Surgical techniques to manage instability have evolved in recent years. Using a multidisciplinary approach, increasing patient survival and improving quality of life are the ultimate goals of treatment.

Spinal Neoplastic Instability: Biomechanics and Current Management Options

Andreas K. Filis, MD, Kamran V. Aghayev, MD, James J. Doulgeris, MSME, Sabrina A. Gonzalez-Blohm, MSBE, and Frank D. Vrionis, MD, PhD

Background: Often the spine is afflicted from primary or metastatic neoplastic disease, which can lead to instability. Instability can cause deformity, pain, and spinal cord compression and is an indication for surgery. Although overt instability is uniformly agreed upon, it is sometimes difficult for specialists to agree on subtle degrees of instability due to lack of objective criteria.

Methods: In this article, treatment options and the spine instability neoplastic system are discussed and the neoplastic instability literature is reviewed.

Results: The Spinal Instability Neoplastic Score helps specialists determine whether instability is present and when surgery may be indicated. However, other parameters such as spinal cord compression and extent of disease dictate whether surgery is the most appropriate option. A wide range of fusion techniques exists, each one tailored to the location of the lesion and goals for surgery.

Conclusions: To optimize results, expert knowledge on the techniques and patient selection is of importance. Furthermore, a multidisciplinary approach is required because treatment of neoplastic disease is multimodal.

Introduction

Neoplastic disease of the spine comprises a wide range of pathology. From a location standpoint, extradural and intradural lesions may exist, with the latter being further subdivided into intramedullary and extramedullary lesions. Intradural pathology rarely leads to instability. Spinal metastasis is the most common type of neoplasm, where autopsy investigations have shown that up to 70% of patients with cancer have spinal metastases.1 The thoracic (70%) and lumbar spine are most commonly affected, and the vertebral body is afflicted in most cases.1 In North America,
approximately 18,000 new cases of metastatic spine disease, with epidural involvement, are diagnosed each year. Cases are increasing as the population ages and cancer therapies evolve that allow patients to survive long enough for neoplastic disease of the spine to become symptomatic.

The management of spinal neoplastic disease has significantly changed during the last few decades. Advancements include the improvement of adjuvant therapy, namely radiotherapy and chemotherapy, and research has improved our understanding of the biomechanics of the tumor-affected spine. Advancements in adjuvant therapy may have decreased the need of surgery, but neoplastic instability remains an important surgical indication. The evolution of stabilization techniques, the development of anterior and posterior instrumentation, and the development of innovative materials allow surgeons more flexibility; alternatively, this technology also dictates the necessity of expertise and careful patient selection for an optimal result.

**Clinical Biomechanics, Traumatic Instability, and Various Classification Systems**

Several authors have attempted to define and classify spinal instability. Denis divided the spine into 3 columns: the anterior consists of the anterior longitudinal ligament and the anterior half of the vertebral body; the middle column includes the posterior half of the vertebral body and the posterior longitudinal ligament; and the further posterior elements (pedicles, facet joints, and intraspinous ligaments) comprise the posterior column. Denis’ 3-column theory for traumatic instability proposed that damaging 2 or more of these columns would render the spine unstable; however, this theory is based on radiological, not biomechanical, studies. White and Panjabi described clinical instability as “the decrease of the spine’s ability, under normal physiological loads, to maintain a consistent displacement pattern so that there is no initial or additional deficit, no major deformity and no incapacitating pain.” In 1992, Panjabi introduced a model consisting of an osteoligamentous (passive), muscle, and neural control subsystem to explain spinal stability. He then defined the neutral zone as the range of physiological intervertebral motion, where motion is produced with the minimal internal resistance, and suggested that it has a higher correlation with instability than range of motion. Another classification system for traumatic instability is the subaxial cervical spine injury score described by Vaccaro et al, which focuses on injury morphology, disc–ligament integrity, and neurological status. Kostuik and Weinstein divided the vertebral column into 6 segments for assessing instability. According to their classification, instability was defined as 3 or more invaded segments.

