Surgical treatment of superior sulcus tumors with spinal and brachial plexus involvement

MARK H. BILSKY, M.D., TODD W. VITAZ, M.D., PATRICK J. BOLAND, M.D.,
MANJIT S. BAINS, M.D., VISWANATHAN RAJARAMAN, M.D., AND VALERIE W. RUSCH, M.D.

Departments of Neurosurgery, Orthopedic Surgery, and Thoracic Surgery Services,
Division of Surgery, Memorial Sloan-Kettering Cancer Center, New York, New York

Object. Non–small cell lung carcinomas with spinal and brachial plexus involvement have traditionally been considered to be Stage IIIb lesions and therefore unresectable. Advances in spinal surgery, the application of magnetic resonance (MR) imaging, and improvements in neoadjuvant therapy require a reassessment of the potential for complete resection.

Methods. The authors conducted a retrospective review of all procedures involving the resection of superior sulcus tumors with spinal or brachial plexus involvement performed between 1985 and 1999. Assessment or resectability and operative planning were based on an MR imaging classification scheme in which the extent of spinal involvement was considered. Class A tumors involved the periosteum of the vertebral body (VB) (16 patients); Class B, distal neural foramen without epidural compression (eight patients); Class C, proximal neural foramen with epidural compression (four patients); and Class D, bone involvement (VB or posterior elements) with or without epidural involvement (14 patients). Brachial plexus involvement was present in 21 patients, including 17 with T-1 nerve root only and four with C-8 or lower-trunk infiltration.

Complete tumor resection was achieved in 27 patients and incomplete resection in 15. Complications occurred in 14 patients, two of which were related to instrumentation failures. The overall median survival was 1.44 years. The median survival for the complete and incomplete resection groups were 2.84 and 0.79 years, respectively (p = 0.0001). There was no statistical difference in survival among classification groups.

Conclusions. Complete tumor resection of superior sulcus tumors is possible in selected patients in whom involvement of the spinal column and/or brachial plexus is present. Preoperative MR imaging is essential for evaluation of the spine and surgical planning. Survival and cure are dependent on complete resection, regardless of the extent of spinal involvement.

Key Words • superior sulcus • brachial plexus • pancoast tumor

Abbreviations used in this paper: CT = computerized tomography; MR = magnetic resonance; PMMA = polymethylmethacrylate; VB = vertebral body.
patients do not present with hand intrinsic weakness, and resection does not generally result in significant weakness. Conversely, pain radiating into the hand, especially the fourth and fifth digits, is indicative of involvement of the C-8 nerve root or lower trunk of the brachial plexus, and these patients often present with substantial hand intrinsic weakness. Resection may result in a flail hand. Both CT and MR imaging demonstrate the brachial plexus well, but they often fail to reveal enough anatomical detail to distinguish T-1 from C-8 or lower-trunk involvement. In our experience, the clinical examination is helpful and reliably correlates with intraoperative findings.

**Spinal Involvement**

**Classification of Imaging Findings and Extent of Resection**

A preoperative MR imaging classification scheme was devised to assess the degree of spinal element involvement and the type and extent of operation required for tumor resection. Magnetic resonance imaging findings are divided into four classes based on the degree of involvement of the spinal column and neural structures (Table 3). Class A and B tumors are T-3 tumors in which an R0 resection (Table 1) can be achieved. Class A tumors involve the VB periosteum only and Class B tumors involve the proximal rib head and distal neural foramen without epidural involvement (Fig. 1). Class C and D tumors are T-4 lesions that are often not amenable to en bloc resection but in which gross-total resection can be achieved. Class C tumors extend through the neural foramen with minimal or no VB involvement but with unilateral epidural compression. Class D tumors involve the vertebral column (VB and/or lamina) with or without epidural compression (Fig. 2).

**Surgical Techniques**

**Class A and B Lesions.** Patients are positioned in the lateral decubitus position on a beanbag. During inflation of the beanbag, care must be taken to avoid compression of the abdomen, which may result in increased bleeding from the epidual venous plexus. A posterolateral thoracotomy is performed (Fig. 3 upper left). The scapula is elevated from the chest wall by cutting the rhomboid and levator scapulae muscles and is secured with an internal mammary retractor (Fig. 3 upper right). The majority of patients require extensive resection of the chest wall. The chest wall is cut distal to the tumor most often involving the first through fourth ribs. The chest contents are explored for pulmonary nodes and mediastinal involvement that may preclude resection. At this point, the paraspinal muscles are dissected from the posterior elements of the spine by using a Bovie cautery to expose the transverse processes, pars interarticularis, and unilateral laminae. Using either an osteotome or drill, the base of the transverse process is

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<th>TABLE 1</th>
<th>Staging for non-small cell lung carcinomas</th>
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‡T1 = <3 cm; T2 = >3 cm, or any size with involvement of main bronchus >2 cm from carina, or any size with associated obstructive pneumonitis; T3 = any size with direct extension into chest wall, diaphragm, mediastinal or parietal pleura, or any size with involvement of main bronchus < 2 cm from carina, or any size with associated obstructive pneumonitis of the entire lung; and T4 = any size involving the carina, great vessels, spine, trachea or esophagus, or any size with satellite tumor nodules in ipsilateral lung.

