

## Importance of Spinal Alignment in Primary and Metastatic Spine Tumors

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### Key words

- Alignment
- Deformity
- Patient outcomes
- Spine oncology
- Spinopelvic parameters
- Tumor

### Abbreviations and Acronyms

**CL:** Cervical lordosis  
**CT:** Computed tomography  
**HRQOL:** Health-related quality of life  
**LL:** Lumbar lordosis  
**PI:** Pelvic incidence  
**PT:** Pelvic tilt  
**SINS:** Spinal Instability Neoplastic Score  
**SVA:** Sagittal vertical axis  
**TK:** Thoracic kyphosis

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Citation: *World Neurosurg.* (2019) 132:118-128.

<https://doi.org/10.1016/j.wneu.2019.08.161>

Journal homepage: [www.journals.elsevier.com/world-neurosurgery](http://www.journals.elsevier.com/world-neurosurgery)

Available online: [www.sciencedirect.com](http://www.sciencedirect.com)

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### INTRODUCTION

Derangements of spinal alignment, particularly related to the defined spinopelvic parameters, are an established cause of morbidity and disability. The importance of correcting spinal alignment for improving postoperative quality of life has been well characterized within the deformity literature.<sup>1,2</sup> However, these parameters have historically been neglected in oncologic spine surgery and have not been studied in either the preoperative or postoperative settings.<sup>1</sup> Because the goal of oncologic surgery is often symptom palliation or improved quality of life, consideration of spinal alignment could prove critical to the optimization of postoperative

Spinal alignment, particularly with respect to spinopelvic parameters, is highly correlated with morbidity and health-related quality-of-life outcomes. Although the importance of spinal alignment has been emphasized in the deformity literature, spinopelvic parameters have not been considered in the context of spine oncology. Because the aim of oncologic spine surgery is mostly palliative, consideration of spinopelvic parameters could improve postoperative outcomes in both the primary and metastatic tumor population by taking overall vertebral stability into account. This review highlights the relevance of focal and global spinal alignment, particularly related to spinopelvic parameters, in the treatment of spine tumors.

outcomes in this population.<sup>3-5</sup> Many of the surgical techniques used to correct spinal deformity are also commonly used in the context of spine tumors, such as intervertebral osteotomies, pedicle subtraction osteotomies, and vertebral column resection.<sup>6</sup> However, no study has evaluated the role of spinal alignment in this context. This review aims to discuss the applicability and relevance of focal and global spinal alignment to oncologic surgery, especially in the context of spinopelvic parameters.

### DEFINING SPINOPELVIC PARAMETERS

The spinal column has evolved to accommodate upright posture, mobility, and bipedalism. As a result, the curvature of the human spine is established by cervical lordosis (CL), thoracic kyphosis (TK), and lumbar lordosis (LL) to support these functions. The concept of the cone of economy introduced by Dubousset<sup>7</sup> posits that there is a range of postures that allows for balance and movement with minimal effort. As an individual moves outside the boundaries of this cone, additional energy is required to maintain balance, leading to accelerated degeneration, pain, and instability. Consequently, deformity of the spinal column can lead to increased strain on the intrinsic musculature of the back, compromised stability, and decreased function. Spinopelvic parameters were

therefore developed to standardize and describe the intrinsic relationship of the components of the spinal column.

When describing spinopelvic balance, particularly in the sagittal plane, it is important to consider 3 main parameters: global, regional, and pelvic (**Table 1**). Global parameters include sagittal vertical axis (SVA), T<sub>1</sub> spinopelvic inclination, T<sub>9</sub> spinopelvic inclination, and T<sub>1</sub> pelvic angle (**Figure 1**). Regional spinal parameters are defined by CL, cervical SVA, TK, and LL (**Figure 2**). Pelvic parameters consist of pelvic incidence (PI), sacral slope, and pelvic tilt (PT) (**Figure 3**). Focal kyphotic deformity is also paramount in the context of localized disease, such as traumatic or pathologic fractures and bony destruction secondary to lytic lesions. The spine acts as a global unit in which the alignment of the cervical spine is both dependent on and affects the alignment of the lower spine.<sup>8</sup> More specifically, Ames et al.<sup>8</sup> found that PI is directly associated with LL, LL is directly associated with TK, and TK is directly associated with CL, based on a retrospective analysis of 55 healthy volunteers. Therefore, increases in PI result in compensatory increases in LL, which lead to increases in TK, which results in increases in CL. Newer measurements such as proximal thoracic slope have also been devised to create a global spinal equation describing the ideal relationship between different parameters.<sup>9</sup>

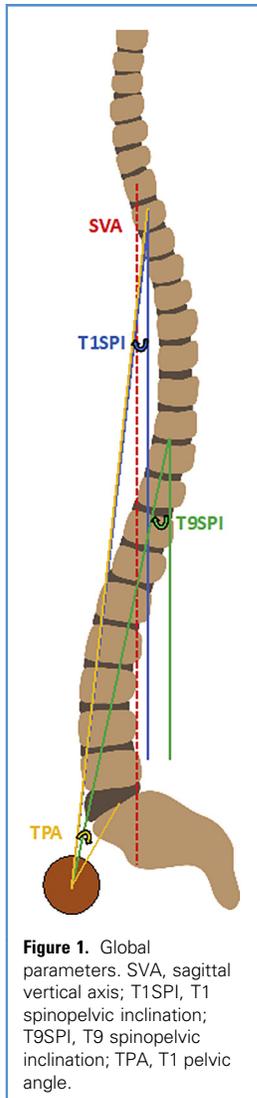
**Table 1.** Summary of Spinopelvic Parameters

