The Oncologist®

Surgical Management of Superior Sulcus Tumors

Philippe Dartevelle and Paolo Macchiarini

Oncologist 1999;4;398-407

Surgical Management of Superior Sulcus Tumors

Philippe Dartevelle,[a] Paolo Macchiarini[b]

Departments of [a]Thoracic and Vascular Surgery and Heart-Lung Transplantation, Hôpital Marie-Lannelongue (Paris-Sud University), Le Plessis Robinson, France and [b]Thoracic and Vascular Surgery, Heidehaus Hospital (Hannover Medical School), Hannover, Germany

Key Words. *Superior sulcus tumors · En bloc surgical resection · Radiation therapy*

Abstract

Superior sulcus tumor refers to any primary lung cancer presenting with constant pain in the nerve distribution of the eighth cervical, first and second thoracic nerve roots and Horner's syndrome caused by invasion of the stellate ganglion. The pain is steady, severe, and unrelenting, involving the shoulder, the vertebral margin of the scapula and ulnar distribution of the arm to the elbow and finally to the ulnar surface of the forearm, and the small and ring fingers of the hand (Pancoast-Tobias syndrome). Weakness and atrophy of the hand muscles can also occur as the lesions spreads to involve the first and second ribs and vertebrae. Radiologically, there is a small shadow at the extreme apex of the lung with rib and possible vertebral body invasion. Pulmonary symptoms are less frequent because of the peripheral location of the lesions. Since Shaw and Paulson approached superior sulcus tumors in 1961 by using preoperative radiationtherapy (30 to 45 Gy in four weeks including the primary tumor, mediastinum and supraclavicular region) followed by surgical resection, this radiosurgical approach shortly became the standard treatment yielding better disease control and survival than that offered by other treatment modalities. It has now become evident that en bloc resection of the chest wall, involved adjacent structures as well as lobectomy must be considered the standard surgical approach for superior sulcus tumors combined with external radiation (preoperative, postoperative, or both). The goal of the operation is the complete and en bloc resection of the upper lobe in continuity with the invaded ribs, transverse processes, subclavian vessels, T1 nerve root, upper dorsal sympathetic chain and prevertebral muscles. *The Oncologist* *1999;4:398-407*

Introduction

Superior sulcus lesions include a constellation of benign or malignant tumors extending to the superior thoracic inlet [1] and causing a steady, severe, and unrelenting shoulder and arm pain along the distribution of the eighth cervical nerve trunk and first and second thoracic nerve trunks, Horner's syndrome (ptosis, miosis, and anhidrosis), and weakness and atrophy of the intrinsic muscles of the hand—a clinical entity named Pancoast-Tobias syndrome [2, 3]. Non-small cell carcinoma represents the most frequent cause of superior sulcus lesions, and we will refer to this histotype throughout the paper. However, a wide diversity of other conditions can result in Pancoast's syndrome (Table 1), imposing a differential histological diagnosis [4].

Presentation

Superior sulcus lesions of non-small cell histology account for less than 5% of all bronchogenic carcinomas [5]. They may arise from either upper lobe and tend to invade the parietal pleura, endothoracic fascia, subclavian vessels, brachial plexus, vertebral bodies, and first upper ribs. Their clinical features are influenced by their location and type of invasion of the thoracic inlet.

Tumors located in front of the anterior scalenus muscle may invade the platysma and sternocleidomastoid muscles, external and anterior jugular veins, inferior belly of the omohyoid muscle, the subclavian and internal jugular veins and their major branches, and scalene fat pad. More frequently, they invade the first intercostal nerve and first ribs rather than the phrenic nerve or superior vena cava, and patients usually complain about pain distributed to the upper anterior chest wall.

Tumors located between the anterior and middle scalenus muscles may invade the anterior scalenus muscle with the phrenic nerve lying on its anterior aspect, the subclavian artery with its primary branches except the posterior scapular

Correspondence: Paolo Macchiarini, M.D., Ph.D., Department of Thoracic and Vascular Surgery, Heidehaus Hospital (Hannover Medical School), 70 Am Leineufer 30419, Hannover, Germany. Telephone: 49-511-7906-0; Fax: 49-511-7906-266.
Accepted for publication May 26, 1999. ©AlphaMed Press 1083-7159/99/$5.00/0

Table 1. Causes of Pancoast's syndrome

Neoplasms:	
Primary bronchogenic carcinomas	
Other primary thoracic neoplasms:	Adenoid cystic carcinomas Hemanogiopericytoma Mesothelioma
Metastatic neoplasms:	Carcinoma of the larynx, cervix, urinary bladder, and thyroid gland
Hematologic neoplasms:	Plasmacytoma, lymphoid granulomatosis, lymphoma
Infectious processes:	
Bacterial:	Staphylococcal and pseudomonal pneumonia, thoracic actinomycosis
Fungal:	Aspergillosis, allescheriasis, cryptococcosis
Tubercolosis	
Parasitic:	Hydatic cyst
Miscellaneous causes:	
	Cervical rib syndrome, pulmonary amyloidoma

Adapted from *Arcasoy* and *Jett* (1997) [1].

artery, the trunks of the brachial plexus and middle scalenus muscle. As such they likely present with signs and symptoms related to the compression or infiltration of the middle and lower trunks of the brachial plexus, e.g., pain and parasthesia irradiated to the shoulder and upper limb.

Tumors lying posterior to the middle scalenus muscles are usually located in the costovertebral groove, and usually invade the nerve roots of T1, the posterior aspect of the subclavian and vertebral artery, paravertebral sympathetic chain, inferior cervical (stellate) ganglion and prevertebral muscles. Because of the peripheral location of the lung tumors, pulmonary symptoms such as cough, hemoptysis, and dyspnea are uncommon in the initial stages of the disease. Abnormal sensation and pain in the axilla and medial aspect of the upper arm in the territory of the intercostobrachial nerve are more frequently observed at these early stages. With further tumor growth, patients may present with a full-blown Pancoast's syndrome.

