Posterior stabilization strategies following resection of cervicothoracic junction tumors: review of 90 consecutive cases

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Object. In this retrospective analysis the authors describe the assessment and outcomes of 90 patients who underwent placement of posterior instrumentation at the cervicothoracic junction following the resection of a primary or metastatic tumor during a 10-year period.

Methods. All patients underwent a posterolateral laminectomy including uni- or bilateral facetectomy, and 44 patients additionally required vertebral body resection and reconstruction. In patients who underwent C-6 or C-7 decompression, the posterior instrumentation strategies changed from the use of lateral mass plate systems (LMPSs) to lateral mass screw/rod systems (LMSRs). Similarly, for T1–3 tumor decompression, the strategy shifted from sublaminar hook/rod systems (SHRSs) to the use of pedicle screw systems (PSSs) in which the surgeon used either a 6.25-mm rod or dual-diameter rods with or without a connector.

Results. The overall surgical complication rate was 19% including fixation failure in 11 patients (12%), 6 of whom required reoperation. Fixation failure rates for cervical decompression decreased from 2 (29%) of 7 patients in the LMPS group to 0 (0%) of 8 in the LMSRS group (p = 0.2). The fixation failure rates for thoracic decompression were 7 (15%) of 48 patients in the SHRS group, and there was a decrease to 2 (7%) of 27 in the PSS group (p = 0.48). Neurological and functional outcomes including American Spinal Injury Association, Eastern Cooperative Oncology Group, and Medical Research Council muscle strength and pain scores remained stable or improved in 94, 96, 100, and 96% of patients, respectively.

Conclusions. Current posterior instrumentation strategies involving LMSRs and PSSs provide excellent and safe stabilization of the cervicothoracic junction following resection of primary or metastatic tumors.

(K1W1RDS • cervicothoracic junction • epidural compression • lateral mass screw • metastatic tumor • pedicle screw • primary tumor)

The CTJ represents unique challenges regarding posterior instrumentation strategies, particularly with regard to reconstruction after tumor resection. Typically posterior reconstruction after tumor removal necessitates the placement of instrumentation at least 2 levels superior and inferior to the level of decompression; thus, C6–T3 tumor resection often requires posterior instrumentation bridging the CTJ. Reconstructing the CTJ is complicated by the need to bridge the normally lordotic, mobile cervical spine to the kyphotic, fixed thoracic spine. The bone morphology and the relationships between neural and osseous elements also change in the transition from the cervical to the thoracic spine, placing significant stress on the posterior instrumentation. A number of strategies have been used for posterior reconstruction of the CTJ in degenerative and traumatic injuries of the spine, but limited data exist regarding reconstruction after tumor excision. Lytic tumor destruction and resected spinal elements place additional biomechanical stresses on CTJ fixation, because tumor resection often requires multilevel facetectomy, chest wall resection (for example, in superior sulcus tumors), and VB resection and reconstruction. Patients with tumors often suffer from osteoporosis, poor soft-tissue healing, and the probability of adjacent-segment tumor progression that must be accounted for by providing posterior-column support.

Abbreviations used in this paper: ASIA = American Spinal Injury Association; CTJ = cervicothoracic junction; EBRT = external-beam radiotherapy; ECOG = Eastern Cooperative Oncology Group; ESCC = epidural spinal cord compression; LMPS = lateral mass plate system; LMSRS = lateral mass screw/rod system; MRC = Medical Research Council; PMMA = polymethylmethacrylate; PS = pedicle screw; PSS = PS system; PTA = posterolateral transpedicular approach; SHRS = sublaminar hook/rod system; VB = vertebral body.
Posterior instrumentation applied to the CTJ has evolved significantly, and thus, our strategies have changed in an attempt to improve both the safety and efficacy of these constructs. Early fixation techniques included spinous process and sublaminar wiring, which resulted in a failure rate of up to 33%. This article represents the evolution of our experience in using different posterior instrumentation strategies over the CTJ in patients with tumors. Patients undergoing C-6 or C-7 decompression had cervical systems placed that could be transitioned from lateral mass screws to PSs using a single system and included LMPS followed more recently by LMSRS. Patients undergoing thoracic decompression including T1–3 initially received SHRS followed by insertion of a PSS in which a 6.25-mm rod, dual-diameter rods with a wedding-band connector, or a tapered rod was used.