Description		Significance
Global parameters		
Sagittal vertical axis	Vertical line from the middle of body of C7 that passes within 2 cm from the superior end plate of S1	Positive sagittal imbalance has been associated with increased pain, fatigue, and disability <sup>6,10-13</sup>
T1 spinopelvic inclination	Angle formed between the line extending from the bicoxofemoral axis to the center of T1 and a vertical reference line from the center of T1	Correlates with patient-reported outcomes in health-related quality of life such as Scoliosis Research Society questionnaire 22R, Oswestry Disability Index, and Short Form-12 scores <sup>4,14</sup>
T9 spinopelvic inclination	Angle formed between the line extending from the bicoxofemoral axis to the center of T9 and a vertical reference line from the center of T9	T9 sagittal offset is a marker of the center of gravity above the femoral heads and is an indicator of the sagittal balance of the spine <sup>15</sup>
T1 pelvic angle	Angle between the line from the femoral head axis to the center of T1 and the line from femoral head axis to the midpoint of S1 end plate	Severe deformity occurs above T1 pelvic angle of approximately 20°; greater values are associated with worse health outcome measures <sup>16,17</sup>
Regional parameters		
Cervical lordosis	Normal inward curvature of the cervical spine between 31° and 40°	Decrease in cervical lordosis results in increase in neck pain and disability <sup>18-20</sup>
Cervical sagittal vertical axis	Distance from C2 plumb line to upper posterior corner of C7, normally between 6 mm and 28 mm <sup>12,21</sup>	Positive cervical sagittal vertical axis negatively affects visual analog scale pain score, Neck Disability Index, and Short Form-36 physical composite score <sup>22-24</sup>
Thoracic kyphosis	Normal outward curvature of the thoracic spine between 10° and 40°	Increase in thoracic kyphosis results in decreased physical function, increased cervical pain, and impaired respiratory capability <sup>25,26</sup>
Lumbar lordosis	Normal inward curvature of the lumbar spine between 40° and 60°	Decrease in lumbar lordosis can lead to flat back syndrome, pelvic retroversion, and thoracic hypokyphosis <sup>4,10</sup>
Pelvic parameters		
Sacral slope	Angle between S1 end plate and a horizontal reference line	Sacral slope and lumbar lordosis have to be made consistent with each individual's pelvic incidence to maintain balanced spinopelvic alignment <sup>27</sup>
Pelvic tilt	Angle between a vertical reference line and a line from the midpoint of the S1 end plate to the center axis of the femoral head	High pelvic tilt indicates pelvic compensation and sagittal imbalance <sup>28</sup>
Pelvic incidence	A fixed parameter, approximated by the summation of sacral slope and pelvic tilt	Correlates with increased pain and disability in patients with spinal deformity <sup>9</sup>

These parameters have been robustly associated with important clinical and health-related quality of life (HRQOL) outcomes. Previous studies have shown that sagittal balance is a reliable radiographic predictor of clinical health status in adults with spinal deformity.<sup>29</sup> For example, positive sagittal balance (defined by  $>2$  cm SVA) is often experienced by patients with cervical spine tumors and is associated with decreased HRQOL.<sup>30,31</sup> There has also been increasing evidence that regional cervical SVA negatively affects HRQOL, particularly related to pain and functional outcomes.<sup>22-24</sup> Poor cervical SVA

significantly contributes to cervical myelopathy, and failure to correct cervical malalignment in patients with cervical myelopathy may result in postlaminectomy kyphosis and worsen postoperative outcomes.<sup>8</sup> Likewise, larger C2 SVA relates to poorer HRQOL scores; and a C2-C7 SVA  $>40-50$  mm results in worse clinical outcomes according to the Neck Disability Index.<sup>23,32</sup> Compensatory mechanisms such as pelvic retroversion, restricted hip motion, and knee flexion can also be a source of major discomfort and disability.<sup>31,33</sup> Increased global SVA results in a compensatory increase in PT and high pelvic retroversion, which can in

turn result in reduced LL, flat back syndrome, decreased ambulation, and pain.<sup>34</sup> Postoperative improvement in sagittal alignment significantly improves Scoliosis Research Society Outcomes Questionnaire (SRS-22) scores for activity, pain, appearance, and total scores, as well as both physical and mental Short Form-36 components and the Oswestry Disability Index.<sup>5,35</sup> Moreover, several mathematical relationships exist among these parameters. A commonly reported ideal relationship between LL and PI that correlates with good postoperative quality of life scores is  $LL = PI \pm 9^\circ$ .<sup>1,10</sup> This relationship may differ



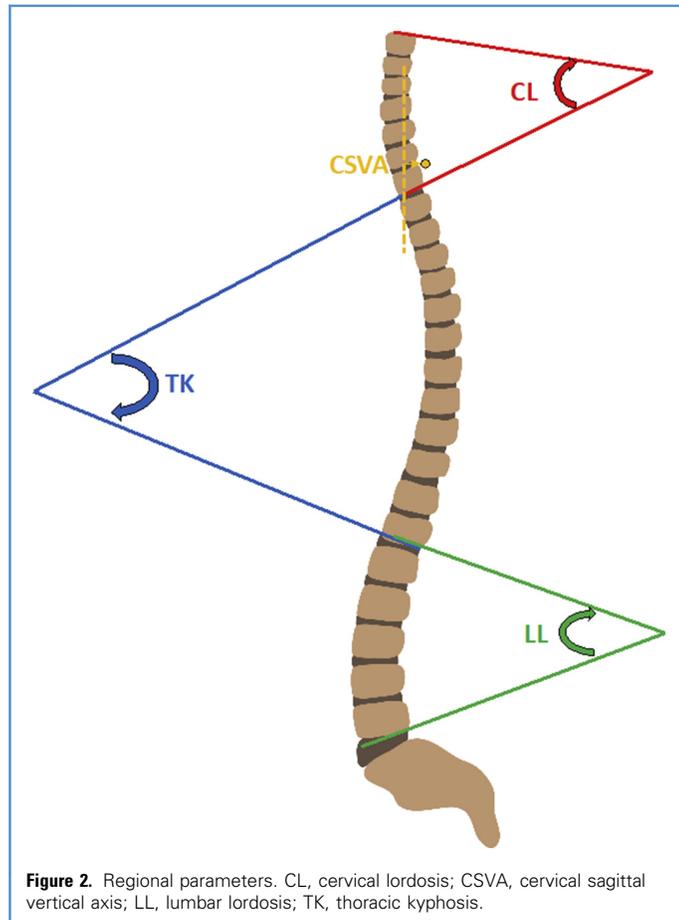
based on patient-specific characteristics such as age. A similar relationship in the cervical spine was found by Hyun et al. in which a mismatch between the T1 slope (i.e., the angle between the horizontal line and superior end plate of T1) and C2-C7 lordosis of  $>26.1^\circ$  (T1-CL  $>26.1^\circ$ ) corresponded to positive cervical sagittal malalignment (defined as C2-C7 SVA  $>50$  mm), and thus worse clinical outcomes.<sup>32</sup>

