

# Superior sulcus tumors (Pancoast tumors)

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**Abstract:** Superior Sulcus Tumors, frequently termed as Pancoast tumors, are a wide range of tumors invading the apical chest wall. Due to its localization in the apex of the lung, with the potential invasion of the lower part of the brachial plexus, first ribs, vertebrae, subclavian vessels or stellate ganglion, the superior sulcus tumors cause characteristic symptoms, like arm or shoulder pain or Horner's syndrome. The management of superior sulcus tumors has dramatically evolved over the past 50 years. Originally deemed universally fatal, in 1956, Shaw and Paulson introduced a new treatment paradigm with combined radiotherapy and surgery ensuring 5-year survival of approximately 30%. During the 1990s, following the need to improve systemic as well as local control, a trimodality approach including induction concurrent chemoradiotherapy followed by surgical resection was introduced, reaching 5-year survival rates up to 44% and becoming the standard of care. Many efforts have been persecuted, also, to obtain higher complete resection rates using appropriate surgical approaches and involving multidisciplinary team including spine surgeon or vascular surgeon. Other potential treatment options are under consideration like prophylactic cranial irradiation or the addition of other chemotherapy agents or biologic agents to the trimodality approach.

**Keywords:** Chest wall resection; multidisciplinary treatment; Pancoast tumor; superior sulcus tumor

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## Introduction

The term Pancoast or superior sulcus tumor defines a wide range of tumors invading the apical chest wall and producing a characteristic syndrome named "Pancoast-Tobias syndrome". The Pancoast-Tobias syndrome involves severe and unrelenting shoulder and arm pain along with the distribution of the eighth cervical and first and second thoracic nerve trunks, Horner's syndrome (ptosis, miosis, and anhidrosis), and atrophy of the intrinsic hand muscles. The unique characteristic of Pancoast tumors lies in the anatomy of the region where these tumors occur. For this reason, the surgical approach to these tumors is technically demanding and a complete resection may be difficult to accomplish. The treatment of Pancoast tumors has evolved greatly during the years: initially thought to be inoperable,

the first case of surgical removal was reported in 1956 by Chardack and MacCallum (1). Since then, various authors published cases of successful surgical resection in association with radiotherapy. This has made the radio-surgical approach the treatment of choice for many years. In 1990s, induction chemo-radiotherapy followed by radical surgical resection was introduced as a new standard treatment for superior sulcus tumors. The treatment brought in impressively improved outcomes, and it still represents the gold standard today.

## Historical background and definitions

In 1838, Hare (2) described the first recorded case of "tumor involving certain nerves", producing constant and characteristic pain in the shoulder and the arm.

However, it was Henry K. Pancoast in 1924 (3), studying radiographic findings of several cases, who first described this clinical entity of “apical chest tumors”, characterized by “small homogeneous shadows at the extreme apex”, “more or less” rib destruction and often vertebral infiltration. These tumors were described as associated with a clinical syndrome of pain in the distribution of the eighth cervical, first and second thoracic nerve trunks and Horner’s syndrome. In 1932, Pancoast published a second report (4), in which he defined them as “superior pulmonary sulcus tumors” and stated that they probably arose from epithelial rest cells from the fifth brachial cleft. The first to propose a pulmonary origin for these tumors was Tobías (5), who better defined the anatomical and clinical aspects of this syndrome. The Pancoast-Tobías syndrome is characterized by one or more of the following symptoms (6):

- (I) Severe shoulder pain that aggravates over time. The pain may radiate to the neck, to the axilla, to the anterior chest wall, to the medial aspect of the arm and forearm as far as the wrist, along with the distribution of the ulnar nerve (C8–T1 nerve roots). The pain is provoked by the invasion of the chest wall and brachial plexus;
- (II) Claude-Bernard-Horner syndrome (ptosis, miosis, enophthalmos and anhidrosis of the ipsilateral side of face), related to invasion of the sympathetic chain and of the inferior cervical (stellate) ganglion;
- (III) Weakness and muscle atrophy of the intrinsic muscles of the hand, indicative of tumor infiltration of the ulnar nerve;
- (IV) Upper arm edema, in case of invasion and partial or complete occlusion of the subclavian vein.