Methods

Retrospective review of a database of patients with spinal tumors surgically treated between 1996 and 2006 identified 90 patients who underwent posterior fixation across the CTJ at Memorial Sloan–Kettering Cancer Center. The list of operations is prospectively maintained and includes detailed information about the operative procedures, histology, and patient demographics. Clinical status was determined from electronic records based on intake and follow-up forms. All relevant radiographs, MR images, and CT scans were re-reviewed by the authors for this paper. The demographic characteristics of the patient population are presented in Table 1. The mean age at the time of surgery was 52 years, and 64% of the population was male. Tumors were classified as primary in 20 patients (22%) and metastatic in 70 (78%); Table 2. Primary tumors included sarcomas (10 cases), lymphoma (2), multiple myeloma (2), osteoblastoma (2), and chordoma (2), and others (2). The most common metastatic tumor was non–small cell lung carcinoma in 16 patients; 8 of these lesions were superior sulcus tumors. Other common metastatic malignancies were renal cell carcinoma (12 cases), sarcoma (9), colorectal (8), and thyroid cancers (8).

The NOMS Algorithm for Decision Making

Decision making regarding the need for surgery was based on the NOMS assessment as described in previous publications. Four fundamental assessments were made regarding treatment including neurological (N), oncological (O), mechanical instability (M), and systemic disease and comorbidities (S). The neurological assessment reflects the presence of radiculopathy, myelopathy, and the degree of ESCC. High-grade spinal cord compression was present in 64 patients (71%). The oncological assessment is determined by the predicted response to treatment including chemotherapy, radiation therapy, and surgery based on tumor histology. Mechanical instability at the CTJ was considered to be present if the patient had movement-related pain, most commonly in extension. The radiographic correlate to this pain was most commonly a burst fracture with extension into a unilateral joint. Systemic disease and medical comorbidities were assessed to determine whether the patient could tolerate surgery.

For metastatic tumors, the most common primary indication for surgery was neurological in 51 patients (73%) and oncological in 19 (27%). In the primary tumor group, the major indication was neurological in 13 patients (65%) and oncological in 7 (35%). Mechanical instability was judged to be present in 3 metastatic and 1 primary tumor but was not the sole indication for surgery in any patient. Patients who were not candidates for surgery based on the presence of advanced systemic disease or significant comorbidities were not captured in this database.

As part of multimodality therapy, conventional EBRT was undertaken preoperatively in 40 patients (44%), either as neoadjuvant therapy for superior sulcus tumors or as primary treatment for metastatic disease. As postoperative adjuvant therapy, 28 (31%) underwent conventional radiotherapy and 2 (2%) had high-dose proton beam therapy. One patient had both pre- and postoperative radiotherapy
Posterior stabilization following tumor resection

and 7 patients had none. Radiation therapy data were not available for the remaining 12 patients.

Patient Outcome Measures

Preoperative and postoperative assessments included pain, performance status, and neurological function. An ordinal pain scale based on patient self-assessment was converted to none (score of 0), mild (1–4), moderate (5–6), or severe pain (7–10) based on the Serlin conversion. Performance status was assessed using the ECOG scores because this scale reflects ambulatory status and is commonly used by oncologists to determine suitability for further systemic therapy. Neurological function was evaluated using ASIA Impairment Scale scores to assess myelopathy, and the MRC grade was used to evaluate muscle strength related to functional nerve root deficits. Finally, ECOG, ASIA, and MRC scores were assessed by neurology or neurosurgery staff preoperatively and by neurosurgery staff at 3 and 6 weeks postoperatively, followed by 3-month intervals to 1 year and then at 6-month intervals.

Plain radiographs to assess hardware were routinely obtained postoperatively at 3 days and 6 weeks and then at 3- to 6-month intervals. Additionally, patients underwent plain radiography to search for any gross change in spinal alignment, cause of new-onset pain, or progressive neurologic symptoms. Repeated MR images were also obtained for new-onset pain, progressive neurological symptoms, elevated serum markers (for example, prostate-specific antigen for prostate carcinoma), and to assess the response to systemic chemotherapy or hormones.