Despite their well-established role in deformity correction, the impact of spinopelvic parameters has yet to be investigated after oncologic resection. Because quality of life is often a principal goal of spine tumor surgery, imbalance has the potential to dramatically hinder postoperative outcomes for these patients.

Conversely, consideration of spinopelvic parameters could prove beneficial to maximizing the chances of quality of life for this unique and vulnerable population. Thus, an improved understanding of the impact of spinal alignment, particularly in the context of spinopelvic parameters, on postoperative outcomes in patients with a primary or metastatic spine tumor may be paramount to optimizing the care of these patients. The case examples in the following sections highlight various aspects that preoperative and postoperative spinal alignment, hardware limitations, and bone quality play in the outcomes after oncologic spine surgery.

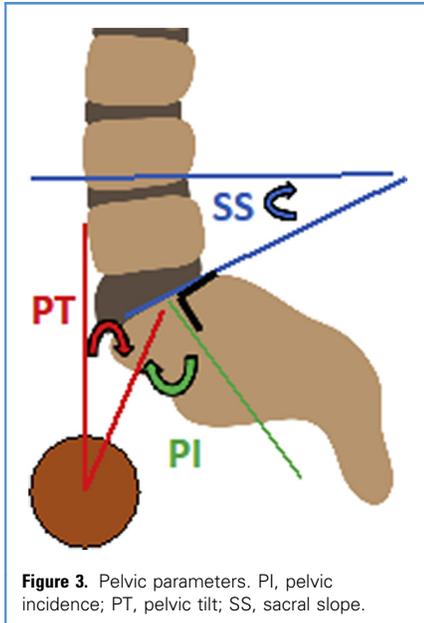
#### Illustrative Case Examples

**Case 1: Multiple Myeloma of the Cervical Spine.** A 59-year-old man presented with weight loss and upper extremity weakness and was found to have C1-C2 cord



compression on initial radiographic workup. He was diagnosed with a lambda light chain plasmablastic myeloma involving the cervical spine. Preoperative cervical imaging (Figure 4A) showed a T1-CL equal to  $27.3^\circ$ , consistent with positive cervical sagittal malalignment. The patient underwent a C1 and C2 decompression and occiput to C3 posterior fusion. Postoperative (Figure 4B) radiographs showed improvement of his cervical parameters, with T1-CL equal to  $0.2^\circ$ . He had an uneventful postoperative course and completed physical therapy and rehabilitation with a good functional outcome and self-reported improvement in quality of life.

**Case 2: Metastatic Non-Small-Cell Lung Carcinoma of the Thoracic Spine.** A 57-year-old woman with a history of stage IV lung adenocarcinoma and previous