A wide variety of diseases can cause Pancoast-Tobías syndrome: primary neoplasms of lung and pleura, metastases from other organs, hematologic malignancies, inflammatory and infectious diseases (7). The term Pancoast Tumor includes, however, only patients with a primary lung cancer in the typical location of the apex of the lung, regardless of whether any symptoms of the syndrome are present. The formal definition of Pancoast tumor, as provided by the American College of Chest Physicians (ACCP) (8), is: “*a lung cancer arising in the apex of the lung that involves structures of the apical chest wall. Invasion of apical chest wall structures is required at the level of the first rib or above, but it is not necessary to have Horner syndrome or pain radiating down the arm. These lesions frequently invade the brachial plexus, subclavian vessels, or spine.*”

## Etiology and biology

The vast majority of Pancoast tumors are bronchogenic carcinomas, with adenocarcinoma as the most frequent histologic type. Small-cell carcinoma is only rarely associated with this syndrome. Less than 5% of all bronchogenic carcinomas evolve into Pancoast tumors (9). Initially Pancoast tumors seemed to have different biology from that of other non-small cell lung cancers (NSCLC), with higher propensity for local invasion and diminished incidence of spread through lymphatic or haematogenous lines (10). However, as pointed out by Detterbeck (11), the rates of pathologic N2 involvement in resected patients are not any different from those of other clinically stage matched NSCLC, and survival rates are better when lobectomy is performed rather than wedge resection. Thus, “*the unique feature of Pancoast tumors appears not to lie in the tumor biology, but rather in the anatomy of the region in which these tumors occur*”.

## Anatomy

The precise anatomic definition of superior pulmonary sulcus is obscure, as most anatomy textbooks do not include it as a defined anatomic area. According to the description provided by Pancoast (4) the superior sulcus corresponds to the most cephalad extent of the costovertebral gutter. Other authors suggest the superior sulcus is formed by the subclavian artery as it crosses the pulmonary apex (12,13). Netter (14), proposed that the superior pulmonary sulcus actually “*does not correspond to any recognized anatomic location*” leading to the disuse of this term. The anatomy of the area affected by Pancoast tumors is rather based upon the description of the thoracic inlet and its subdivision into three compartments (15). The first rib forms the base of the thoracic inlet (*Figure 1*).

### *Anterior compartment (Figure 2A)*

It is delimited anteriorly by the sternum and posteriorly by the attachment of anterior scalene muscle on the first rib. It contains sternocleidomastoid and omohyoid muscles, subclavian and jugular veins, and scalene fat pad.

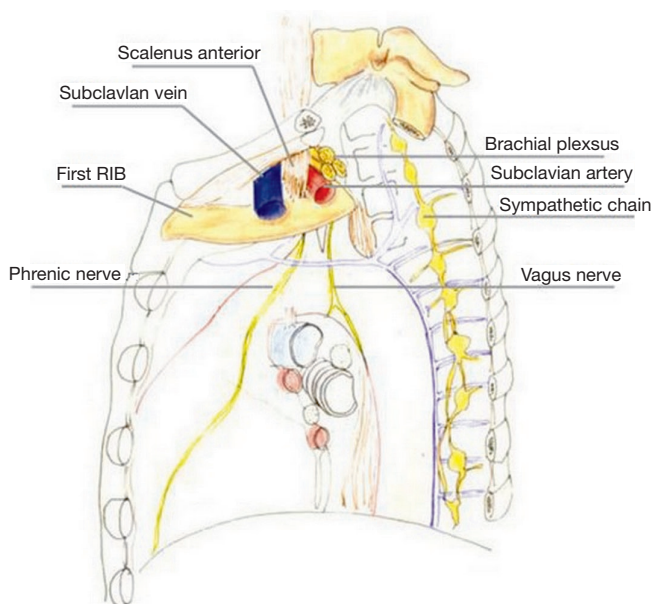
### *Middle compartment (Figure 2B)*

It is located between the anterior and middle scalene muscles; subclavian artery, phrenic nerve, and trunks of the

brachial plexus cross it.

### Posterior compartment (Figure 2C)

It lies behind the middle scalene muscle. It contains the posterior scalene muscle, posterior scapular artery, the stellate ganglion, sympathetic chain, long thoracic and accessory nerves, neural foramina, and vertebral bodies.