Staging Work-Up

Any patient who presents with signs and symptoms evoking the involvement of the thoracic inlet should undergo a careful and detailed preoperative work-up to establish the histological diagnosis and to ultimately assess operability. These patients usually present with small apical tumors that are hidden behind the clavicle and the first rib on routine chest x-ray. The diagnosis is established by history and physical examination, biochemical profile, chest x-ray, bronchoscopy and sputum cytology, fine needle transthoracic or transcutaneous biopsy and aspiration, and computed tomography (CT) of the chest. A video-assisted thoracoscopy might be indicated to obtain tissue proof when the other investigations are negative, and to eliminate the presence of pleural metastatic diffusion. If there is evidence of mediastinal adenopathy on chest x-ray or CT scanning, histological proof is mandatory since patients with clinical N2 disease are not suitable for operation. Neurologic examination and electromyography delineate the tumor's extension to the brachial plexus, phrenic nerve and epiduritis. Vascular invasion is studied with venous angiography, subclavian arteriography and cervical doppler ultrasonography. Magnetic resonance imaging (MRI) should be routinely performed when tumors approach the intervertebral foramina to rule out invasion of the extradural space.

The initial work-up also includes all preoperative cardiopulmonary functional tests routinely performed before any major lung resection and investigative procedures delineating the extrathoracic tumor extension.

Treatment Management

Despite their small size and general lack of extrathoracic metastasis at presentation, one of the most perplexing characteristics of superior sulcus tumors has been their almost universal and rapid mortality. For many years it was felt that they were not amenable to surgery, until *Chardack* and *MacCallum* [6] reported a cure of Pancoast tumor by performing a lobectomy and chest wall excision followed by 65 cGy of irradiation. Five-years later, *Shaw* and *Paulson* [7] approached superior sulcus tumors by using preoperative radiation therapy (30 to 45 Gy in four weeks including the primary tumor, mediastinum and supraclavicular region) followed by surgical resection. This radiosurgical approach shortly became the standard treatment, yielding better disease control and survival than that offered by other treatment modalities.

In 1987 *Wright* and associates [8] studied 21 patients who underwent combined therapy with irradiation and radical resection. Median survival was 24 months and the actuarial survival rate was 55% at three years and 27% at five years. *Shahian* and associates [9] reported improved locoregional control and survival with sandwich irradiation (preoperative and postoperative external irradiation) in 14 patients with lymph node involvement, tumor at the resection margin, or both. The five-year survival rate in five patients with positive lymph nodes as well as in nine patients with residual tumors at the resection margins was 50%. *Ginsberg* and colleagues [5] studied seven patients receiving sandwich radiation treatment; four of them survived long term. Too few patients have received this sandwich treatment to assess its effectiveness. In 1971 and 1987 *Hilaris* and associates [10] studied 129 patients receiving intraoperative brachytherapy combined with surgical resection to achieve better locoregional control and ultimately improve survival. The five-year survival rate was 25%.

In 1994, *Ginsberg* and associates [5] studied 102 patients receiving brachytherapy in addition to resection. Of 69 (56%) patients who underwent a complete resection, 49 received brachytherapy. Their overall five-year survival rate was 41%. Intraoperative brachytherapy had no influence on locoregional recurrence or survival in patients with completely resected tumors. The survival rate of 55 patients who had an incomplete or no resection was 9%. A total of 53 of 55 patients received intraoperative brachytherapy. In 24 patients no resection was performed; brachytherapy combined with preoperative radiotherapy was the primary local control treatment. *Ginsberg* and associates [5] questioned the role of surgical exploration and the intraoperative brachytherapy because it did not improve overall survival when compared with treatment solely with external radiation.

More recently, *Hagan et al*. [11] reported an overall five-year survival rate of 33% in patients who received irradiation followed by surgery, and median survival was significantly prolonged for those patients who could tolerate high-dose radiation treatment.

Surgical Indications

Different surgical approaches have been described, all of which must be known since the ultimate hope for cure depends on whether a complete resection is performed. As a general rule, superior sulcus tumors not invading the thoracic inlet are completely resectable through the classical posterior Shaw-Paulson [7] approach alone. This posterior approach does not allow a direct and safe visualization, manipulation and complete oncological clearance of all anatomical structures composing the thoracic inlet. The superior sulcus lesion extending to the thoracic inlet may be resected by the anterior transcervical approach [12]. This last approach is increasingly being accepted as the standard for all benign and malignant lesions of the thoracic inlet structures other than bronchogenic cancers as well, e.g., osteosarcomas of the first rib, tumors of the brachial plexus [4].

Absolute surgical contraindications are the presence of extrathoracic sites of metastasis and clinical and histologically confirmed mediastinal lymph node involvement. Invasion of the brachial plexus above T1 as supported by sensitive or, even worse, motor deficits in the nerve distribution of the median and radial nerves, indicate inoperability. Extensive involvement of the subclavian vessels is not a contraindication, provided a complete surgical resection may be anticipated. Patients whose tumors abut the vertebral body should not be deemed inoperable unless invasion of the spinal canal through the intervertebral foramina is confirmed. The role of palliative incomplete resection is highly questionable and without any individual benefit.

Operative Techniques

Before operating on a patient with an apical tumor, thoracic surgeons should have all approaches to these tumors available in their armamentarium; the ultimate hope for cure depends on whether a complete resection is performed, and to accomplish this, the most appropriate approach should be selected.

The goal of operation is resection of the upper lobe along with the invaded ribs and transverse processes and all invaded structures such as the lower trunk of the brachial plexus, stellate ganglion and upper dorsal sympathetic chain. Our philosophy is that any apical tumor without invasion of the thoracic inlet can be completely resected through the posterior Shaw-Paulson approach alone. Those lesions with a high suspicion of invading the thoracic inlet should be first explored by an anterior transclavicular approach and possibly followed by the Shaw-Paulson approach.

Posterolateral Approach (Shaw-Paulson)

The patient is placed in the lateral decubitus position, leaning slightly forward with the upper arm loosely supported by folded sheets and free to move as the scapula is elevated. The skin preparation is carried out from the base of the skull (included are the spinal processes above C7), down to the iliac crest and past the mid-line posteriorly and the midline anteriorly. An adhesive plastic draping is then placed over the skin.