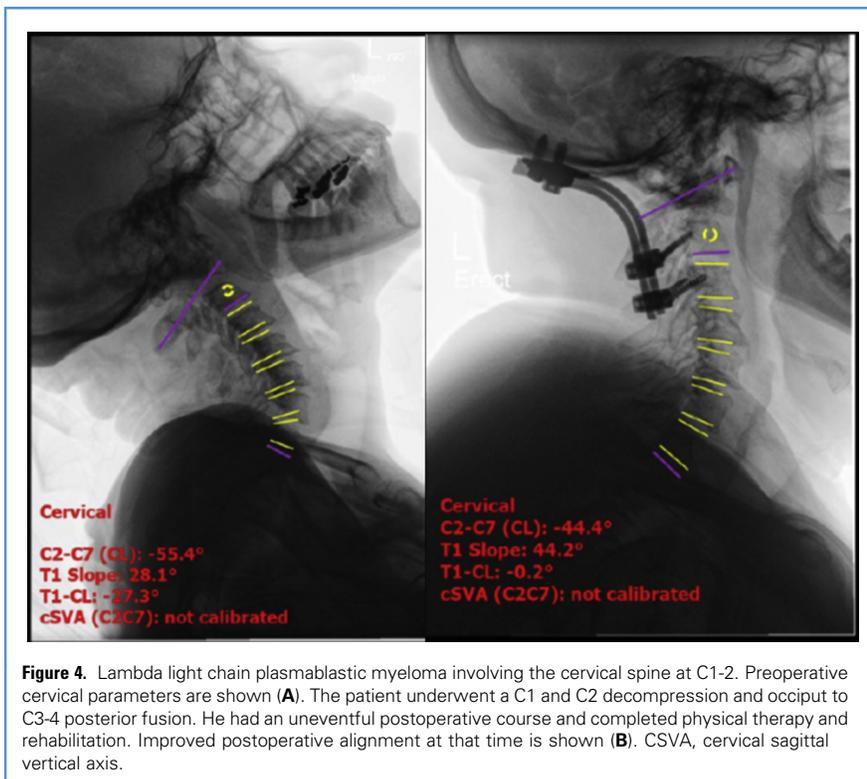


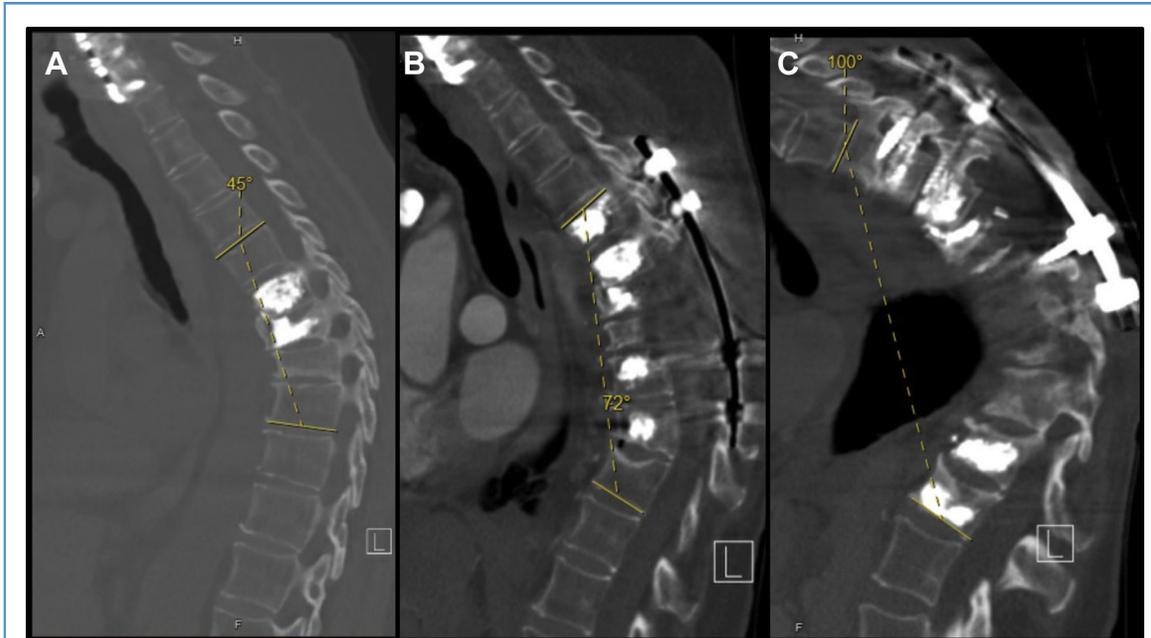
radiofrequency ablation of the T6 and T7 vertebral bodies with adjuvant kyphoplasty followed by radiation re-presented with increasing radicular back pain and tumor recurrence at T7 and T8. She had a baseline Spinal Instability Neoplastic Score

(SINS) of 10, showing indeterminate instability. Her preoperative computed tomography (CT) imaging is shown in **Figure 5A**. Her baseline focal kyphosis across T5-T9 was approximately  $45^\circ$ . After a thorough discussion by the multidisciplinary tumor board, the recommendation was made for separation surgery with a T7-T8 corpectomy and T5-T10 fusion followed by adjuvant stereotactic body radiation therapy (1800 cGy in 3 fractions) to T6-8. At 4 weeks postoperatively, the patient's CT showed stable focal kyphosis of  $45^\circ$  (realignment limited by previous kyphoplasty). She initially reported significant improvement in her back pain. However, at her 6-week follow-up, she reported new pain at the bottom of her incision, which limited her activities of daily living. CT imaging (**Figure 5B**) showed a new anterior compression fracture at T11 with approximately 25% height loss and worsening of her focal kyphosis from T5-T11 to approximately  $72^\circ$ . The patient subsequently underwent a kyphoplasty to the T11 vertebral body, with improvement in her pain. She then re-presented 7 weeks later with new-onset focal back pain and interval mild

compression fractures of T12 and L1. The patient then underwent additional kyphoplasties to T12 and L1. At last follow-up (8 months postoperatively), the patient reported persistent back pain, with continued bony destruction and development of a severe kyphotic deformity of approximately  $100^\circ$  from T5-L1, as shown in **Figure 5C**. This second case example shows the commonly encountered issue of poor bone quality in the setting of metastatic osteolytic disease, which frequently results in progressive sagittal malalignment and impaired quality of life.

**Case 3: Metastatic Prostate Cancer of the Thoracic Spine.** A 67-year-old man with a history of known metastatic prostate cancer to the spine status post previous palliative radiation to T11 presented with several months of progressive low back pain. He remained neurologically intact. A lumbar MRI was obtained, which showed interval worsening of a known T12 pathologic compression fracture with 70% height loss and new retropulsion, resulting in cord compression. His baseline SINS was 13, indicating probable instability. The patient underwent a T10-L3 instrumented fusion with L2/L3 laminectomies. Cement augmentation was recommended at the time of surgery but was declined by the patient. His immediate postoperative standing films showed intact hardware and normal SVA of 152.9 mm (**Figure 6A**). At his 8-week postoperative appointment, he reported persistent low back pain, which increased with movement. A follow-up standing radiograph was obtained, which showed that the T10 screws had backed out, with screw tips projecting within the T9-10 disc space, resulting in progressive kyphosis of  $37^\circ$  (from  $29^\circ$  at baseline and immediately postoperatively) between T9 and L3 (**Figure 6B**). Operative revision was offered at this time, but the patient declined and decided to continue to monitor these changes without intervention until several more pressing issues related to his systemic disease burden were addressed. The patient is currently waiting to undergo an extension of fusion, cement augmentation, and anterior column reconstruction for further stabilization of his construct within appropriate spinopelvic alignment. This case example shows the importance





**Figure 5.** Metastatic lung adenocarcinoma status post previous radiofrequency ablation of the T6 and T7 vertebral bodies with kyphoplasty. Patient presented with several weeks of increasing radicular back pain with imaging showing a compression fracture of the T8 vertebral body with approximate 50% height loss (A). At the recommendation of a multidisciplinary tumor board, the patient underwent a T5-T10 fusion with T7-T8 corpectomy and separation surgery. She also received 3 fractions of adjuvant stereotactic body radiation therapy to T6-8. At 6 weeks follow-up, the patient continued to have postoperative pain. Computed tomography imaging showed a new anterior

compression fracture at T11 with approximately 25% height loss (B). The patient was initially braced for 6 weeks without relief, and underwent kyphoplasty to the T11 vertebral body, with improvement in her pain. She then returned 7 weeks later with new-onset focal back pain, and imaging showed interval mild compression fractures involving the upper end plates of T12 and L1. The patient subsequently underwent an additional kyphoplasty to T12 and L1. At the time of last follow-up, the patient-reported persistent back pain and continued to wear a thoracic lumbar sacral orthosis brace. Most recent imaging shows continued bony destruction and progressive kyphosis (C).

of stabilizing techniques, such as cement augmentation and anterior reconstruction in the oncologic spine population, particularly in the setting of improper spinal alignment, because of aforementioned considerations such as adjuvant chemotherapy and radiation, poor baseline bone quality, and osseous destruction caused by the tumor.