†Node status: N0 = no lymph node involvement; N1 = spread to ipsilateral hilar or peribronchial nodes; N2 = spread to mediastinal or subcarinal nodes; and N3 = spread to contralateral nodes or spread to ipsilateral scalene or supraclavicular nodes.

‡Metastatic status: M0 = no distant metastasis; and M1 = distant metastasis.

1999 was conducted. Forty-two patients (28 men and 14 women; mean age 54 years; range 31–72 years) were identified and form the basis of this study. Demographic information, and tumor histological grading, extent of resection, and outcome data were collected. Extent of resection was evaluated as complete, defined as R0 (en bloc resection with negative margins) or R1 (gross-total resection with microscopic tumor-positive margins). Incomplete resection was defined as R2 (gross resection with positive margins) (Table 2). Statistical analysis was performed using Kaplan–Meier analysis and comparison between subgroups using log-rank test.

**Preoperative Assessment**

**Nerve Involvement.** Routine history and physical examination were performed with an emphasis on defining the quality and characteristics of the patient’s pain symptoms and function of the hand intrinsic muscles. It is important to distinguish clinically T-1 nerve root involvement from that of C-8 or the lower trunk of the brachial plexus. Pain extending along the ulnar aspect of the forearm to the wrist suggests isolated involvement of the T-1 nerve root. These
sectioned distal to the pedicle at the level of the neural foramen and fractured through the costovertebral junction by using forward traction (Fig. 3 lower left). Tenotomy scissors are used to dissect the intercostal muscles and identify the nerve roots at the level of the neural foramen. Rhizotomy is accomplished by double ligation of the nerve roots by using small vascular clips and sectioning. Proximal nerve roots should be sent for evaluation of margins and resected more proximally if pathologically positive. The VB periosteum is dissected using Bovie cautery starting from a normal plane, and segmental feeding vessels are ligated using vascular clips or No. 2-0 silk ligatures. Placement of spinal instrumentation is not required in a Type 1 dissection because the pars interarticularis and facet joints remain intact. Following resection, attention is then returned to completion of lobectomy or pneumonectomy as indicated (Fig. 3 lower right).

**Class C Lesions.** Tumor may extend through the neural foramen to compress the epidural space without bone infiltration. Patient positioning and exposure of the spine are the same as those in the Type 1 resection for Class A and B lesions. Using the M-8 burr on a Midas Rex drill (Fort Worth, TX), the laminae and facet joints are cut proximal to the facet joint, transverse process, and pars interarticularis, and the pedicles are drilled to the base of the VB. This provides exposure of the proximal neural foramen and lateral dura. The tumor is dissected from the dura by using tenotomy scissors, and a rhizotomy is performed as previously described. Unilateral single-level facet resection is generally tolerated without the need for placing instrumentation, but multilevel resection may result in scoliosis if fusion is not performed. Although instrumentation has been used in patients treated in the lateral position, our preference is to perform a second posterior approach to ensure coronal- and sagittal-plane alignment.

**Class D Lesions.** The extent of resection and spinal fixation in cases involving Class D tumors depends on the degree of VB, posterior element, and epidural involvement. In patients harboring isolated epidural and VB tumor, the technique required for a Class C tumor is performed and followed by intralesional resection of the involved VB level(s). Polymethylmethacrylate and Steinmann pins or autologous rib or iliac crest bone graft are used for anterior VB reconstruction. Stabilization is augmented by placement of an anterior plate or screw/rod construct. No posterior instrumentation is required.

For tumors that involve the VB and posterior elements and/or extensive epidural tumor, our preferred approach is a posterolateral transpedicular route in which circumferential fusion is performed. Patients are positioned prone on lateral chest supports with the head in the Mayfield fixation device. A C5–T7 midline incision is made. An additional perpendicular incision along the rib can aid in lateral dissection. The laminae, bilateral pedicles, facet joints, and pars interarticularis are resected using a high-speed drill. The epidural tumor is resected using tenotomy scissors. Intralesional resection of the VB is then performed, including the posterior longitudinal ligament. Anterior reconstruction is conducted using PMMA and Steinmann pins and posterior segmental fixation with sublaminar hooks in the cervical spine and hooks or pedicle screws in the thoracic spine. Recently, we have begun to explore the use of hybrid lateral mass–pedicle screw fixation systems to help avoid placement of sublaminar hooks in the cervical spine. All instrumentation is placed prior to chest wall and intrathoracic dissection to provide a protective barrier around the spinal cord.

