and poorly tolerated external orthoses (rigid collar or halo vest) can be avoided.

Occipitocervical stabilization may involve a simple contoured rod or an occipital plate/rod construct. Although we have used Wisconsin spinous process wires and sublaminar wires to achieve segmental fixation, we now prefer more rigid constructs that involve bicortical screw purchase within the occipital bone and lateral masses of the cervical spine (Fig. 2). Depending on the clinical situation, the construct may be augmented with C-2 pedicle screws or C1–2 transarticular screw fixation in patients in whom the surrounding bone is adequate.[28]

Subaxial Cervical Spine

Tumors involving the VBs of the subaxial spine can be approached via a standard anterior neck dissection. After resection and reconstruction, placement of cervical locking plate/screw constructs provide excellent internal fixation.[19] Kyphotic deformity is not uncommon in cases involving neoplasms in this region. Lateral mass screw constructs should generally be used to supplement an anterior reconstruction and stabilization in patients in whom more than one spinal level is involved and in those with significant kyphotic deformity. Patients with more wide-

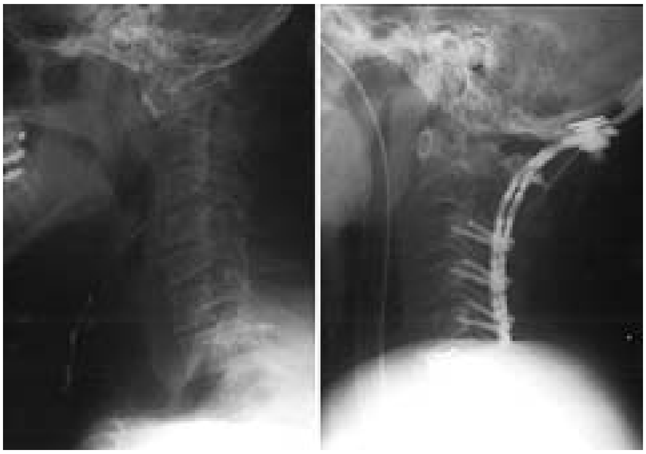

Fig. 2. Plain lateral *(left)* pre- and postoperative *(right)* x-ray films obtained in a patient with multiple myeloma. The preoperative study demonstrates pathological dens fracture with C1–2 subluxation, and the postoperative study reveals reduction of deformity and posterior occipitocervical hardware.

spread disease who are medically fit and in whom life expectancy is of reasonable length may benefit from posterior decompression combined with long-segment stabilization.

In patients with lesions located at the cervicothoracic junction, anterior reconstruction and placement of instrumentation alone are probably not sufficient, because of the risk of progressive kyphosis. Posterior stabilization at the cervicothoracic junction may be performed using a number of methods, including those involving a combination of lateral mass screws and pedicle screws or hooks.[12]

Thoracic Spine

Because the thoracic spine has traditionally been presumed to be well supported by the rib cage, the general belief was that supplemental spinal stabilization was not always needed after posterior or posterolateral thoracic resections. Supplementary stabilization, however, is often necessary after a posterior resection because a significant portion of the facets and pedicles is commonly excised. Progressive kyphosis is the most common deformity pattern resulting from thoracic neoplasms (Fig. 3).

Because spinal metastases most commonly involve the VB, transthoracic vertebrectomy and anterior plate reconstruction are most commonly undertaken when the disease is limited to one or two levels.[10] Single-stage posterolateral decompression combined with stabilization is reserved for patients with more widespread disease or a specific contraindication to thoracotomy.[8]

In cases of significant kyphosis with VB collapse, the surgeon should be aware that the posterior ligamentous complex has been compromised and that this may contribute to progressive kyphosis despite vertebral reconstruction and plate fixation. This is particularly true of lesions at the thoracolumbar junction because of the more sagittal orientation of the facet joints in this region and the presence of increased biomechanical stress between the relatively rigid thoracic levels and the more mobile lumbar segments. In most patients with thoracolumbar junction metastases whom we have treated, supplemental posterior stabilization is performed along with resection and reconstruction of the VB.

Supplementary posterior stabilization is also indicated for most patients who undergo thoracic vertebrectomies in which anterior reconstruction is performed at two or more adjacent levels, because lengthy anterior constructs (with or without anterior plating) may not provide adequate stability.

Whenever a significant portion of the adjacent chest wall has been included in the tumor resection, such as in cases involving Pancoast tumors[29] or locally invasive sarcomas invading the chest wall,[8] posterior fixation should be considered because of the risk of kyphoscoliosis.