Given the palliative nature of surgery for metastatic spinal disease and the myriad issues regarding systemic disease and medical comorbidities, patients did not meet all prescribed time point assessments. The reported surgical outcomes for pain, ECOG scores, ASIA grades, and MRC grades are reported at the 3- to 6-week postoperative interval. All available radiographic images were reviewed to assess for hardware failure. A Wilcoxon signed-rank test was used to test the difference in pre- and postoperative scores. Survival was estimated using the Kaplan–Meier method.

Technique: Approach, Decompression, and Instrumentation

Fifteen patients (17%) underwent preoperative embolization for hypervascular tumor histologies. Six patients with cervical spine tumors had vertebral artery balloon occlusion tests to provide functional information regarding collateral circulation if a unilateral artery required sacrifice or was at risk of intraoperative injury. The overall mean estimated blood loss was 900 ml.

All patients underwent a posterolateral decompression, which included a laminectomy and at least a unilateral facetectomy and pedicle resection. The median number of laminae resected was 3 (range 2–5). All patients additionally underwent facetectomy to facilitate tumor resection from the facet joint, epidural space, and/or functional nerve root. Bilateral facetectomies were performed in 50 patients (56%). Facetectomy levels included 1 level in 22 patients, 2 levels in 60 patients, and ≥3 levels in 8 patients. Thirteen patients required significant chest wall resections, including all 8 patients with superior sulcus tumors (Table 3).

Resection of the VB followed by reconstruction was required in 44 patients, and 7 additional patients had partial vertebrectomies but did not require a reconstructive procedure. In the patients who underwent anterior reconstruction, the posterolateral PTA was used to resect 37 tumors and followed by anterior reconstruction involving Steinmann pins and PMMA, as described previously. Thoracic approaches included a trap door in 1 patient, posterolateral thoracotomy in 3, and a manubrial osteotomy in 3. In these patients, anterior reconstruction was accomplished using an autologous iliac crest graft (2 patients) or a fibula allograft with an anterior cervical plate (3 patients) or PMMA and Steinmann pins (2 patients).

The choice of posterior instrumentation was dependent on the levels of decompression and the time period in which the instrumentation was placed. In principle, if the level of decompression was C-6 or C-7, a cervical instrumentation system was used. Early in our experience, Axis LMPSs (Medtronic Sofamor Danek) were used in 7 patients (8%) (Fig. 1). Over the past 5 years, 8 patients (9%) underwent placement of the LMSRS with a 3.0-mm rod (Summit, Depuy Spine) or 3.5-mm rod (Mountaineer, Depuy Spine) (Fig. 2). Lateral mass screws were placed at C3–6, pars interarticularis screws or translaminar screws at C-2, and PSs at C-7 and the thoracic spine. Palpation of the medial wall of the C-2 pars and the C-7 pedicle via a laminoforaminotomy was routinely performed to facilitate screw placement. In the thoracic spine, anatomical landmarks were used for placement of thoracic screws, using the freehand technique described by Kim and Lenke.

Patients undergoing T1–3 decompression had 1 of 3 constructs placed. Initially in our experience, an SHRS (Isola, Acromed) was used in 48 patients (53%) (Fig. 3). Sublaminar hooks were placed by drilling a laminotomy site and

<table>
<thead>
<tr>
<th>TABLE 3</th>
<th>Decompression techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technique</strong></td>
<td><strong>Value (%)</strong>*</td>
</tr>
<tr>
<td>approach</td>
<td>80 (89)</td>
</tr>
<tr>
<td>posterolat only</td>
<td>37 (41)</td>
</tr>
<tr>
<td>PTA</td>
<td>10 (11)</td>
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<tr>
<td>combined anterior–posterior</td>
<td>3 (3)</td>
</tr>
<tr>
<td>cervical</td>
<td>1 (1)</td>
</tr>
<tr>
<td>trap door</td>
<td>3 (3)</td>
</tr>
<tr>
<td>posterol thoracotomy</td>
<td>3 (3)</td>
</tr>
<tr>
<td>manubral osteotomy</td>
<td>90 (100)</td>
</tr>
<tr>
<td>median no. of levels</td>
<td>3</td>
</tr>
<tr>
<td>facet joint</td>
<td>90 (100)</td>
</tr>
<tr>
<td>bilat</td>
<td>50 (56)</td>
</tr>
<tr>
<td>1 level</td>
<td>22 (24)</td>
</tr>
<tr>
<td>2 levels</td>
<td>60 (67)</td>
</tr>
<tr>
<td>≥3 levels</td>
<td>8 (9)</td>
</tr>
<tr>
<td>corpectomy</td>
<td>51 (57)</td>
</tr>
<tr>
<td>chest wall</td>
<td>13 (14)</td>
</tr>
<tr>
<td>anterior reconstruction</td>
<td>37 (41)</td>
</tr>
<tr>
<td>PMMA/Steinmann pins</td>
<td>18 (20)</td>
</tr>
<tr>
<td>bone graft</td>
<td>13 (14)</td>
</tr>
<tr>
<td>allograft</td>
<td>4 (4)</td>
</tr>
<tr>
<td>autograft</td>
<td>1 (1)</td>
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</tbody>
</table>