Incision

A long posterior thoracotomy incision is made (Fig. 1) [7]. It starts superiorly midway between the spinous process

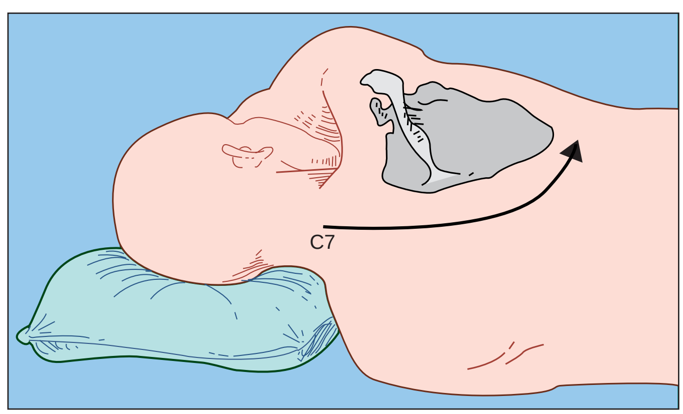

Figure 1. The posterior thoracotomy incision. *Initially, the anterior one-third of the incision only might be used to enter the pleural cavity and assess resectability. If the lesion is deemed resectable, the incision is extended posteriorly to the level of the C7 spine.*

of the seventh cervical vertebra and the posterior aspect of the scapula, describes a gentle arc between the thoracic spineous processes and the medial margin of the scapula, extends downward 2 cm below the inferior angle of the scapula, and ends 2 cm beyond it or just lateral to the breast in women. The incision is then carried deeper with electrocautery. Anteriorly, the latissimus dorsi and the fascia posterior to the serratus anterior muscle are incised along their posterior edge; the serratus anterior muscle is then divided toward the lower margin of the incision. Posteriorly, the trapezius muscle is divided along the full length of the incision. Below the trapezius muscle, the levator scapulae and rhomboideus minor and major muscles (from superior to inferior) are then divided in the line of the incision. The rhomboid muscles insert into the medial border of the scapula; care should be taken to avoid injury of the dorsal scapular nerve and satellite scapular artery, which run down the medial border of the scapula. The division of the rhomboid muscles elevates the medial border of the scapula from the chest wall. A right angle clamp is placed behind the upper digitations of the serratus anterior and serratus posterior superior muscles, and the muscles are then divided by electrocautery. The scapula, fully mobilized from the chest wall, is then retracted upward and forward by placing a scapula (Fruchaud) retractor anchored on its inferior angle.

Assessment of Resectability

The thorax is then entered through the intercostal space below the lowest rib to be resected, as determined by preoperative chest x-ray, CT scan or MRI (usually the third intercostal space). For local resection to be complete, one intact rib with its intercostal muscles below the lower margin of the lesion is removed. At this time the interspace selected is opened only to the extent that permits inspection of the cavity and assessment of the resectability; the exact evaluation of the tumor's extension on the thoracic chest wall, thoracic inlet, lung and mediastinum should be assessed. The chest wall resection should be started first, the philosophy being that it can then be released into the pleural cavity permitting a safer pulmonary resection.

Chest Wall Resection

Once resectability has been determined, the previously made intercostal incision is extended posteriorly towards the angle of the rib, taking care to keep the incision 2-3 cm away from the costovertebral angle. The erector spinae muscle is incised along its anterior border and retracted laterally and posteriorly from the first to the fifth thoracic vertebrae; this exposes the angle of the invaded ribs and transverse processes. Hemostasis is usually obtained by packing the space between the muscles and bony structures.

A Tuffier rib spreader is then placed and the tumor is palpated from within the chest to determine the anterior (usually 4 cm away from the tumor) and inferior (usually includes one rib and intercostal muscle below) margins of the chest wall resection. All involved ribs should be resected en bloc; we do not recommend an extrapleural dissection without rib removal, since this inevitably may lead to incomplete procedures. The division of the ribs is started anteriorly along the previously established margins of resection beginning with the healthy rib. Electrocautery is used to score the periosteum of all ribs to be resected, except the first one. Using rib shears, the intercostal muscles and ribs are divided anteriorly in succession from below to above and labeled as the anterior margin of the resection. The intervening intercostal neurovascular pedicles are then sutured-ligated and divided. By performing a gentle traction of the previously divided anterior margins of the invaded ribs, the anterior end of the first rib is exposed. The anterior and middle scalenus anterior muscles are then divided with cautery, either at their insertion on the first rib or above the level of the tumor; the scalenus posterior muscle is divided where it crosses the outer border of the first rib. The superior margin of the first rib is then freed in tumor-free margins after protection of the subclavian vein, artery and brachial plexus by the operator's finger. Thereafter the relation of the apical tumor with this inlet structure is outlined and the operation continues posteriorly.

The previously placed pack between the erector spina muscle and the bony structures is withdrawn, an erector spinae muscle retractor is placed and the angle of the ribs pushed towards the pleural cavity to improve exposure. After having dissected the angle of the invaded ribs, they are either disarticulated or transected at the costotransverse or transverse level, respectively; this should be done while holding the operator's finger along the costovertebral groove to avoid injury of this region. If the parietal pleura is invaded but not the ribs or vertebrae, the invaded head of the ribs are disarticulated from the transverse process without transecting them by using a periosteal elevator and after division of the costotransverse ligaments. Conversely, if the tumor erodes the ribs posteriorly, the transverse processes are transected along with the lateral cortex of the vertebrae using an osteotome. Once completed, the entire intercostal bundles are successively sutured with prolene 3-0 and divided. Attempts to control bleeding at the costovertebral angle by electrocautery or by packing the wound with oxidized but not pledges of cellulose should be made gently to avoid migration of these elements into the spinal cord or occlusion of an anterior spinal artery. This posterior step of the resection is then continued upwards until the angle of the first rib is reached.