#### Case 4: Metastatic Chondrosarcoma of the Thoracic Spine.

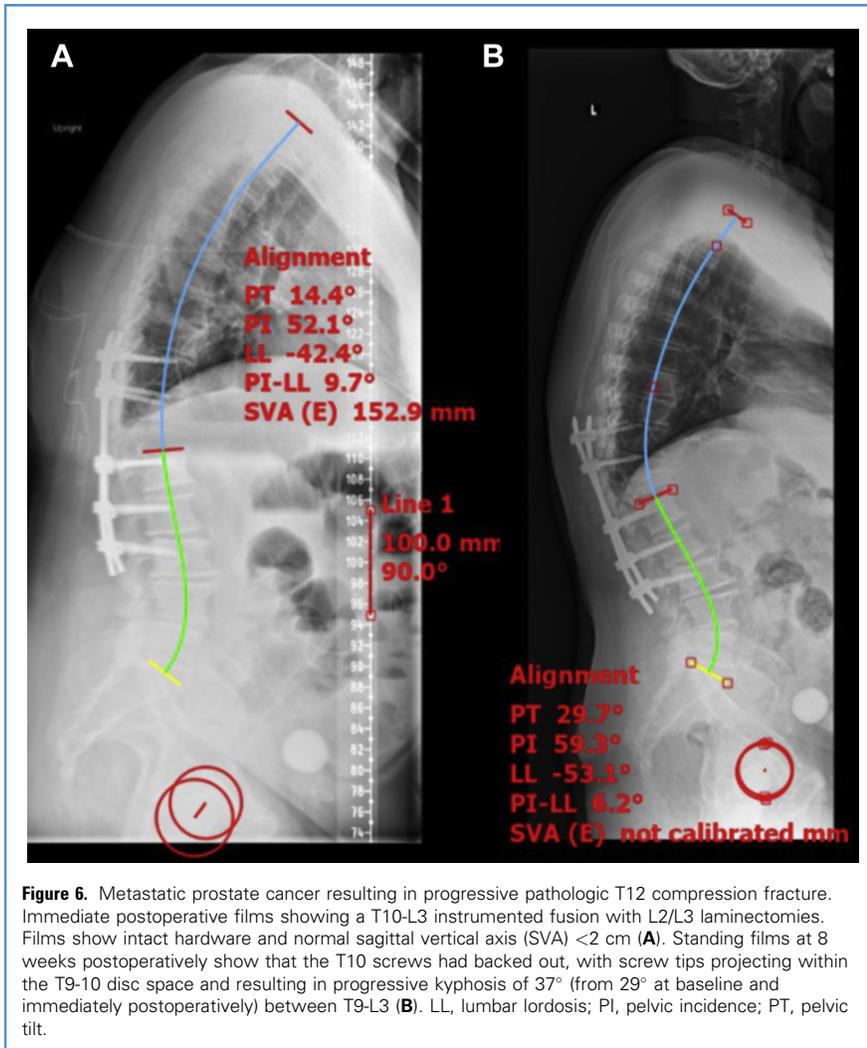
A 44-year-old woman with a history of chondrosarcoma presented with several weeks of progressive bilateral lower extremity 4/5 weakness. Baseline SINS was 10, with indeterminate instability. An MRI was obtained, which showed a large metastasis involving the entire T12 vertebral body and posterior elements with epidural extension into the central canal. Baseline PI was within normal limits at  $53.9^\circ$ . However, she required a decreased PT of  $1^\circ$  and increased LL of  $70.9^\circ$ , to maintain a

normal SVA of 66.1 mm. In addition, her baseline PI-LL was  $>9^\circ$  (Figure 7A), suggesting increased strain on the intrinsic musculature of her back and compromised stability. The patient underwent a T10-L2 decompression and fusion with T12 corpectomy. Postoperative imaging showed improvement in her spinopelvic alignment to an SVA of 31.2 mm and PI-LL within  $6^\circ$ . She was seen 2 months postoperatively with significant improvement in her back pain and resolution of her bilateral lower extremity weakness. Follow-up imaging shows stable hardware and alignment (Figure 7B).

#### Case 5: Chordoma of the Lumbar Spine.

A 45-year-old woman was diagnosed with a lumbar mass invading the L3 and L5 vertebral bodies and anteriorly displacing the inferior vena cava, aorta, and iliac vessels. A CT-guided biopsy was performed and results were consistent with chordoma. The patient's baseline

SINS was 8, with concern for potential instability. The patient underwent a 3-stage, en bloc spondylectomy of the L3-5 vertebral bodies, with pedicle screw instrumentation of the T10-L1 and S1 vertebral bodies, placement of S2-alar iliac bolts bilaterally, and anterior column reconstruction with a distractible titanium cage (Figure 8A). Scoliosis films acquired 4 months postoperatively showed minor improvement of her overall alignment. The patient also received adjuvant proton beam radiation therapy. She remained stable for 15 months, at which time she began experiencing left-sided paraxial pain. Standing films (Figure 8B) showed pseudarthrosis and progressive loosening of her hardware. She underwent surgical revision 2 months later, comprising a T10-pelvis instrumented fusion with cobalt chrome rods. Standing radiographs taken 2 days postoperatively showed good overall alignment (Figure 8C). This patient remains alive with metastatic systemic



**Figure 6.** Metastatic prostate cancer resulting in progressive pathologic T12 compression fracture. Immediate postoperative films showing a T10-L3 instrumented fusion with L2/L3 laminectomies. Films show intact hardware and normal sagittal vertical axis (SVA) <2 cm (A). Standing films at 8 weeks postoperatively show that the T10 screws had backed out, with screw tips projecting within the T9-10 disc space and resulting in progressive kyphosis of 37° (from 29° at baseline and immediately postoperatively) between T9-L3 (B). LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt.

disease at 76 months after the revision operation. This case example shows the impact of adjuvant therapy such as radiation on bone quality and subsequent postoperative outcomes and the importance of obtaining standing scoliosis films in this patient population.