The limiting factor in this approach is the extent of intrathoracic involvement, because it requires undertaking a
thoracotomy with the patient in the prone position. Its advantages related to the spine are the ability to resect an epidural tumor from a normal dural plane and the ease of placing both anterior and posterior instrumentation via a single approach. In patients in whom the prone position does not permit chest dissection, the tumor excision and placement of the anterior and posterior instrumentation can be performed via either a single-stage posterolateral thoracotomy approach or a two-stage anterior–posterior approach, depending on the tumor size, involvement of adjacent structures, and surgeon’s preference.

Brachial Plexus

The T-1 nerve root is frequently involved as it traverses the apex of the chest cavity to join the lower trunk of the brachial plexus. Stimulation of the nerve root with an electrical current (2 mA) rarely induces a motor response. The T-1 nerve root is resected with No. 2-0 silk ties because it is larger than the remaining thoracic roots. If tumor is suspected to involve the C-8 nerve root and lower trunk of the brachial plexus, biopsy samples may be obtained using tenotomy scissors to strip the suspicious tissue. Often in patients treated with neoadjuvant therapy, this represents scar and not viable tumor. We do not routinely sacrifice the C-8 nerve root or lower trunk of the brachial plexus because of the resultant flail hand syndrome. The sympathetic ganglia traverse the rib heads and generally are not identified during resection. Tumor involvement or rib resection of T-1 will result in a Horner syndrome due to excision of the stellate ganglion and is an expected outcome when this procedure.

Results

Between 1985 and 1999 spine resection was undertaken in 42 of 187 patients who underwent operations for superior sulcus tumors at Memorial Sloan-Kettering Cancer Center. Twenty-nine tumors were right sided. Presenting symptoms are listed in Table 1. Forty patients presented with chest, shoulder, or back pain. A single patient presented with Brown–Séquard myelopathy, but in no other patient was there clinical evidence of spinal cord compression. Histological subtypes are summarized in Table 4. The tumor stage, MR imaging classification, and completeness of resection are shown in Table 5. The most common classification was A (16 patients), followed by D (14 patients), B (eight patients), and C (four patients). The brachial plexus was involved in 21 patients. In 17 patients T-1 only was involved, and in four patients C-8 or the lower trunk of the brachial plexus was additionally involved.

Complete resection (R0/R1) was achieved in 27 patients and incomplete (R2) in 15. When stratified by MR imaging classification, complete resection was achieved in 11 of 16 Class A tumors, six of eight B tumors, two of four C tumors, and eight of 14 D tumors. No attempt was made to achieve an R0 resection in Class C or D tumors. Positive margins for incompletely resected tumors included dura, brachial plexus, bone, lymph nodes, esophagus, subclavian artery, or a combination.

Fourteen patients (33%) experienced postoperative complications, the majority of which were related to pulmonary issues (Table 6). Spine-related complications included two instrumentation failures. This resulted from failure to attain bicortical screw purchase in one patient in whom an anterior plate was placed and tumor progression in the second. Both patients were treated with external orthosis because of limited symptoms and advanced disease. There were no cases of surgery-related neurological progression.

Adjuvant Therapy

Twenty-eight (67%) of the 42 patients received neoadjuvant therapy: radiotherapy alone in 13, chemotherapy in four, and a combination in 11. The median preoperative radiation dose was 4500 cGy. Intraoperative 125I brachytherapy implants were placed in 24 patients. Postoperative adjuvant therapy was undertaken in nine patients: radiotherapy in six and chemotherapy in three.

Statistical Results

One patient was lost to long-term follow up, leaving data in 41 patients for survival analysis. The overall median survival was 1.44 years with a 2- and 5-year survival of 43.8 and 26.0%, respectively (Fig. 6 upper). Twenty patients (48%) suffered known disease recurrence at a mean of 35 months (range 5–160 months) following diagnosis. The recurrences included 16 local and four distant metastases.
Outcome analysis included factors that were associated with improved survival. In patients who underwent a complete tumor resection median survival was improved compared with those in whom incomplete tumor resections were performed (2.84 and 0.79 years, respectively; p = 0.0001) (Fig. 6 lower). In the group of patients who underwent complete resection, the 2- and 5-year survival rates were 63 and 39.8%, respectively. There was no 2-year survival in patients who underwent incomplete resection. There were no statistically significant survival differences when MR imaging classifications (Class A, B, C, or D) were compared, either individually or when combined A and B were compared with combined C and D classes (p > 0.05, chi-square test).