In patients with large thoracic or upper lumbar tumors involving both the VB and the posterior elements, or in those with significant adjacent chest wall involvement, a combined anterior–posterior approach (with the patient in the lateral decubitus position) should be considered.[8] This approach permits radical tumor resection, correction of deformity, VB reconstruction, and complete (posterior and anterior) stabilization in a single-stage procedure.

The standard method for stabilization of the upper thoracic spine is hook fixation in a claw configuration, although more widespread use of pedicle screws in this region has developed concurrently with advances in image-guided surgery.[7] Posterior stabilization of lower thoracic and lumbar regions is best performed using pedicle screws.

In our recent review of 100 consecutive cases involving pedicle screw fixation for malignant spinal disease, the rate of late screw-related failure was only 2%.[7] The low failure rate, even among long-term survivors, was attributed to an emphasis on the concurrent use of anterior approaches to reconstruct the weight-bearing capacity of the spine.

Lumbar Spine

A retroperitoneal approach provides excellent exposure for most lumbar metastatic tumors. Palliative posterior/posterolateral decompression and stabilization may be considered in patients with multilevel disease. In patients with disease limited to L-5, posterolateral decompression and stabilization are usually performed in lieu of anterior approaches because anterior fixation is difficult to achieve at this level and complete anterior decompression can be readily accomplished via a posterior approach.

Patterns of deformity in neoplastic destruction of the lumbar spine are characterized by kyphosis (with simple VB collapse) or kyphoscoliosis (when unilateral VB collapse or failure of the pedicle unilaterally has occurred). Significant deformity is unusual when lesions are located below L-3.

As in the thoracic spine and the thoracolumbar junction, stabilization after lumbar vertebrectomy and reconstruction can be achieved by placing anterior locking plate and screw constructs. For single-level L1–3 vertebrectomy, supplementary posterior stabilization is usually unnecessary because collapse tends to be symmetrical and kyphotic deformity is minimized by preexisting lumbar lordosis. Anterior hardware cannot be reliably applied caudal to L-4. Pedicle screw fixation provides the best method of posterior stabilization in the lumbar spine.