### IMPACT ON PRIMARY SPINE TUMORS

Primary tumors within the spine are rare and include both benign tumors (e.g., osteoid osteoma, osteoblastoma, hemangiomas, eosinophilic granuloma, aneurysmal bone cyst, neurofibroma, and giant cell tumors) and malignant tumors (e.g., chordoma, chondrosarcoma, osteosarcoma, and other sarcomas).<sup>36-38</sup> Because of the rarity of these lesions, and their

unique rates of growth and invasion, there is significant variability among practitioners regarding their optimal management.<sup>39</sup> Benign asymptomatic tumors are often managed with close observation.<sup>40</sup> On the other hand, malignant primary tumors have a propensity to invade and metastasize and thus require treatment.<sup>40</sup> Surgical resection can offer patients long-term tumor control, and the extent of resection has been shown to inversely correlate with the degree of local recurrence and tumor-related morbidity.<sup>41-45</sup> Some studies have shown that spinal instability secondary to tumor invasion may negatively affect perioperative outcomes. For example, in a retrospective cohort study of 14 patients with giant cell tumors of the spine who underwent either

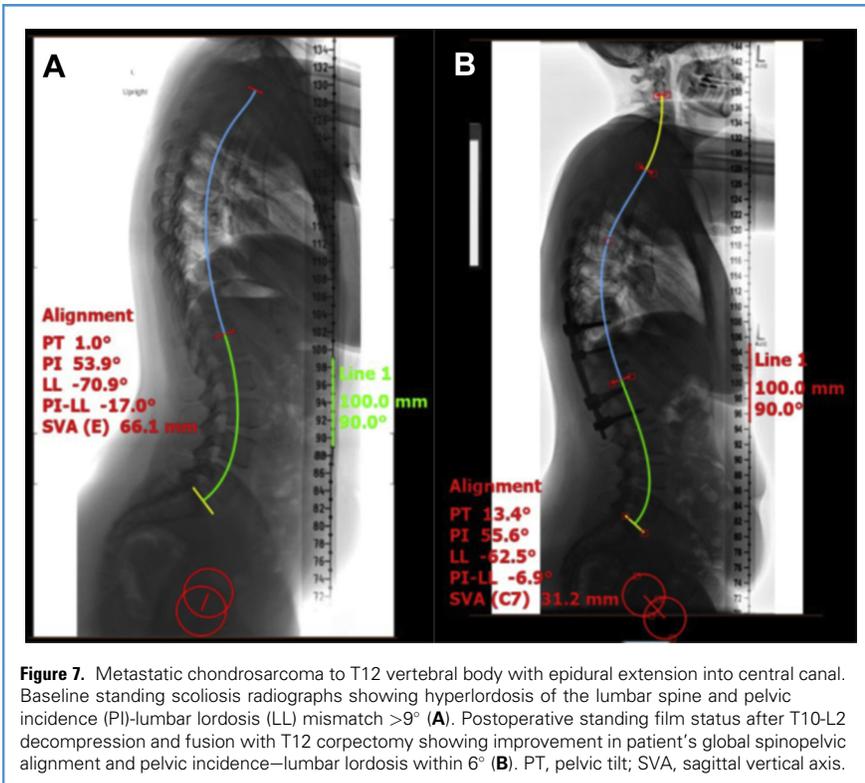
en bloc marginal (n = 6) or intralesional (n = 8) resection, Elder et al.<sup>46</sup> reported that significant instability, assessed by SINS, is associated with high intraoperative blood loss despite embolization and independent of resection method.

In addition, there exists the possibility of postoperative deformity, especially in cases that require extensive resection and iatrogenic destabilization, potentially necessitating reoperation (e.g., case 5).<sup>39,40</sup>

### IMPACT ON METASTATIC SPINE TUMORS

In an era of advancing oncologic therapies, improved survival is accompanied by an increase in the prevalence of metastatic disease.<sup>47,48</sup> Metastatic lesions represent the most common type of spine tumor.<sup>41-45</sup> Surgical intervention significantly increases survival in patients with spinal metastasis from the liver, lung, and skin.<sup>3,49,50</sup> Several factors affect postoperative survival in this patient population, including advanced age, presence of additional comorbidities, presence of pathologic fractures at the affected vertebral level, acute neurologic deficit, and primary tumor type of known poor prognosis.<sup>51</sup> Older age and comorbidities that entail aggressive pharmacologic management or higher probability of wound infection can often induce bone stress and poor bone quality, which are known risk factors for construct failure and poor surgical outcomes.<sup>52,53</sup> Furthermore, tumor progression as a result of local or global recurrence can produce vertebral fractures that may require additional revision surgery.<sup>52</sup> Moreover, because spinal metastasis often involves multiple levels, the larger operative field that is required frequently leads to increased risk of delayed wound healing and infection.<sup>54</sup> Although there is added survival benefit of adjunct therapy, radiotherapy and chemotherapy can further increase time of wound healing and decrease bone density, disrupting overall spinal stability and contributing to negative postoperative complications.<sup>3,50,54</sup>

Spinal metastases are also often associated with spinal deformity.<sup>55,56</sup> Several factors contribute to the risk of deformity in this patient population. Systemic



oncologic disease can induce major bone density loss, which in turn weakens vertebral integrity and leads to a high prevalence of spinal malalignment and associated neurologic compromise.<sup>57-61</sup> Misaligned spinopelvic parameters can increase the risk of occurrence of vertebral collapse, and high PT and pelvic retroversion are correlated with an increased rate of vertebral fractures.<sup>62</sup>