Benzel divides instability into acute (overt and limited) and chronic (glacial and dysfunctional). He also divided the vertebral body into 27 cubes (a system of interlocking blocks) and emphasized that removing these cubes in certain parts of the vertebral body had a different effect on overall stability.

Other factors, such as bone mineral density, may also play a role. Overall, the anterior column of the spine (vertebral bodies and discs) carries 75% to 97% of the compression loads, while the posterior elements serve as a tension band and carry 3% to 25% of the loads. Removal of the posterior elements (facets, lamina) predisposes the spine to translational deformity secondary to shear forces. By contrast, compression fractures may depend on whether the forces act in line with the instantaneous rotational axis of the spine. Taneichi et al showed that removal of the costo-vertebral joint in the thoracic spine was the largest contributor to instability compared with the lumbar spine, wherein the vertebral body was most important.

Tumors differ from traumatic conditions in the sense that ligaments and discs are rarely affected, the mechanism of injury is not as important, and the ability of the spine to heal is compromised. Consequently, classifications of spinal instability based on trauma classifications are not as valid for tumors. In addition, iatrogenic instability, particularly in cases of en bloc tumor resections, and impending instability, with the potential for collapse and further injury, are concepts that primarily involve neoplasia.

Instability is often determined by factors derived from clinical scenarios and biomechanical data. Ranking several qualitative observations and comparing the score to a preset value generally determines clinical instability. The point system approach has become very popular in determining spinal instability, but it often includes several “shades of grey,” thus leaving the ranking systems as more of a “probability of instability,” rather than an absolute system. For example, the stable portion may be interpreted as low probability and unstable as high probability, whereas the “grey zone” represents more of a medium probability. Therefore, it may be advisable to interpret the scores as a proportion (score divided by maximum point value) to help determine the likelihood of instability. Regardless of the criteria used or interpretation, the clinical decision as to whether a particular surgery or tumor will lead to instability relies on the intuition and experience of the surgeon.

Alternatively, biomechanical instability is experimentally determined, with respect to quantitative values, and extrapolated to help determine the ranks of the injury or trauma. Several biomechanical factors, such as neutral and elastic zone stiffness, have been used to explain stability. These factors are useful in a biomechanical environment, but extrapolating them to
an in vivo situation can be difficult because the body can react to trauma in different ways. For example, if an osteoligamentous injury decreases stability, then the stabilizing muscles may preserve stability by preventing excessive motions, and, although muscle contributions may maintain loading stability, over time the spine may creep until it is out of alignment.

Anticipated instability is understood as iatrogenic sequelae of extended resection. In neoplastic disease, a major concern is the acute instability via infiltration of osseous structures. The degree of instability varies depending on the location and extent of osseous infiltration. For example, ligaments are crucial to stability in the craniovertebral junction, most likely equally or more significant than the osseous integrity. By contrast, the ribs and the sternum provide internal stabilization in the thoracic spine.

Scoring System for Neoplastic Instability and Indications for Surgery

For several years, neoplastic instability was undefined, which meant that knowledge about degenerative or traumatic instability was applied to neoplastic cases. However, extrapolation is problematic because oftentimes bone mineral density and ligaments are abated and pathological fractures do not follow the usual patterns with respect to traumatic and osteoporotic cases. In 2010, the Spine Oncology Study Group published a novel classification system with 6 components referred to as the Spinal Instability Neoplastic Score (SINS).

According to the SINS system, localization of the pathology plays an important role in terms of instability. Junction areas, such as the cervicothoracic and occipitocervical junction, contribute to more points in the overall SINS, whereas less mobile areas, such as the subaxial and lumbar spine, add fewer points. For example, a tumor at a junction of the spine (occipitocervical, cervicothoracic, thoracolumbar) may be more destabilizing than a similar tumor in a less mobile part of the spine such as the sacrum. The semi-rigid thoracic spine contributes 1 point, and the most rigid sacral spine does not add any points to the overall score.