Dissection of the Brachial Plexus

At this point the roots of the eighth cervical nerve above and first thoracic nerve below the neck of the first rib, which join to form the lower trunk of the brachial plexus, are well seen as well as their relation with the tumor. The head of the first rib is then disarticulated from the costovertebral joint after transecting the respective transverse process. Most commonly the tumoral invasion is limited to the first thoracic nerve root; in this case, it should be divided as it emerges from the intervertebral foramen while keeping intact the eighth cervical nerve component. Little bleeding is generally encountered. If the lesions also involve the eighth cervical nerve, then the lower trunk of the brachial plexus should be divided after its invasion. The nerve roots should be secured with a ligature before transecting them at the intervertebral foramen to prevent cerebral fluid leakage. If that occurs, again, the foramen should be gently packed or the erecta spinae muscle should be transposed to the lateral aspect of the vertebral body to tamponade the leak.

Dissection of Subclavian Vessels

Careful dissection of the subclavian artery can usually be done following a subadventitial plane. Local branches such as the internal mammary artery and the thyrocervical trunk are identified and transected if necessary. If the subclavian vein and artery are encased or occluded by the tumor, efforts should be made to complete the operation by removing the segment of involved subclavian vein, which should be simply sutured and ligated but not revascularized. If the subclavian artery is invaded, it should be crossclamped (after adequate systemic heparinization, e.g., 0.5 mg/kg) beyond the invaded segment and revascularized either by an end-to-end anastomosis or by interposing a polytetrafluoroethylene (PTFE) graft (#6 or 8 mm). However, the management of the subclavian vessels is very hazardous through the posterior approach since most tumoral invasion extends beyond the subclavian vessels into the planes of the anterior scalenus muscles and phrenic nerve. One obvious option should be to continue the operation by an additional anterior approach.

Vertebral Body Resection

The last step includes the eventual removal of part of the vertebral body of the upper thoracic vertebrae, depending on the tumor's attachment and frozen section of uncalcified periosteum; up to one-quarter of the vertebral body may be resected without affecting stability. The sympathetic chain is then divided above and below the tumor mass and the stellate ganglia removed. The segment of chest wall including the first, second, and third ribs and a portion of the vertebrae, if necessary, is then dropped into the thorax and the hemostasis secured.

Pulmonary Resection

A standard upper lobectomy is the preferred extent of lung parenchyma resection even if the lesion is small in size and peripheral. This should be usually performed through the hole of the previously made chest wall resection. We suggest completing the lobar fissures with stapler instruments to avoid unnecessary air leaks. Sampling of the upper mediastinum and subcarinal nodes is necessary.

Two straight thoracostomy tubes are placed through two separate stab incisions; one tube (32 Fr) located at the apex for removal of air, and another tube (28 Fr), in the costovertebral groove for removal of fluid. The muscles of the chest wall are closed with running #1 Vycril sutures after interposition of a multihooled silicone rubber #15 tube. Since the scapula and clavicle will cover the bony defect of the thorax, no attempt should be made to reconstruct the chest wall. The subcutaneous tissue as well as the skin are closed with a transdermic suture.

A recently proposed approach by *Tatsamura et al*. [12] for apical lung tumors invading the thoracic inlet includes an incision starting at the level of the spinal process of the second or third thoracic vertebrae, is continued downward along the paravertebral line and the tip of the angle continues upward to above the nipple level, and follows the axillary line up to the level of the sternoclavicular joint (Fig. 2). The management of the thoracic inlet mirrors that proposed by the Shaw-Paulson and anterior approaches.

Anterior Approaches

Transclavicular Approach

The patient is placed in the supine position with the neck hyperextended and head turned away from the involved

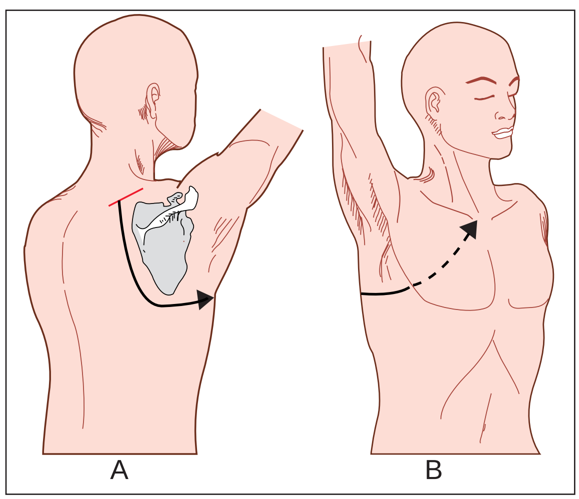

Figure 2. A) Semidorsal and B) semiventral view of the incision. *(Adapted from:* Tatsamura T, Sato H, Mori A et al.*) A new surgical approach to apical segment lung diseases, including carcinomas and inflammatory diseases [12].*

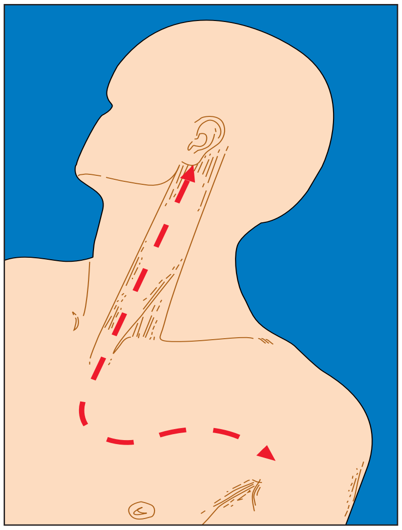

Figure 3. A left L-shaped incision cervicotomy is made and includes a vertical presternocleidmastoid incision prolonged horizontally below the clavicle up to the delto-pectoral groove. *However, to increase the exposure and make the entire resection through this incision only, the interception between the vertical and horizontal branches of the L-shaped incision is lowered at the level of the second or third intercostal space, as indicated by the level of tumoral invasion.*

side. A bolster is placed behind the shoulder to elevate the operative field. The skin preparation extends from the mastoid downward to the xiphoid process and from the middle axillary line laterally to the hemiclavicular line.