Postoperative radiation and systemic chemotherapy may also negatively affect bone quality, further hindering bony fusion and putting this patient population at even further risk for deformity.<sup>58,63,64</sup> Moreover, immunotherapy and small-molecule therapeutics are increasingly used in this population, but their potential impact on healing and fusion remains poorly understood. Bone-modifying agents such as bisphosphonates and denosumab have been used to treat osteoporosis and facilitate bone remodeling but have not been shown to meaningfully affect spinal stability.<sup>65</sup> Steroid use among patients with spinal metastasis may also contribute to poor bone quality and suboptimal healing, as well as increased rates of postoperative infections and

wound dehiscence.<sup>66,67</sup> In light of these contributors to poor wound healing, these patients may be at increased risk for elements of their constructs externalizing, leading to further complications or delayed wound healing. This risk of screw or rod externalization is amplified in patients with increased deformity, making postoperative alignment paramount in patients with spinal tumors.

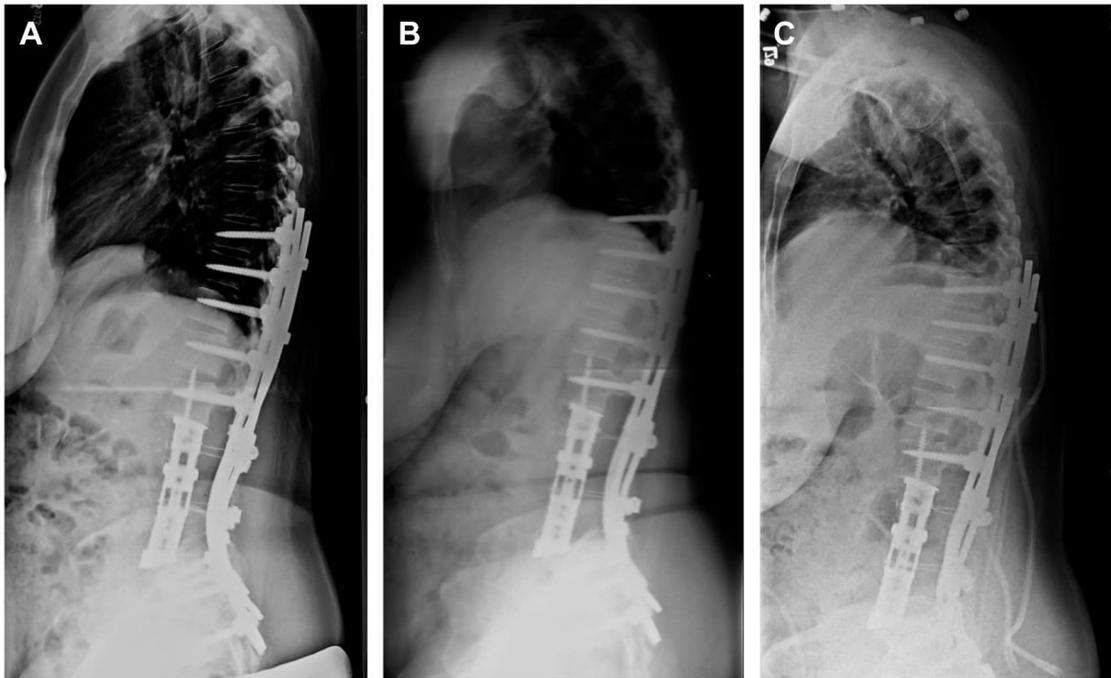
## DISCUSSION

Indications for oncologic spine surgery include mechanical instability, pain, local tumor control, and neurologic compromise.<sup>1,2</sup> A comprehensive understanding of the factors that affect patient quality of life is therefore critical to evaluating the role of surgery. The goals of care for spinal oncology patients vary based on their overall prognosis, systemic disease status, and concurrent therapies.<sup>68-70</sup> Because improvement in quality of life is often a principal goal of surgery, deranged spinal alignment has the potential to dramatically hinder postoperative outcomes for these patients. Given the relatively long

overall survival of patients with many primary spine tumors, proper alignment can prevent long-term sequelae and junctional issues. The operative considerations for these patients can therefore be conceptualized as similar to patients with degenerative disease or deformity. On the other hand, short-term complications and outcomes are paramount in patients with metastatic spine disease, given their shorter life expectancy, systemic disease status, and need for timely systemic therapies. Patients with aggressive or metastatic lesions are also more likely to be symptomatic at baseline and may therefore stand to regain crucial quality of life after surgical alignment.

Patients with both primary and metastatic lesions may present with symptoms secondary to deformity either at baseline or postoperatively. When deformity is a presenting symptom, early recognition of spinal instability and any subsequent compromise of the spinal canal is vital to minimize the debilitating effects of deformity.<sup>61</sup> Postoperative deformity has been well described, particularly within the contexts of thoracic tumor excision, aneurysmal bone cysts, pediatric chondromas, osteoma, and sarcoma resections.<sup>71</sup> Postoperative deformity occurs in about 16% and 18% of adult patients who undergo laminoplasty and laminectomy, respectively, and ranges from 23% to 52% for cervical spine surgery.<sup>72,73</sup> Children with a history of spinal tumors are at a significant risk for the future development of deformity and instability, with reported rates between 8% and 88%.<sup>74-76</sup> Prophylactic fusion may protect against postoperative deformity, although this intervention is not without its own risk of iatrogenic deformity.<sup>71,77-80</sup> Overall, focal and spinopelvic alignment provides a critical clinical variable that may profoundly affect patient HRQOL.