In summary, the remaining components of the SINS system include pain, type of bone lesion, radiographic spinal alignment, vertebral bone collapse, and involvement of posterolateral spine elements. Pain present when a patient is in an upright position but is relieved by recumbence (mechanical pain) is indicative of instability. Lytic tumors are unstable compared with blastic or mixed tumors. The presence of translational or kyphotic deformity and the degree of vertebral body involvement (≥ 50%) significantly contribute to the instability score. Finally, the added involvement (or lack thereof) of 1 or 2 bilateral facet joints points to the importance of the posterior elements of the spine.

The SINS classification was designed to efficiently communicate among medical oncologists, radiation oncologists, and surgeons, as well as other health care professionals, and to guide decision making with regard to patient care. Beyond the mechanical aspect as reflected by the SINS, the neurological status of the patient, the epidural extension of tumor, oncological parameters (eg, sensitivity of disease to adjuvant therapy), and systemic considerations (eg, tumor burden, comorbidities) comprise the neurological, oncological, mechanical, and systemic factors algorithm for decision making between surgery or radiation in cases of neoplastic spine disease.

The SINS has a range of 0 to 18 and the score separately applies to each spinal lesion; that is, values for many lesions should not be added. The sensitivity and specificity rates for SINS were found to be 95.7% and 79.5%, respectively. A score of 6 or below implies a stable segment (Fig 1), whereas a score of 13 or higher implies instability (Figs 2 and 3). Instability is ambiguous in the grey zone between 7 and 12 (Fig 4). Generally, surgical consultation is warranted for scores higher than 7. Moreover, in cases of an unstable spine, the neurological, oncological, mechanical, and systemic factors algorithm will dictate the need for surgery. For example, surgery is not advisable in a patient with multiple morbidities because the complication risk may be unacceptably high.

**Fig. 1A-C.** — (A) Sagittal and (B) axial T1-gadolinium–enhanced magnetic resonance imaging of a 71-year-old patient with a history of prostate cancer. Spinal metastatic tumor is present in the lumbar spine with consecutive stenosis leading to radiculopathy. Spinal Instability Neoplastic Score: 4. No fusion required. Panel C shows postoperative computed tomography following decompression and kyphoplasty.
high. According to a panel of experts, the interobserver and intraobserver variability rates of the system were 0.846 and 0.886, respectively; however, a large-scale validation of SINS in routine clinical practice has not yet been performed.

Every case of acute, overt spinal instability in neuro-oncology should be evaluated as soon as possible for surgical intervention. Patients with spine neoplasm as well as saddle anesthesia, high-grade paresis, and urinary retention may need emergent decompression with or without fusion. In such cases, instability is indeed a phenomenon of increments; therefore, dynamic imaging may be considered as a means of increasing sensitivity as to which spines are unstable. However, limited patient cooperation, particularly in the oncological and elderly patient populations, poses significant difficulties to assess instability, thus underlining the importance of clinical judgment and personal experience in terms of surgical indication.

Craniovertebral Junction

Stability is often an issue in cases of neoplastic disease of the craniovertebral junction because this section of the spine undergoes the most motion. In the SINS system, pathology in the craniovertebral junction contributes 3 points to the overall score. By contrast, if the pathology were localized in more rigid areas like S2 to S5, then no points would be added. Intracranial tumors (eg, meningioma, schwannoma) may extend to the foramen magnum and may cause instability during their removal. The most common extradural pathology is chordoma, while other entities, such as eosinophilic granuloma, plasmocytoma, and fibrous dysplasia, are possible although rare. Metastases in the vertebral bodies are also worth mentioning because resection of most of the vertebral body of C2, more than 70% of one or more than 50% of both of the occipital condyles, or C1 lateral masses may generate instability. Tumor growth or surgical resection can also lead to instability insomuch that the stabilizing ligamentous elements could be weakened during surgical access to the pathology.