* Data are number of patients, unless otherwise indicated.
placing a compression construct on one side of the spine and a claw construct on the contralateral side. As polyaxial PSs became available, a transition was made to dual-diameter rod systems in 16 patients (18%) (Fig. 4) and PSSs involving a 6.25-mm rod (Monarch, Depuy Spine) in 11 patients (12%) (Fig. 5). The dual-diameter rod systems were initially created with wedding-band connectors and subsequently with tapered rods that transitioned from 6.25 to 3.5 mm. The placement of screws was identical to that used for LMSRSs. For patients undergoing tumor decompression at T-2 or below, a 6.25-mm rod was anchored at the superior end of the construct with C-7 and T-1 PSs (Fig. 5). The use of this construct was predicated on the size of the C-7 pedicle being > 4.75 mm, which was the smallest PS diameter offered in the system used. Otherwise, a dual-diameter rod system was employed in conjunction with lateral mass screws in the cervical spine. Autologous and allograft bone grafts were placed in patients with expected extended survival and in all patients with primary bone tumors. The Fisher exact test was used to analyze differences among instrumentation failures.

Results

Pain Status

Overall, pain improved in 57 patients (63%), remained unchanged in 30 (33%), and worsened in 3 (3%) patients. Among 57 patients with moderate or severe pain preoperatively, 46 (81%) improved to experience no or only mild pain.

Neurological Status

The ASIA grades improved in 29 patients (32%), remained stable in 59 (65%), and deteriorated in 2 (2%). Within a subgroup of 5 patients with preoperative scores of ASIA Grade B–C, 4 (80%) improved to a grade of D–E postoperatively. Among the 85 patients with preoperative scores of D–E, 83 (98%) remained stable or improved. The postoperative ASIA grades significantly improved compared with preoperative scores (p < 0.001).

Functional Status

With regard to functional outcomes, ECOG scores improved in 32 patients (36%), remained stable in 53 (59%), and worsened in 5 (6%) postoperatively. Of 21 patients
with preoperative ECOG scores of 3–4, 15 (71%) improved to an ECOG score of 0–2 postoperatively. Of the 69 patients with preoperative scores of 0–2, 65 (94%) remained stable or improved. Overall, the ECOG scores significantly improved after surgery ($p < 0.001$).

Muscle Strength

A total of 18 patients presented with functional radiculopathy preoperatively. In 11 cases (61%), muscle strength improved, whereas in the other cases it remained stable. In 8 patients with MRC grades of 4/5 in the affected myotomes, 5 (63%) regained full strength postoperatively. The mean score increased from 3 to 4 ($p < 0.01$).

Complications

Medical and surgical complications are listed in Table 4. Surgical complications were documented in 17 patients (19%), with 12 (13%) requiring reoperation. The 11 instrumentation failures (12%) are summarized in Table 5. Six of the 11 patients with instrumentation failures required reoperation for symptom control, and no patient required reoperation for a misplaced screw, or a rod or screw breakage. The failure localized to the cervical spine in 5 cases and the thoracic spine in 6. Chest wall resection was involved in 2 cases of instrumentation failure. Two (29%) posterior LMPSs failed, but there were no cases of failure with the LMSRS with either a 3.0- or 3.5-mm rod ($p = 0.2$). Of 48 SHRS constructs, 7 (15%) failed, with 4 of those failures occurring in the cervical spine. This failure rate was not significantly different from the failure rate in PSS cases (2 cases [7%]; $p = 0.48$). Both patients with PSS construct failures had dual-diameter rod implants, 1 failing within the 1st month and 1 failing 7 months after the initial operation. The dual-rod failures were both junctional, 1 occurring superior and the other inferior to the instrumentation. There was no significant difference in the rate of failures among the 3 construct types ($p > 0.2$).