Several tools have been developed to help guide surgical management and prognosticate postoperative outcomes for these unique patients. In an attempt to standardize definitions of spinal instability in both populations, the Spinal Oncology Study Group developed the SINS.<sup>59,81</sup> The SINS incorporates several important parameters, including tumor location, primary disease, radiographic alignment, percent vertebral collapse, posterolateral



**Figure 8.** Invasive chordoma involving the lumbar spine from L3-L5. Scoliosis films showing adequate global alignment acquired 4 months status post a 3-stage en bloc spondylectomy of the L3-5 vertebral bodies, with pedicle screw instrumentation of the T10-L1 and S1 vertebral bodies, placement of S2-alar iliac bolts bilaterally, and anterior column reconstruction with a distractible titanium cage (A). The patient also received adjuvant

proton beam radiation therapy. She remained stable for 15 months, at which time she began having left-sided paraxial pain. Standing films showed pseudarthrosis and progressive loosening of her hardware (B). She underwent surgical revision 2 months later, comprising a T10-pelvis instrumented fusion with cobalt chrome rods. Standing radiographs taken 2 days postoperatively showed good overall alignment (C).

element involvement, and mechanical back pain.<sup>81</sup> Primary disease contributes greatly to overall bone quality and is also an important factor in assessing spine stability. For example, lytic lesions inherently carry a greater risk of collapse because of a lack of mineralization.<sup>82</sup> Previous work<sup>83-86</sup> has shown a strong correlation between bone mineral density, vertebral body collapse, and pathologic fracture risk. Radiographic spinal alignment is also a significant contributor to SINS score because subluxation leads to translational instability.<sup>87</sup> Misalignment can impair a patient's function, and positive sagittal balance has been correlated with poor quality of life.<sup>87</sup> Furthermore, components of pain and spinal alignment in the SINS criteria have been shown to be predictive of vertebral compression fracture occurrence, indicating the importance of considering the single-level vertebral alignment in evaluating the stability of the entire

vertebral column.<sup>11</sup> The SINS has proved to be a reliable tool for the evaluation of spinal instability and the need for surgical intervention.<sup>12-14</sup>

Although SINS can be useful in describing spinal instability at the specific site of tumor encroachment, spinopelvic parameters offer a more comprehensive evaluation of the entire vertebral column and the relationships between each region. Thus, understanding a patient's baseline alignment with respect to these standardized parameters may help contextualize their symptoms. Previous work<sup>15</sup> has also suggested that correlation of radiographic measurements with patient-reported outcomes could provide surgeons with a more nuanced understanding of a patient's deformity and aid surgical planning. In addition, if spinopelvic parameters were found to correlate with baseline symptoms and quality of life, these measurements could be used to risk-stratify an asymptomatic patient according to their likelihood of becoming

symptomatic in the future. Although data are lacking for the population with spine tumor, several findings in the deformity literature may also be pertinent to this patient population. For example, Mesfin et al.<sup>16</sup> found that positive sagittal balance is one of the major risk factors for instrumentation failure. Iwata et al.<sup>17</sup> observed that  $>5$  cm of distance from vertical line from the middle of C7 body to the middle of fractured vertebral body and  $>30^\circ$  of PI-LL were major risk factors for nonunion in thoracolumbar osteoporosis-related vertebral compression fractures. Hsieh et al.<sup>18</sup> found that higher PI is associated with more severe spondylolisthesis in the lumbosacral region. Inappropriate spinopelvic parameters can also increase the risk of occurrence of vertebral collapse in patients with deformity. Kim et al.<sup>62</sup> showed that high PT and consequently high pelvic retroversion were correlated with the vertebral fracture group. As highlighted earlier, this relationship

between alignment and vertebral integrity is well established in the deformity literature but is limited in oncology studies; consideration of spinopelvic parameters would be beneficial for both primary and metastatic patient populations and warrants further study.

## FUTURE DIRECTIONS

Despite the well-described influence of spinopelvic parameters in the deformity literature, these parameters have been traditionally neglected when evaluating tumors of the spinal column.<sup>1</sup> Because improving quality of life is a central goal of many oncologic spine surgeries, it follows that focal and spinopelvic parameters may provide a critical component of improving the care of this patient population. Within the preoperative context, one could hypothesize that patients within the normal limits of age-corrected sagittal balance parameters may experience better baseline HRQOL and decreased pain compared with patients outside these parameters. Investigation of such a relationship could arm surgeons with useful prognostic information and inform upfront surgical decision making. From a postsurgical perspective, evaluation is warranted to assess patient outcomes after procedures planned with versus without consideration of spinopelvic parameters. Future work should focus on elucidating the relationship between preoperative and postoperative spinopelvic parameters and patient-centered outcomes such as pain, function, and HRQOL. Spinopelvic parameters may advance our care of patients diagnosed with tumors of the spinal column and help clinicians optimally evaluate and treat this unique and vulnerable population.

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*Conflict of interest statement:* E.W.S. receives a resident research grant from the North Carolina Spine Society. M.A.El-B. is a consultant for Spineology. I.O.K. is a consultant for Nuvasive and Depuy and receives a spine fellowship fund from NuVasive. C.I.S. holds patents with, receives royalties from, and is a consultant for Medtronic, Nuvasive, and Zimmer Biomet; is a stockholder in Nuvasive; consultant for K2M, Stryker, and In Vivo; and has received grants from the U.S. National Institutes of Health, Department of Defense, ISSG, DePuy Synthes, and AOSpine. Z.L.G. has stock ownership in Spinal Kinetics and has previously received support from AOSpine International. D.S. is a consultant for Orthofix, Globus, K2M, Medtronic, Stryker, and Baxter. C.R.G. received grants from the Burroughs Wellcome Fund, North Carolina Spine Society, and the NIH/NINDS K12 NRCDF Physician Scientist Award, Robert Wood Johnson Harold Amos Medical Faculty Development Program. The other authors have no conflicts to declare.

Received 2 April 2019; accepted 22 August 2019

Citation: *World Neurosurg.* (2019) 132:118-128.

<https://doi.org/10.1016/j.wneu.2019.08.161>

Journal homepage: [www.journals.elsevier.com/world-neurosurgery](http://www.journals.elsevier.com/world-neurosurgery)

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