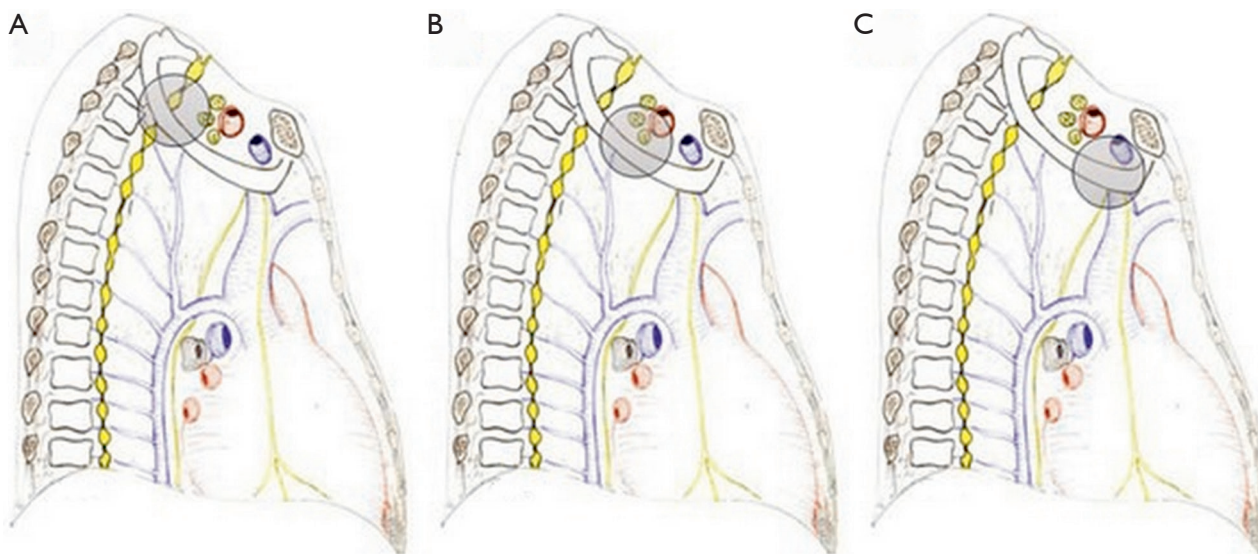


**Figure 1** Diagram of the thoracic inlet from a left lateral view.

The invasion of this complex anatomical area accounts for the classic symptoms of Pancoast tumors.

### Clinical presentation and diagnosis

Due to the fact that the thoracic inlet is a narrow compartment, a modest growth and direct extension of the tumor will produce the aforementioned symptoms. Cough, hemoptysis, and dyspnea are uncommon during the initial stages of the disease, due to the peripheral location of these tumors (9,11). (I) Shoulder pain is the most common initial symptom; this leads to consultation with multiple non-thoracic specialists. As the syndrome progresses, there may be (II) paresthesia and (III) weakness in the ulnar nerve distribution and intrinsic hand musculature. (V) Horner's syndrome is present in 15–50% of patients (9). Chest radiography (Figure 3) may show a mass or a pleural thickening in the apex of the lung, associated or not with invasion/destruction of the ribs and adjacent vertebrae. However, the tumor can easily be missed on chest X-rays. Computed tomography (CT) of the chest (Figure 4) will confirm the presence of an apical mass and its relationships with the bony thorax and with the other structures of the thoracic inlet. Magnetic resonance imaging (MRI) is recommended for better characterization of suspected brachial plexus, subclavian vessels, spine, and neural foramina invasion, because it can achieve a more precise assessment of the local extent of the disease and of the amount of nerve-root involvement (15). Given

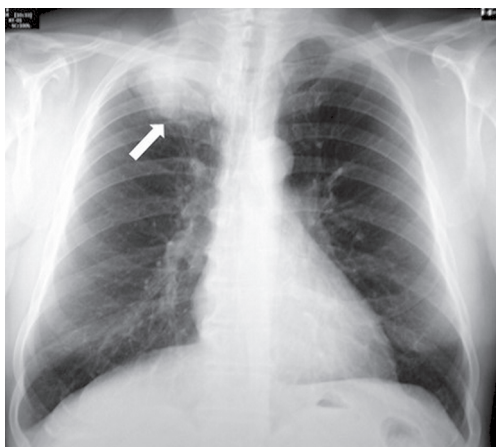


**Figure 2** The Pancoast tumor can invade the thoracic inlet in a posterior (A), middle (B) or anterior (C) site.

the peripheral location of the disease, the most sensitive procedure to obtain a tissue diagnosis is a percutaneous transthoracic needle biopsy, while biopsies obtained by fiberoptic bronchoscopy have a low diagnostic yield (9). When the above-mentioned methods are inconclusive, considering that a histological diagnosis is mandatory before starting any treatment, a video-assisted thoracoscopy or even minithoracotomy might be required (7).