Wound Revisions

A total of 7 wound dehiscences required reoperation. Six of these patients underwent either pre- or postoperative radiation therapy and 1 received postoperative chemotherapy. Two of these patients required a rotational trapezius flap. Three patients who had undergone radiotherapy within 6 weeks of surgery had a prophylactic trapezius flap rotated to prevent a delayed wound dehiscence or infection.

Survival

The median survival of the entire patient population was

![Fig. 4. Anteroposterior (left) and lateral (right) radiographs obtained in a 68-year-old man with a history of non–small cell lung cancer who underwent a C7–T2 posterolateral resection and posterior fixation of C3–T6 using a PSS with lateral mass and PSs connected by a dual-diameter rod.](image1)

![Fig. 5. Anteroposterior (left) and lateral (right) radiographs obtained in a 67-year-old man with a Pancoast tumor who underwent a 1-level vertebrectomy and PMMA-augmented reconstruction, T1–3 posterolateral resection, and C7–T5 stabilization using a PSS with a 6.25-mm rod.](image2)
12 months (Fig. 6). Patients with primary tumors survived significantly longer \( (p = 0.0124) \) than those with metastatic disease. The median survival in the primary tumor population was 33 months, while in the metastatic population median survival was 10 months.

The overall median radiographic or clinical follow-up duration was 6 months with a median follow-up of 5 months in the plate/hook group (range 10 days–90 months) and a median of 7 months in the screw/rod group (range 10 days–55 months). The median time to instrumentation failure in the plate/hook group was 6 months, and the 2 documented failures in the screw/rod groups occurred at 0.5 and 7 months. Seventy patients \( (78\%) \) had attended follow-up within 6 months before dying or the end of the study period, including 39 patients \( (71\%) \) treated with the plate/hook system and 31 patients \( (89\%) \) treated with polyaxial screw/rod systems.

### Discussion

Cervicothoracic junction posterior instrumentation was required in 8\% of patients undergoing tumor resection at Memorial Sloan–Kettering Cancer Center, which reflects the prevalence of tumor involvement between C-6 and T-3. In this series, the most common rationale for surgery in both the metastatic \( (74\%) \) and primary \( (65\%) \) tumor groups was high-grade ESCC from radioresistant tumor. In accordance with the findings of Patchell et al.,\textsuperscript{17} patients with high-grade ESCC and myelopathy due to solid metastatic tumors (that is, radioresistant tumors) had improved outcomes with surgery followed by conventional EBRT rather than radiotherapy alone with regard to recovery and maintenance of ambulation, recovery of bowel and bladder function, and even survival. By extension, radioresistant primary tumors, such as chordoma and chondrosarcoma, that presented with high-grade spinal cord compression were surgically treated to decompress the spinal cord with the expectation that conventional EBRT would not decompress the spinal cord or reduce the tumor burden enough to make the patient a candidate for en bloc resection to achieve marginal or wide margins. Stereotactic radiosurgery has been shown to improve local tumor control for

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**TABLE 5**

<table>
<thead>
<tr>
<th>Decompression Level &amp; Construct</th>
<th>No. of Patients (%)</th>
<th>No. of Failures (%)</th>
</tr>
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<tbody>
<tr>
<td>C6–7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMPS</td>
<td>7 (8)</td>
<td>2 (29)</td>
</tr>
<tr>
<td>LMSRS</td>
<td>8 (9)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>T1–3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHRS</td>
<td>48 (53)</td>
<td>7 (15)</td>
</tr>
<tr>
<td>PSS (dual-diameter)</td>
<td>16 (18)</td>
<td>2 (13)</td>
</tr>
<tr>
<td>PSS (6.25-mm rod)</td>
<td>11 (12)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

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Fig. 6. Graph of Kaplan–Meier survival curves of the overall patient population and patients with metastatic and primary CTJ tumors. The combined median survival was 12 months. The median survival of patients with primary tumors was 33 months and was 10 months in patients with metastatic tumors.
radioresistant tumors but cannot be safely used in the presence of high-grade ESCC due to the constraints of spinal cord tolerance. However, stereotactic radiosurgery is currently being used to improve local tumor control as a postoperative adjuvant in radioresistant tumors.