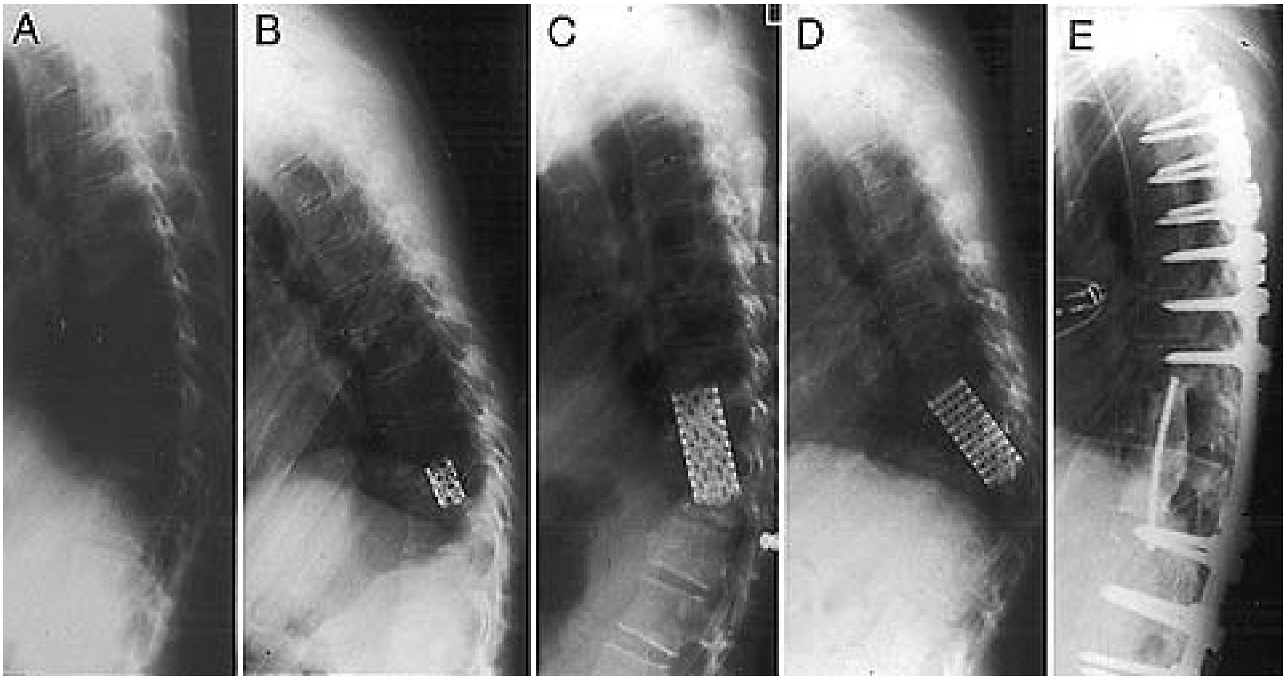

Fig. 3. Serial lateral thoracolumbar x-ray films obtained in a patient with T-10 metastatic breast cancer. A: Preoperative plain x-ray film demonstrating minimal kyphosis. B: Postoperative x-ray film acquired after laminectomy, costotransversectomy, posterolateral vertebrectomy, and cage-assisted reconstruction. No posterior stabilization was performed. The patient subsequently developed mechanical pain, progressive kyphosis, and neurological dysfunction. C: Postoperative x-ray film obtained after a second operation for thoracotomy, T-9 and T-10 corpectomies, revised cage reconstruction, and no anterior stabilization. D: The patient later developed recurrent mechanical pain and gait difficulties; the x-ray film demonstrates severe kyphosis. E: Postoperative x-ray film obtained after a third operation (performed via a single-stage anterior–posterior approach), revealed posterior thoracolumbar pedicle screw fixation, anterior reconstruction, and correction of kyphotic deformity.

Lumbosacral Junction and Sacrum

Neoplastic lysis at the lumbosacral junction or sacrum, in our experience, seldom results in spondylolisthesis or other obvious deformity because the tumor rarely involves the strong ligamentous support structures and the L5–S1 facet complex, which confer most of this region's stability. Although significant deformity is unusual, clinical instability with severe axial pain is not.

The lumbosacral junction is exposed to the largest loads borne by the spine. As in the cervicothoracic and thoracolumbar regions, the lumbosacral junction represents a high-stress region of the spine. Relatively abrupt changes in anatomy and regional mechanics between the mobile lumbar and fixed sacral segments increase the risk of fracture and instability and present challenging problems in terms of spinal stabilization.

The S-1 pedicle is larger than the lumbar pedicles and may often be fitted with 7- to 8-mm screws. Additional osseous purchase can be obtained if the screw penetrates the anterior S-1 cortex or the superior S-1 endplate. Medially directed S-1 pedicle screws that are cross-linked and attached to rods create a triangulation effect that greatly increases torsional stability and resists pullout.[2,3,17,23] Triangulation with an oblique orientation also interferes less with the superjacent facet joint and allows greater osseous purchase with a longer screw.[16]

A screw-related technique to enhance sacral fixation is to place an additional pair of laterally directed bone screws into the sacral alae below S-1. This has a biomechanical advantage over a single pair of S-1 pedicle screws;[17] however, the bone of the alae is usually of low density, and purchase may be tenuous.[22] Moreover, the risk of neurovascular injury due to laterally directed screws in this region must be kept in mind.

The S-2 (or lower-level) pedicle screws are often of little use because the pedicles are very short. In biomechanical testing it has been shown that pedicle screws placed below the S-1 level do not significantly enhance stability.[17] In addition, the thin sagittal dimension of the sacrum at lower levels increases the risk of penetration of its anterior surface, with a potential for vascular and visceral structure injury. Screws inserted at lower sacral levels are often prominent posterior and may even create a "tent" effect in the overlying skin.

Sacral screw fixation may be sufficient in cases involving short segmental stabilization (that is, one or two levels) and in which there is minimal instability. If a longer construct is placed, the sacral attachment is subjected to considerable cantilevered forces that may lead to screw pullout. Finally, the use of sacral screws may be precluded in certain cases, such as when the pedicles, VB, or alae of the sacrum are involved with tumor. In such cases, one should consider instrumentation fitted to the pelvis.

A simple method of sacropelvic fixation involves the placement of long variable-angle screws placed obliquely across the sacroiliac joint into the iliac bones.[13] A tripod effect may be gained by combining the sacroiliac fixation with additional sacral fixation points.[1] Our preferred method of fixation to the pelvis, however, entails a modified Galveston technique (Fig. 4).[13] This involves the insertion of an angled distal limb of a spinal fixation rod into the posterior iliac bones, just above the sciatic notch. Custom bending and insertion of the rod requires some technical skill. Preformed rods are also available. Alternatively, iliac screws (ISOLA iliac screws; Acromed, Cleveland, OH) can be placed independently of the spinal rod, with the two subsequently linked together. In the biomechanical testing of 10 different lumbosacral instrumentation techniques in a bovine model, McCord, et al.,[17] found that the most effective construct entailed medially directed S-1 pedicle screws and an iliac purchase in the Galveston-type fashion.