An L-shaped incision cervicotomy is made and includes a vertical presternocleidmastoid incision prolonged horizontally below the clavicle up to the delto-pectoral groove (Fig. 3) [13]. The incision is then deepened with cautery. Division of the sternal attachment of the sternocleidomastoid muscle is made and the cleidomastoid muscle along with the upper digitations of the ipsilateral pectoralis major muscle are scraped from the clavicle; a myocutaneous flap can be folded back giving a full exposure of the neck and thoracic inlet and upper part of the anterolateral chest wall.

Once the inferior belly of the omohyoid muscle is divided, the scalene fat pad is dissected and pathologically examined to exclude scalene lymph node micrometastasis. Inspection of the ipsilateral superior mediastinum is then made by the operator's finger along the tracheoesophageal groove, after division of the sternothyroid and sternohyoid muscles. The tumor's extension to the thoracic inlet is then carefully assessed. We recommend resection of the internal half of the clavicle only if the tumor is deemed resectable.

Jugular veins are first dissected, so that branches to the subclavian vein can eventually be divided. On the left side, ligation of the thoracic duct is usually required. Division of the distal part of the internal, external and anterior jugular veins makes the visualization of the venous confluence at the origin of the innominate vein easier; one should not hesitate to suture-ligate the internal jugular vein to increase the exposure to the subclavian vein. If the subclavian vein is involved, it can be easily resected after its proximal and distal control has been achieved. The tumor's direct extension to the innominate vein does not preclude resection.

Next the scalenus anterior muscle is divided either on its insertion on the scalene tubercle on the first rib or in tumor-free margins with cautery. If the tumor has invaded the upper part of this muscle, it needs to be divided at the insertion on the anterior tubercles of the transverse processes of C3 through C6. Before dealing with the anterior scalenus muscle, the status of the phrenic nerve is carefully assessed since its unnecessary division has a deleterious influence on the postoperative course; it should be preserved whenever possible.

The subclavian artery is then dissected. To improve its mobilization, its branches are divided; the vertebral artery is resected only if invaded and provided that no significant extracranial occlusive disease was detected on preoperative Doppler ultrasound. If the tumor rests against the wall of the subclavian artery, the artery can be freed following a subadventitial plane. If there is an invasion of the arterial wall, resection of the artery in order to obtain tumor-free margins is necessary. After its proximal and distal crossclampage, the artery is divided on either side. Revascularization is performed at the end of the procedure either with PTFE graft (#6 or 8 mm) or, more often, with an end-to-end anastomosis after freeing the jugulo-carotid and subclavian arteries. The pleural space is usually opened by dividing Sibson's fascia.

The middle scalenus muscle is divided above its insertion on the first rib or higher as indicated by the extension of the tumor. It might require, especially for apical tumors invading the middle compartment of the thoracic inlet, division of its insertions on the posterior tubercles of the transverse processes of the second through seventh cervical vertebrae. The nerve roots of C8 and T1 are then easily identified and dissected in an out-to-inside fashion until their confluence forms the lower trunk of the brachial plexus. Thereafter, the ipsilateral prevertebral muscles are resected along with the paravertebral sympathetic chain and stellate ganglion from the anterior surface of the vertebral bodies of C7 and T1. This permits an oncological clearance of the major lymphatic vessel draining the thoracic inlet and visualization of the intervertebral foramina as well. The T1 nerve roots are usually divided beyond the visible tumor, just lateral to the T1 intervertebral foramen. Although the tumor's spread to the brachial plexus may be high, neurolysis is usually achieved without division of the nerve roots above T1. The nerve damages of the lateral and long thoracic nerves should be avoided since this may result in winged scapula.

Before performing the upper lobectomy, the chest wall resection is completed. The anterolateral arch of the first rib is divided at the costochondral junction while the second rib is divided at the level of its middle arch and the third rib is scraped on the superior border toward the costovertebral angle. Then the specimen is progressively freed. The first ribs are then disarticulated from the transverse processes of the

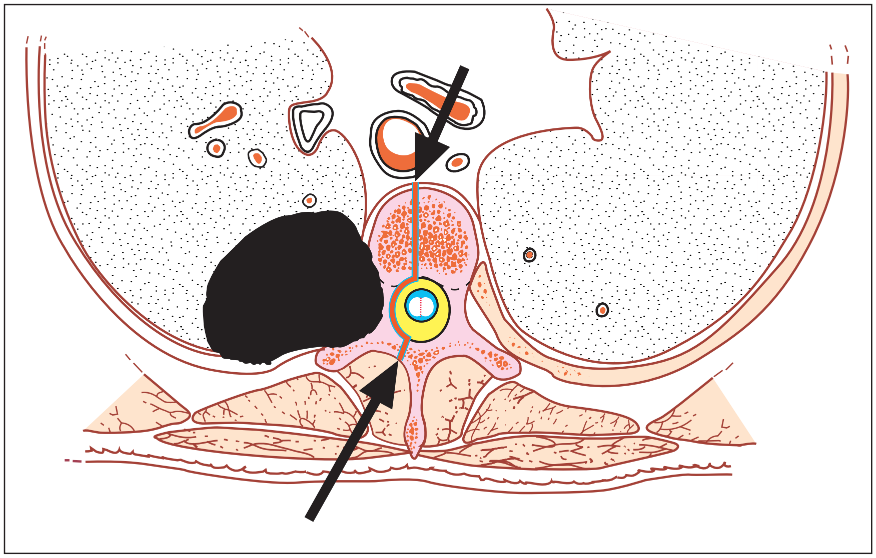

Figure 4. Right-sided apical tumor involving the costo-transverse space and intervertebral foramen and part of the ipsilateral vertebral body. This tumor is usually first approached anteriorly as described in the text and then the operation is completed through a hemivertebrectomy performed through a posterior cervical midline approach.

first two or three thoracic vertebrae. It is through this cavity that an upper lobectomy, although technically demanding, can be performed to complete the operation. In effect, with increasing experience it has become evident that an additional posterior thoracotomy is usually not required and the upper lobectomy and the chest wall resection of the first four ribs can be performed through the transcervical approach only without recurring to the posterolateral thoracotomy. The cervical incision is closed in two layers after the sternal insertion of the sternocleidomastoid muscle is sutured and a conventional post-lobectomy drainage of the ipsilateral chest cavity is placed.