The second most common rationale for surgery in the metastatic and primary groups was oncological. Patients with tumors such as superior sulcus non–small cell lung carcinoma (Pancoast tumors) and osteogenic sarcoma are routinely offered neoadjuvant therapy followed by resection in an attempt to cure the tumor.\(^1\) In the absence of high-grade spinal cord compression, patients with tumors such as chordoma and chondrosarcoma are offered en bloc or gross-total resection in an attempt to achieve marginal or wide margins. At present, patients with these tumors are routinely offered high-dose proton beam or image-guided photon beam therapy postoperatively.

Of note, mechanical instability is a rare indication for surgery at the CTJ. No consensus definition of instability exists with regard to the CTJ. In our experience, both movement-related pain and radiographic correlates must be present to define instability resulting from lytic tumor destruction. At the CTJ, the movement-related pain is often seen in extension, as the patient straightens an unstable kyphosis. Radiographically, patients with burst or compression fractures, even in kyphosis, rarely manifest instability pain. However, a patient with the combination of burst fractures that extend into a unilateral joint will often present with instability-related pain. The presence of the ribs and clavicles adds stability to this region, resulting in only 4 patients who manifested mechanical instability in the present series.

Cervicothoracic tumors represent unique challenges with regard to tumor resection and reconstruction due to the transition from the mobile lordotic spine to the fixed kyphotic thoracic spine. A number of posterior instrumentation systems have been developed for the cervical, thoracic, and lumbar spine, but none of the early systems was specifically designed to bridge the CTJ. Additionally, significant additional stresses are placed on posterior instrumentation in tumor resection-related reconstruction compared with other pathological entities. All patients in our series underwent either uni- or bilateral facetectomies over \(\geq 1\) spinal levels. A VB resection and anterior reconstruction were required in 44 patients. Chest wall resection also increases the stress on the posterior hardware, as evidenced by the fact that 2 (15%) of 13 patients with chest wall resection experienced hardware failure.

Anterior instrumentation as stand-alone fixation has several disadvantages when in relation to the CTJ in cancer patients compared with anterior and posterior fixation. From a clinical perspective, in an operative series of 14 patients treated exclusively with anterior instrumentation of the CTJ, the authors reported 5 clinically significant failures (36%).\(^7\) In a cervicothoracic tumor series of Le et al.,\(^\text{13}\) 2 (66%) of 3 patients with stand-alone anterior constructs required reoperation, while none of the 14 patients with posterior fixation had construct failures. Additionally, concern regarding the development of adjacent-segment tumor commonly seen in the metastatic population argues for posterior supplementation of anterior constructs in the cancer population.

In our series, 37 (84%) of 44 patients underwent anterior or resection and reconstruction via a posterolateral PTA to avoid the morbidity of anterior exposures, such as trapdoor, transmanubrial, transsternal, or posterolateral thoracotomy approaches. These anterior approaches are more often used for resection of primary and superior sulcus tumors or for attempted en bloc excisions. Patients with metastatic tumors often have multiple medical comorbidities that may preclude an extensive thoracotomy; thus, the PTA approach is preferred for this population. Via a posterior approach, an epidural tumor can be resected from a normal dural plane and the anterior margin on the dura mater is achieved by resecting the posterior longitudinal ligament. Anterior reconstruction is typically performed using PMMA and Steinmann pins, but cages and bone grafts can be placed via a posterior approach. These patients received posterior segmental fixation as a supplement to VB resection and reconstruction via a single approach.

Anterior VB reconstruction is supported in biomechanical studies examining fixation across the CTJ. Studies comparing a posterior plate/screw system to rod/screw systems in a 2-column injury model, also known as distractive flexion model according to the Allen classification,\(^4\) showed that all constructs (C5–T2) provided adequate stabilization of the CTJ. However, when an anterior-column injury was added, simulating distractive extension injury, all posterior constructs showed greater range of motion and decreased stiffness in extension when compared with intact spines,\(^11\) supporting the application of anterior and posterior instrumentation in these cases. In our series, we used supplemental anterior constructs, primarily involving PMMA and Steinmann pins, allograft bone, or cages, in 44 patients.