Various techniques common in occipitocervical stabilization, such as wiring, plate-rod systems,
in/out buttons, and occipital condyle screw fixation, are often compared in the medical literature. Compared with wiring, current studies suggest that plate-rod systems have an increased fusion rate and a decreased pseudarthrosis rate.\textsuperscript{15,16} Uribe et al\textsuperscript{17} reported that stabilization with condyle screws is biomechanically equivalent to the standard plate-rod system. For atlantoaxial stabilization, combining the lateral mass C1 screws with C2 pedicle or pars screws is an option.\textsuperscript{18} De Iure et al\textsuperscript{19} reported positive outcomes with the Harm technique (C1 articular mass to C2 pedicle screws), which spared wiring as used in the Magerl method of transarticular C1-C2 fusion. In some cases in which parameters preclude surgery, a halo-vest or sternal-occipital-mandibular immobilizer brace may be considered to provide satisfactory stability for the upper cervical spine.\textsuperscript{20,21} Pathology located ventral to the medulla in the craniovertebral junction can be resected via an anterior approach (eg, transoral odontoidectomy with or without maxillotomy), but stabilization must be dorsally performed, thus making a second surgery necessary. In patients with cancer who undergo further radiotherapy, transoral tumor resections are strongly discouraged because these resections are associated with major wound healing complications.

**Subaxial Cervical Spine**

The subaxial cervical spine is composed of levels C3 to C7. It is considered less mobile than the craniovertebral junction; thus, it contributes 2 points to the overall SINS. Posterior stabilization with lateral mass screws and C7 pedicle screws and rods is common practice following multilevel laminectomy in the subaxial cervical spine. Theoretically, cervical laminoplasty could spare the need for stabilization, but it may not be an option in certain neoplastic diseases. If the anterior column is compromised during intervention, then anterior fusion of the vertebrae with a plate may be required. In cases in which the vertebral body must be removed, it is mandatory to fill the gap with an expandable cage, bone graft, or polymethylmethacrylate (PMMA). Thus, a variety of different systems have been developed for this purpose. Percutaneous vertebral augmentation via a posterolateral or anterolateral route, as well as the transoral route, for metastatic disease in C1 to C2 has been reported.\textsuperscript{22,23} Vertebroplasty and kyphoplasty have also been employed for pain control in vertebral metastases as well as in the subaxial cervical spine.\textsuperscript{24} The presence of vertebral arteries and the narrow space between cervical nerve roots make corpectomy and reconstruction technically difficult from a posterior approach. In the majority of cases, the location of pathology dictates the surgical approach. Generally, lateral mass screw rod stabilization is considered more stable than anterior plating. Therefore, for multilevel anterior corpectomies with subsequent reconstructions, 360-degree fixation may be an option to provide robust stabilization.

**Cervicothoracic Junction and Thoracic Spine**

The cervicothoracic junction is one of the most difficult areas of the spine to assess because osseous, major vascular, and neural structures hinder anterior approaches. Similar to the craniovertebral junction, it contributes 3 points to the overall SINS.

Cauchoux and Binet\textsuperscript{25} described a direct approach through sternotomy. Over time various less-invasive techniques have been reported, such as midclavicle resection without manubriotomy and a transthoracic approach through rib removal. The transthoracic approach can be either lateral extrapleural (retropleural), where the surgical route is between the parietal pleura and the endothoracic fascia, or lateral transpleural (intrapleural), which involves opening the parietal pleura. The cervicothoracic junction can also be assessed through the posterior route, either using a midline approach and a pedicle screw fixation or via costotransversectomy or a lateral extracavitary approach. The posterior transpedicular approach can offer direct access to ventral pathology and 3-column stabilization when necessary.\textsuperscript{26}

In most cases, in the cervicothoracic junction following posterior decompression and tumor removal, the instrumentation should extend 2 levels above and below the decompression. In terms of biomechanics, it may be challenging to bridge the lordotic and mobile cervical spine with the rigid thoracic spine. Cement augmentation through fenestrated screws is an emerging method that has been reported to reduce the likelihood of loosening of instrumentation.\textsuperscript{27} Posterior techniques are also employed in surgery of the middle and lower thoracic spine.