There is increasing concern regarding the functional and esthetic benefit provided by the preservation of the clavicle. We believe that the indications to preserve and reconstruct the clavicle are limited to the combined resection of the serratus anterior muscle and its nerve (long thoracic nerve) since if this occurs, the scapula rotates and draws forward. This entity, named scapula alata, combined with the resection of the internal half of the clavicle, pushes the shoulder anteriorly and medially, and leads to severe cosmetic and functional discomfort. If this circumstance is anticipated, then we recommend making an oblique section of the manubrium that fully preserves the sternoclavicular articulation, its intrarticular disk, and the costoclavicular ligaments rather than the simple sternoclavicular disarticulation. Clavicular osteosynthesis can then be accomplished by placing metallic wires across the lateral clavicular edges and across the divided manubrium.

We have recently developed a technique [14] for resecting those posteriorly located superior sulcus tumors extending into intervertebral foramen without intraspinal extension (Fig. 4). The underlying principle is that a radical procedure can be performed by resecting the intervertebral foramen and dividing the nerve roots inside the spinal canal; this is made by a combined anterior transcervical and posterior midline approach. The first step of the operation includes the transcervical approach during which resectability is assessed and all tumor-bearing area is freed in tumor-free margins as described above. Upon completion the patient is placed in a ventral position and a median vertical incision extending from the spinal processes from C7 to T4 is performed; after a unilateral laminectomy on three levels, the nerve roots are divided inside the spinal canal at the emergence of the external sheath covering the spinal cord. After cutting the vertebral bodies on the middle part, the specimen is resected en bloc with the lung, ribs and vessels through a posterior incision. The spinal fixation is made on the side of the tumor in the pedicle above and below the resection of hemivertebrae; contralaterally, a screw is placed in each pedicle. However, the presence of an anterior spinal artery penetrating into the spinal canal through one of the invaded intervertebral foramina contraindicates surgery.

Hemiclamshell or Trapdoor Incision

This incision includes a partial sternotomy prolonged into an anterior thoracotomy (Fig. 5) [15]. The patient is positioned supine, usually with the ipsilateral operative side elevated. An oblique incision is made along the lower third of the anterior border of the sternomastoid muscle to the midsternal notch. It is continued vertically in the midsternal plane to the third intercostal space, and then laterally as a slightly curved incision in the axillary line, eventually below the breast line. The incision is carried deeper with cautery and after a standard partial (up to the third interspace) median sternotomy, the internal mammary vessels are divided and the lateral half of the sternum is transected transversely to meet the sternotomy incision. A rib-spreading retractor or sternal hook is then placed, elevating the chest wall superolaterally; this allows exposure of the upper half of the superior mediastinum and apex of the thoracic

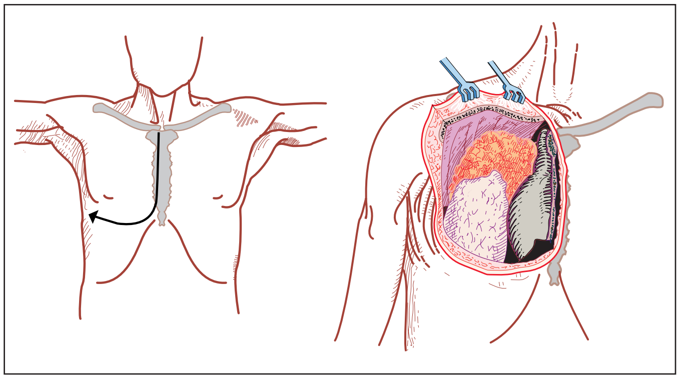

Figure 5. Hemiclamshell incision, made with the patient lying supine. *(Adapted from:* Bains MS, Ginsberg RJ, Jones WG et al.) *The clamshell incision: an improved approach to bilateral pulmonary and mediastinal tumors [15].*

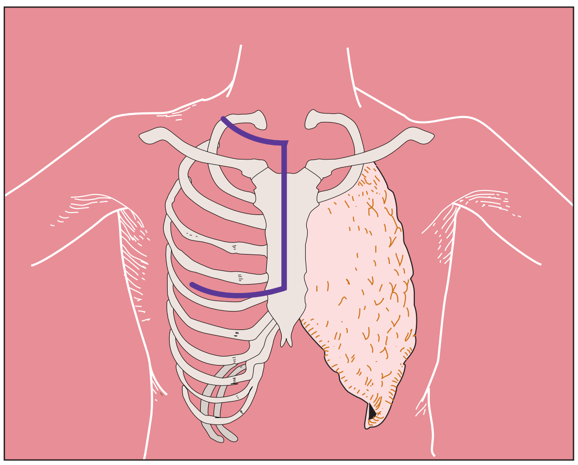

Figure 6. This approach includes a proximal median sternotomy (1) extending to the fourth anterior intercostal space below (2) and the base of the invaded neck above (3) transverse collar incision. *(Adapted from:* Mosoaka A, Ito Y, Yasumitsu T.*) Anterior approach for tumors of the superior sulcus [16].*

cavity. The superior vena cava and ipsilateral innominate vein in the superior mediastinum are then dissected until the subclavian vein is found. After having assessed the resectability, the clavicle can be removed for better exposure of the subclavian vessels and brachial plexus. The involved ribs are divided at the costochondral or costosternal junctions and the appropriate intercostal space below and the visible tumor is entered. The posterolateral aspects of the involved ribs are then divided and the specimen released within the chest cavity, remaining attached to the apical fascia. The dissection and management of the subclavian vein and artery and brachial plexus are then made as outlined by the transclavicular approach. The operation is completed by a standard closure of the incision after the chest tube has been inserted.

Masoaka Incision

This includes a proximal median sternotomy below with an incision in the anterior fourth intercostal space and above with a transverse cervical incision at the base of the neck (Fig. 6) [16]. The management of this region is thereafter made as in the previously described approaches.