The need to improve the durability of posterior fixation and reduce morbidity has led to a transition from cervical LMPSs to LMSRSs for C6–7 decompression and from SHRSs to PSSs for T1–3 resections. Fixation of the lateral elements of the cervical spine provides better rotational stability\(^15,27\) than sublaminar wires, as is seen with both LMPSs and LMSRSs. Numerous posterior plate systems have been successfully employed in stabilization of the CTJ.\(^15,27\) However, in our series, the transition from cervical plate systems to a 3.0- or 3.5-mm rod system was initially made due to the high failure rate (29%) associated with the cervical plate system. The inability to constrain the screw to the plate led to a high rate of screw pullout. Additionally, posterior plate systems require uniform spacing of holes and the same screw direction. This is particularly problematic at junctional segments of the spine where the distance between screws and their direction may undergo large modulations.\(^24\) Using a 3.0- or 3.5-mm rod system to bridge the CTJ allows for accurate screw placement compared with plates. No patient in our series experienced screw or rod breakage, despite biomechanical data suggesting that this construct is inferior across the CTJ compared with dual-rod systems.\(^26\) Thus, in tumor patients undergoing C6–7 decompression, a 3.5-mm screw/rod system provides reliable fixation.

For T1–3 decompression, initial fixation attempts involved the SHRS. The SHRSs, initially popularized by Cotrel and Dubousset, have been used for stabilization of the CTJ.\(^10\) The disadvantage of using sublaminar hooks is predicated on the fact that it requires laminar integrity and cannot be utilized in a stenotic spine. Although our fixation failure rate was relatively low (15%) when using sublami-
nar hooks, a patient who underwent reoperation for a spinal tumor treated at an outside institution experienced a significant spinal cord injury after hook placement, which was the impetus to change to a PSS as these systems became available.

Three screw/rod systems are used for CTJ reconstruction after tumor decompression in the upper thoracic spine, including a 6.25-mm rod system, ending the construct with a PSS at C 7; a solid domino connector extending between a 6.25- and 3.0-mm rod, and a dual-diameter tapered rod transitioning from 6.25 to 3.5 mm. On biomechanical testing, there is no difference between the dual-diameter and solid domino connected rod. In our series, the fixation failure rate was 6% when using a PSS and 15% when using a SHRS. The safety and ease of screw placement with comparable rates of failure make this the preferred method of fixation at the CTJ.

Our instrumentation strategies and failure rates are similar to those of others. In 2003 Le et al. reported their experience with 19 patients harboring CTJ tumors; the authors used a posterior or posterolateral approach in 14 patients. In addition to the use of polyaxial screw/rod systems, the authors reinforced cervical constructs with sublaminar wires connected to a cross-link. They reported 2 hardware failures (11%), with both failures occurring in patients who had stand-alone anterior constructs.

Mazel et al., operated on 32 patients with cervicothoracic tumors including 19 superior sulcus non–small cell lung carcinomas, 11 metastatic tumors, and 2 primary bone tumors. Three instrumentation strategies were employed including a Roy-Camille thoracolumbar plate (20 patients), cervicothoracic plate (8 patients), and an Agora rod system (4 patients). Two mechanical failures (6%) were reported, both involving progression of thoracic kyphosis and requiring revision of posterior hardware.

Patients with cancer have multiple risk factors predisposing them to hardware failure. Adjuvant radiation therapy compromises bone quality and increases their predisposition to pseudarthrosis. Furthermore, the required resection of structure-support elements, namely facet joints, VBs, and the chest wall, places the reconstruct under significant mechanical stress.

The overall postoperative improvement in functional, pain, and neurological scores in patients with CTJ tumors was comparable to the outcomes in patients with tumors in other regions of the spine. In the subaxial cervical spine, decompression and stabilization resulted in durable improvement in pain, ASIA, and motor scores in 93% of patients. In our series of thoracic tumors, which includes some of the CTJ patients, 96% experienced pain improvement and 71% either remained neurologically intact or had an improved ASIA grade and 68% either had an improvement in their ECOG score or remained at 0.

Conclusions

Patients with tumors of the CTJ who undergo resection experience significant improvement in the neurological and overall functional status, as well as alleviation of their pain. Newer fixation strategies, such as the LMSRS and PSS, provide adequate stabilization across the CTJ after resection, with relatively low rates of instrumentation failure.
Posterior stabilization following tumor resection


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