Discussion
The treatment of non–small cell lung carcinoma of the superior sulcus continues to evolve. Although radiotherapy alone often provides excellent pain palliation, it is not curative. Multimodality therapy, including surgery, provides substantially improved survival rates.
compared with radiotherapy alone. The large variety of radiation treatment strategies and chemotherapy precludes analysis in this study.

In cases of superior sulcus tumors, the goal should be complete resection and cure. There is a limited role for a palliative operation except in patients with high-grade epidural compression or mechanical instability; however, these factors are decidedly rare at presentation as evidenced in this and other studies. Contraindications to operation for extraspinal sites include the presence of contralateral mediastinal nodes and metastatic tumor.

Assessment for resectability includes both CT and MR imaging for superior sulcus tumors that abut the spine. Although CT scanning demonstrates lytic bone destruction of the ribs and VBs, it does not provide enough anatomical detail to assess spinal canal adequately and the data are discordant with intraoperative findings in up to 40% of cases. Magnetic resonance imaging is superior for defining the degree of tumor infiltration into the VB and the extent of epidural extension through the neural foramina. Both CT and MR imaging are useful for assessing the brachial plexus; however, these studies should be considered in combination with clinical signs and symptoms. We have not assessed the use of MR neurography in preoperative planning.

In our practice, the proposed MR imaging classification has been a useful preoperative assessment for determining the type of spinal surgery required to achieve complete resection. Resection for Class A and B tumors has been well described in the literature, and depending on the extent of chest and mediastinal involvement, these tumors are amenable to an R0 resection. DeMeester, et al., described a technique for en bloc resection of Class A tumors in which the pedicle and a portion of the VB are removed with the chest wall and lung so that an R0 resection can be achieved. Our approach to Class A and B tumors does not include partial VB resection, but we achieved complete resections (R0 and R1) in all patients by excising the chest wall at the level of the neural foramen and ligating the proximal nerve roots. Incomplete resections in these patients usually resulted from incomplete removal of extraspinal mediastinal structures (for example, the esophagus).

Class C tumors are uncommon with tumor extending through the proximal neural foramen and compressing the dura unilaterally on the side of the tumor. Gross-total resection of tumor is readily accomplished by excising the unilateral lamina, facet, and pedicle, but tumor-free margins are difficult to achieve. One might argue that the presence of epidural tumor precludes the ability to achieve histologically tumor-free margins. We have been resistant to excising dura as a margin in patients undergoing intralaminar resection because of concern for intradural seeding of tumor, which we have observed in our metastatic population.

A great deal of interest has been generated recently in the resection of Class D tumors involving the VB. In two articles addressing this issue, the authors have described advanced operative techniques. Gruenwald, et al., discussed two-stage anterior and posterolateral thoracotomy by which they achieved an en bloc, and presumably R0, resection of these tumors. Although the long-term outcomes are not known, in the original description of this technique, both patients died at 5 and 18 months, respectively, after surgery.
Physicians at the M. D. Anderson Cancer Center presented a series of patients with Class D tumors who underwent R1 resection via a single-stage posterolateral thoracotomy. Their technique involved an en bloc chest wall resection followed by intralesional VB excision. The PMMA–chest tube technique was used for anterior reconstruction, and posteriorly placed Wisconsin wires or lateral mass screws in the cervical spine connected to thoracic hooks were used for posterior fixation. Long-term survival data are not available, but in three patients fixation-device–related failures occurred. There are inherent difficulties in performing combined anterior–posterior segmental fixation in the lateral position, particularly at the cervicothoracic junction. Maintaining sagittal and coronal alignment may be difficult because the head is not in a fixed position.

Our approach to Class D tumors has also been the aggressive pursuit of en bloc chest wall resection followed by intraleisional VB excision. The PMMA–chest tube technique was used for anterior reconstruction, and posteriorly placed Wisconsin wires or lateral mass screws in the cervical spine connected to thoracic hooks were used for posterior fixation. Long-term survival data are not available, but in three patients fixation-device–related failures occurred. There are inherent difficulties in performing combined anterior–posterior segmental fixation in the lateral position, particularly at the cervicothoracic junction. Maintaining sagittal and coronal alignment may be difficult because the head is not in a fixed position.

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resection of the superior sulcus tumors of overall survival in patients undergoing resection of superior sulcus tumors (upper) and results stratified by complete or incomplete resection of the superior sulcus tumors (lower).
Superior sulcus tumors

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Address reprint requests to: Mark H. Bilsky, M.D., Division Neurosurgery, Memorial Sloan-Kettering Cancer Center, 1275 York Avenue, New York, New York 10021. email: bilskym@mskcc.org.