Generally, if part of the vertebral body is afflicted and must be removed, then expandable cages may be beneficial; other options include reconstruction with bone graft or PMMA. Rajpal et al\textsuperscript{28} reported that although metal implants are used in the majority of reconstruction cases, they also have the highest rate of overall complications. In another study, reconstruction with expandable cages packed with bone graft revealed better fusion rates than PMMA, whereas the latter is more cost effective and might be preferable in patients with limited life expectancies.\textsuperscript{29}

**Lumbar Spine**

The lumbar spine is considered mobile and, similar to the subaxial spine, contributes 2 points to the overall SINS. For patients with tumors, when comorbidity dictates the least invasive type of surgery, percutaneous fusion may be an option that can be performed.
with pedicle screws augmented with cement. In cases in which the pathology is located anteriorly, laterally, or both, an anterior retroperitoneal approach may be indicated. Following vertebrectomy, reconstruction should be carried out with a cage or bone graft, as well as a plate-screw system for stabilization. For the lower thoracic, upper lumbar levels, a combined transthoracic–transabdominal approach may be considered. Vertebroplasty and balloon kyphoplasty are useful for the reconstruction of compressed vertebral bodies as well as pain reduction if tumor removal and decompression are not the primary goals. For patients with metastatic disease who have a limited life expectancy, epidural tumor resection and open vertebroplasty/kyphoplasty followed by radiotherapy may also be an appropriate option.

**Orthoses**

External stabilization with orthoses is employed in selected cases when surgery is not an option or has been scheduled for a later date. The goal is to restore alignment and prevent neurological deterioration. Many kinds of orthoses have been developed to provide the best possible biomechanical stability in different spinal levels.

Most data derive from spine injury series. To our knowledge, no systematic reviews exist regarding the usage of orthoses in pathological fractures. With that in mind, the literature supports halo-vest immobilization as an effective method of reconstruction of the unstable upper cervical spine and should be considered in cases of nonunion surgery. The Philadelphia collar is considered to be sufficient in stabilizing the upper cervical spine, and it may be an alternative to the halo-vest. The sternal-occipital-mandibular immobilizer orthosis controls flexion more effectively than extension in the cervical spine. Other cervicothoracic orthoses include the Minerva and Yale types. Thoracolumbosacral and lumbosacral orthoses are also available and generally increase the intra-Abdominal pressure, thus decreasing the strain on the spine and intervertebral discs.

**En Bloc Resection**

Theoretically, en bloc resection in spinal neoplasia is a curative treatment option. However, because the extent of the tumor is multilevel in most cases, the strategy is not feasible. En bloc spondylectomy, a technically demanding, often 2-stage procedure, has previously been described. The resection must be followed by anterior reconstruction of the vertebra and posterior instrumentation. Local malignancies such as chordomas, selected sarcomas and chondrosarcomas, Pancoast tumors, giant cell tumors, and osteoblastomas are types of tumors in which en bloc resection should be considered.

**Surgery and Quality of Life**

Many classification systems for spinal tumors and prognostic scores have been developed over time. Most patients referred to spine surgeons have advanced disease and often adjuvant therapy is not possible. If neurological deterioration is imminent through a pathological fracture or instability, then the need for fusion becomes obvious. However, non-emergency surgery is controversial when performed in cases in which a patient’s life expectancy is less than a few months. Evidence should corroborate that a fusion can improve quality of life, which should ultimately guide the surgical decision. Pain reduction and an appropriate amount of ambulation following surgery are important because patients are likely to be motivated to continue with adjuvant therapy.

**Conclusions**

Fusion systems have evolved and now offer a variety of treatment options for use by health care professionals. However, the patient with cancer often has limited reserves to compensate, so a major issue of therapy is complication avoidance. Therefore, careful patient selection and an overall multidisciplinary approach to master surgical techniques are both required. Increasing patient survival and improving quality of life are the ultimate goals of treatment. However, a need for palliative therapy still exists in the majority of cases of oncological surgery.

**References**