Surgical Morbidity and Mortality

Surgical complications include: A) *Spinal fluid leakage*. The risks of air embolism into the subarachnoid space, ventricles and central canal of the brain and spinal cord justify reoperation for which even a cerebral ventricular-venous derivation may be required; B) *Horner's syndrome and nerve deficits*. While division of the T1 nerve root does not induce significant muscle palsy in the nerve territory, resection of the lower trunk of the brachial plexus may result in an atrophic paralysis of the forearm and small muscles of the hand with paralysis of the cervical sympathetic system (Klumpke-Déjérine syndrome). This should be discussed with the patient preoperatively; relief of the preoperative pain and cure are, however, worth the nerve sacrifice and adaptation is usually reasonable; C) *Hemothorax*. Results from extensive pleural adhesion, chest wall resection or blood spillage from veins around the intervertebral foramina; D) *Chylothorax*. This complication should be first prevented intraoperatively by detailed and extensive ligation of the cervical and intrathoracic lymphatic vessels. Whenever occurring, continued chest tube drainage, lung expansion or reoperation may be necessary, and E) *Prolonged ventilatory support*. Because of the chest wall dyskinesia and phrenic nerve resection (or even simple dissection), patients having a combined transcervical and midline approach are more likely to develop postoperative atelectasis and perfusion and ventilation mismatch, and are unable to breath spontaneously in the early postoperative course.

The postoperative course is usually characterized by atelectasis because of the concomitant extended chest wall resection and phrenic nerve resection. As such, measures to achieve complete lung expansion should be taken to ensure: A) adequate ventilation using mechanical support, if necessary; B) satisfactory chest tube function; C) clear secretion by mobilizing, coughing, chest physiotherapy, nasotracheal or orotracheal or bronchoscopic suctioning, or a temporary tracheostomy; D) adequate analgesia, and E) increased transpulmonary pressure with incentive spirometry or continuous positive airway pressure mask. Fluid overload should be avoided and diuretics used judiciously to avoid acute respiratory distress. Chest tubes remain in place until all air leaks have stopped, there is complete lung expansion and almost no fluid drainage. Incomplete lung expansion

Table 2. Results of patients treated surgically for superior sulcus tumors

Author (year)	No. of Cases	Five-year survival (%)	Mortality (%)
Paulson DL (1985)	79	35	3
Anderson et al. (1986)	28	34	7
Devine et al. (1986)	40	10	8
Miller et al. (1987)	36	31	NS
Shahian et al. (1987)	18	56	0
McKneally et al. (1987)	25	51	NS
Komaki et al. (1990)	25	40	NS
Sartori et al. (1992)	42	25	2.3
Maggi et al. (1994)	60	17.4	5
Ginsberg et al. (1994)	100	26	4
Okubo et al. (1995)	18	38.5	5.6
Hagan et al. (1999)	34	33	0
Dartevelle P (1999)	70	34	0

NS = not stated; Values are number ± standard deviation. Adapted from *Macchiarini* and *Dartevelle* [20].

with persistent intrapleural air space should be ignored since ultimately it will be filled with serous fluid.

Resection of the subclavian vein should be accompanied by elevation of the ipsilateral forearm to facilitate the venous drainage and generation of a collateral venous pathway within one to two months. One should closely follow the radial pulse to control the patency of the revascularized subclavian artery; after a preoperative loading dose of intravenous heparin, anticoagulant treatment should be switched to oral doses for a six-month postoperative period only.

Results and Prognosis

The overall five-year survival rates after combined radiosurgical (posterior approach) treatment for bronchogenic superior sulcus tumors range from 18% to 56% (Table 2), the best prognosis belonging to those patients without nodal involvement, T4 stage [11, 17] or Horner's syndrome and having had a complete resection [1, 5, 11, 17].

Despite the improvement in survival of patients with superior sulcus tumor treated with the combined preoperative radiation and operation, there is still a high incidence of local recurrence, between 25% and 70%. *Ginsberg* and associates [5] studied 69 patients with complete resections and with negative margins after preoperative irradiation. The first sign of recurrence was locoregional in two-thirds of the cases, and the incidence of distant metastases was between 40% and 80%. Similarly, *Hagan et al*. [17] studied 34 patients receiving combined resection and irradiation, and distant metastasis eventually developed in 56% of patients.

Table 3. Factors influencing survival and disease-free survival in completely resected patients whose superior sulcus tumors invaded the thoracic inlet and were surgically resected through the anterior approach

Adverse prognostic factors:
- Female gender
- Positive bronchoscopy
- Abnormal serum carcinoembryonic antigen
- Full-blown Pancoast-Tobias syndrome
- Positive lymph nodes (N1-3)

Factors without prognostic influence:
- Side and site of the tumor
- Type of surgery (wedge versus lobectomy)
- Subclavian vessel invasion (absent versus present)
- Invasion of the intervertebral foramen

By multivariate analysis, only the nodal status was able to adversely affect disease-free survival. Adapted from *Macchiarini* and *Dartevelle* [20].

Over the last 20 years, we operated on 70 patients (mean age, 53 ± 12 years) presenting with malignant bronchogenic apical lesions through the anterior cervical approach. The majority of the lesions were of nonsquamous histology (*n* = 51), right-sided (*n* = 41), and extending to the anterior (*n* = 23), middle (*n* = 5) or posterior (*n* = 42) compartments of the thoracic inlet. All tumors were completely resected through the anterior approach, either alone (*n* = 33) or with (*n* = 37) an additional posterior approach (early on in our experience). Forty-seven lobectomies, 21 wedge resections and two pneumonectomies were made. The majority (*n* = 55) of the patients were without pathological diseased lymph nodes while five, seven, and three patients respectively had N1, N2 or N3 disease. The 28 invaded subclavian arteries were revascularized 16 times by a synthetic graft and 12 by an end-to-end anastomosis; nine vertebral arteries were also invaded and resected. The T1 nerve root was invaded either alone (*n* = 25) or along with the phrenic nerve (*n* = 21). The first rib was invaded and resected in all patients either alone (*n* = 8) or with the second (*n* = 29), third (*n* = 17), fourth (*n* = 15), and fifth (*n* = 1) ribs. There were no hospital deaths. The overall five and 10-year survivals were 35% and 20%, respectively, and the only predictor of long-term disease-free survival was the presence of N2 disease (Table 3). The two-year survival for 13 patients having a hemivertebrectomy was 59%.