CORRECTION OF SPINAL DEFORMITY

In general, spinal deformities that develop as a result of neoplastic conditions are secondary to collapse of the VB. Therefore, with the exception of the upper cervical spine, where translational and rotational deformities may occur, neoplastic spinal deformities are usually kyphotic in nature. With additional chest wall or unilateral pedicle disruption, kyphoscoliosis may be seen. Occasionally, shearing deformities (antero- or posterolisthesis) are encountered.

A second feature of neoplastic deformities is that characteristically they can be corrected (that is, they are considered flexible). This is in contrast to certain congenital and degenerative spinal conditions that require osteotomies for correction. The majority of neoplastic deformities can therefore be corrected by careful positioning of the patient on the operating room table. Exceptions are certain upper cervical deformities (for example, pathological dens fracture with translation, as well as rotatory atlantoaxial subluxation), which may require the application of cervical traction.

The recent availability of distractible cages (Synex cage, Synthes Spine) has enhanced our ability to correct kyphosis after anterior vertebrectomy.

Correction can also be accomplished by applying forces to the posterior instrumentation. Although individual surgery-related preferences vary with regard to the steps of deformity correction, it is universally accepted that to prevent neurological dysfunction, distraction across a deformity should not occur. Thus, the instrumentation must be fixed at one point, either cephalad or caudad, so that the spine remains mobile during the translational maneuver.[27]

BONE FUSION

Bone fusion per se is not a practical goal in cancer patients with limited life expectancy, many of whom require adjuvant chemotherapy or radiotherapy that further compromises the chance of successful fusion. Our goal in these cases is to provide an immediately stable construct that minimizes or eliminates axial pain and helps to prevent neurological deterioration during the patient's remaining lives. Onlay bone graft may be applied after the spine has been stabilized to promote fusion for the occasional long-term survivor. We do not favor the use of autograft because of the potential for graft-site morbidity and the occurrence of unrecognized metastatic disease within the iliac crest bone of some patients.

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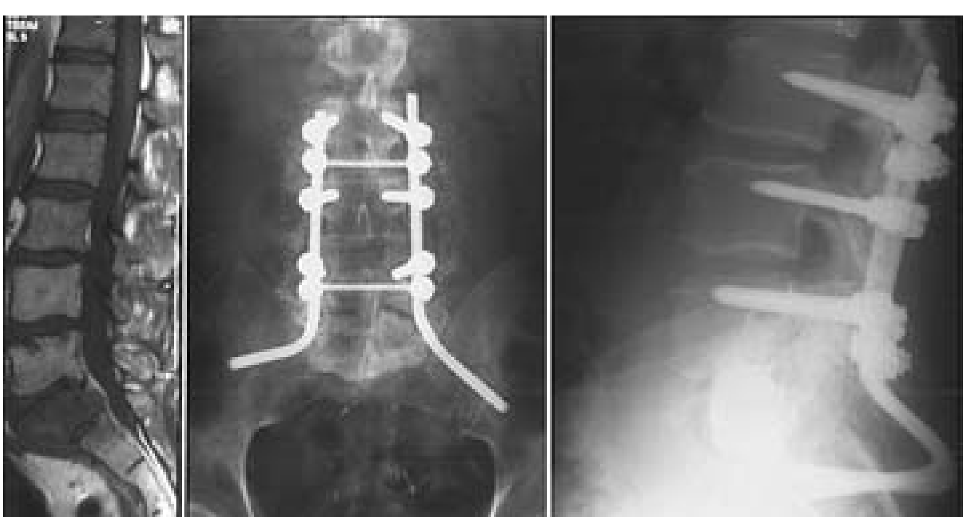

Fig. 4. Imaging studies obtained in a patient with colon cancer metastatic to S-1 who presented with severe axial pain and bilateral sciatica. *Left:* Preoperative T_1-weighted MR image. *Center* and *Right:* Postoperative plain anteroposterior *(center)* and lateral *(right)* x-ray films obtained after transpedicular S-1 corpectomy, reconstruction with PMMA/chest tube, and spinopelvic fixation involving the modified Galveston L-rod technique.

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Address reprint requests to: Ziya L. Gokaslan, M.D., Department of Neurosurgery, Johns Hopkins University, Meyer 7-109, 600 North Wolfe Street, Baltimore, Maryland 21287. email: zgokasl1@jhmi.edu.