Conclusions

Although it is now established that radical surgery represents the only hope for long-term survival and cure, optimal management for superior sulcus tumors continues to be a major challenge. Recent diagnostic advances have made it possible to establish the diagnosis early on, usually before the full-blown Pancoast-Tobias syndrome occurs. Yet the time elapsed between the onset of the Pancoast-Tobias syndrome and diagnosis is still around six months. Moreover, it is discouraging to observe that in clinical practice there still is a substantial percentage of patients who continue to be treated exclusively with radiation, chemotherapy or a combination of both once the diagnosis has been established, or in whom the definitive diagnosis is proved when the disease is beyond surgical curability. In these circumstances, intraoperative brachytherapy or palliative resections are ineffectual [5].

As to whether surgery should proceed or follow radiation therapy in newly diagnosed superior sulcus tumors, our opinion is to first resect, because dissecting on a previously (chemo)irradiated thoracic inlet unquestionably increases the technical difficulties and postoperative morbidity. Radiation therapy is warranted in the postoperative course since total doses of 60 Gy can then be safely delivered.

Absolute surgical contraindications in the management of superior sulcus tumors are the presence of extra-thoracic sites of metastasis, histologically confirmed N2 disease, extensive invasion of the cervical trachea, esophagus and the brachial plexus above the C7 nerve root; this because it indicates that the tumor is locally too extensive to achieve a complete resection or that limb amputation is necessary. Invasion of the subclavian vessels should no longer be considered a surgical contraindication. Massive vertebral invasion, diagnosed preoperatively, is synonymous with unresectability. Invasions limited to the intervertebral foramen without extension into the spinal canal may be resectable, but our early results await long-term confirmation.

Despite all technical and survival improvements, distant metastasis represents the most common first failure and cause of deaths in Pancoast patients, regardless of whether there are operable or unoperable patients [11]. Given the improved results obtained with chemotherapy in several [18, 19] randomized phase III trials in patients without Pancoast tumors with stage IIIA or IIIB disease, it may be logical to propose such therapy to patients with Pancoast tumor. Such a trial is actually under investigation by the Southwest Oncology Group 9416 with an intergroup phase II trial for superior sulcus tumor with concurrent chemoradiation as induction therapy.

References

1 Arcasoy SM, Jett JR. Superior pulmonary sulcus tumors and Pancoast's syndrome. N Engl J Med 1997;1370:337-343.

2 Pancoast HK. Importance of careful roentgen-ray investigations of apical chest tumors. JAMA 1924;83:1407-1411.

3 Tobias JW. Sindrome apico-costo-vertebral-doloroso por tumor apexiano: su valor diagnostico en el cancer primitivo del pulmon. Rev Med Lat Am 1932;19:1552-1556.

4 Macchiarini P, Chapelier A, Monnet I et al. Technique for resecting primary or metastatic non-bronchogenic tumors of the thoracic outlet. Ann Thorac Surg 1994;57:966-973.

5 Ginsberg RJ, Martini N, Zaman M et al. Influence of surgical resection and brachytherapy in the management of superior sulcus tumor. Ann Thorac Surg 1994;57:1440-1444.

6 Chardak WM, MacCallum JD. Pancoast syndrome due to bronchiogenic carcinoma: successful surgical removal and postoperative irradiation: a case report. J Thorac Surg 1956;31:535-542.

7 Shaw RR, Paulson DL, Kee JLJ. Treatment of the superior sulcus tumor by irradiation followed by resection. Ann Surg 1961;154:29-36.

8 Wright CD, Moncure AC, Shepard JA et al. Superior sulcus lung tumors. Results of combined treatment. J Thorac Cardiovasc Surg 1987;94:69-74.

9 Shahian D, Neptune W, Ellis F Jr. Pancoast tumors: improved survival with preoperative and postoperative radiotherapy. Ann Thorac Surg 1987;43:32-38.

10 Hilaris BS, Martini N, Wong GY et al. Treatment of superior sulcus tumor (Pancoast tumor). Surg Clin North Am 1987;67:965-977.

11 Hagan MP, Choi NC, Mathisen DJ et al. Superior sulcus tumors: impact of local control on survival. J Thorac Cardiovasc Surg 1999;117:1086-1094.

12 Tatsamura T, Sato H, Mori A et al. A new surgical approach to apical segment lung diseases, including carcinomas and inflammatory diseases. J Thorac Cardiovasc Surg 1994;107:32-33.

13 Dartevelle P, Chapelier A, Macchiarini P et al. Anterior transcervical-thoracic approach for radical resection of lung tumors invading the thoracic inlet. J Thorac Cardiovasc Surg 1993;105:1025-1034.

14 Dartevelle P. Extended operation for lung cancer. Ann Thorac Surg 1997;63:12-19.

15 Bains MS, Ginsberg RJ, Jones WG et al. The clamshell incision: an improved approach to bilateral pulmonary and mediastinal tumors. Ann Thorac Surg 1994;58:30-33.

16 Masoaka A, Ito Y, Yasumitsu T. Anterior approach for tumors of the superior sulcus. J Thorac Cardiovasc Surg 1979;78:413-415.

17 Attar S, Krasna MJ, Sonett JR et al. Superior sulcus (Pancoast) tumor: experience with 105 patients. Ann Thorac Surg 1998;66:193-198.

18 Rusch V, Albain K, Crowley J et al. Surgical resection of stage III A and stage III B non-small cell lung cancer after concurrent indication chemoradiotherapy. A Southwest Oncology Group trial. J Thorac Cardiovasc Surg 1993;105:97-106.

19 Rosell R, Gomez-Codina J, Camps C et al. A randomized trial comparing preoperative chemotherapy plus surgery with surgery alone in patients with non-small cell lung cancer. N Engl J Med 1994;330:153-158.

20 Macchiarini P, Dartevelle P. Extended resections for lung cancer. In: Roth JA, Hong WK, Cox JD, eds. Lung Cancer (2nd Ed). Cambridge, MA: Blackwell Scientific Publications, Inc., 1998;135-162.