### Staging

By definition Pancoast tumors are classified as T3 tumors when they invade only the chest wall and/or the sympathetic chain. Tumors that invade the brachial plexus, vertebral bodies, and vascular structures are classified as T4. According to their N status, the final stage is IIB if the tumor is T3N0, IIIA if T3N1–2 or T4N0–1 and

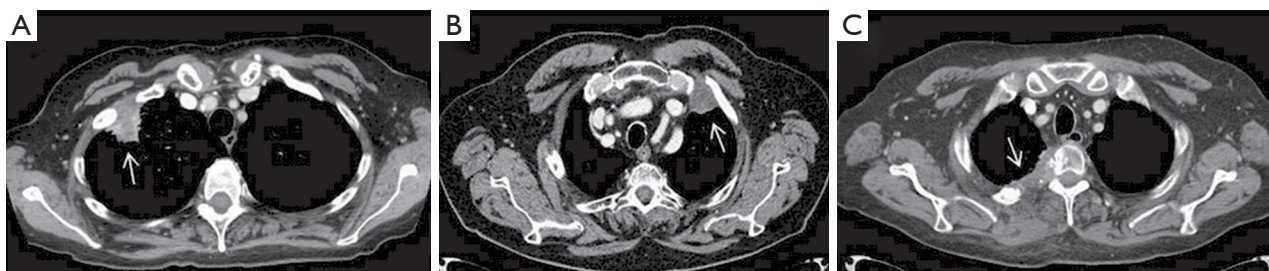


**Figure 3** Postero-anterior chest radiography of the chest of a patient with a right-sided superior sulcus tumor. The white arrow indicates the abnormal opacity in the apex of the right lung.

IIIB if T3N3 or T4N2–3 (16). A careful mediastinal staging is necessary as pN2 or pN3 involvement in Pancoast patients represents a particularly poor prognostic factor (17). Chest-CT and positron emission tomography-computed tomography (PET-CT) scans are mandatory before and after preoperative therapy, while no unequivocal recommendation can be made about whether mediastinoscopy or endobronchial ultrasound/esophageal ultrasound should be performed (8). Supraclavicular ipsilateral lymph nodes deserve a special mention because they seem to be involved in Pancoast tumors more frequently than in other NSCLC (17). It is a matter of debate whether positive lymph nodes at this level represent N3 metastatic spread or rather a direct involvement for local extension, given the contiguity of this area to the thoracic inlet. According to this hypothesis, supraclavicular lymph node involvement would result in a better prognosis than the presence of other mediastinal N2 or other N3 stations. Given the locally advanced extent of the disease, a careful search should be made for clinically silent distant metastases, especially in the brain (15). The ACCP (8) guidelines recommend to perform brain CT or MRI in association with either whole-body PET-CT or abdominal CT plus bone scan.

### Treatment and survival

The particular growth features of the Pancoast tumor have affected the treatment regimen since its disclosure. In the early years (1930s–1950s), Pancoast tumor was recognized as a singular clinical entity and considered inoperable and incurable. In 1932, Pancoast stated “... [*Superior sulcus tumor*] resisted all efforts at irradiation treatment, it is obviously not subject to surgical removal although it is accessible, and it is rather rapidly fatal” (4). In the following years, Walker (18) and Herbut and colleagues (19) reported their experience



**Figure 4** Computed Tomographic Images. Superior sulcus tumor located in the lateral (A), anterior (B), and posterior (C) part of the thoracic inlet (white arrows).

with irradiation in superior sulcus tumors, although their reports didn't show any substantial benefit, even in a palliative setting. The first reported cure of a superior sulcus tumor was attempted only in the fifties: Chardack and MacCallum (20) performed a surgical resection followed by postoperative radiation. The patient was alive and disease-free 5 years later. In 1956, Shaw (10) introduced a new treatment paradigm: he reported a case with typical Pancoast syndrome that initially underwent radiotherapy with a palliative intention, which resulted in resolution of pain and decrease in tumor size, and therefore it was followed by a radical resection. Since then, bimodality therapy (radiotherapy plus surgery, through postero-lateral approach) has become the standard of care. A large number of series (17,21-25) with this bimodality approach have been published, reporting similar survival (between 26% and 35% at 5 years) and complete resection rates ( $\pm 60\%$ ). These survival and resection rates remained poor and unchanged over the subsequent 40 years. Surgical resection continued to be limited only to tumors invading the ribs. Any involvement of vascular or neural structures was considered a contraindication to surgery (26). In the Eighties, novel surgical approaches were introduced for the resection of tumors involving the spine and subclavian vessels. Darteville *et al.* (23) developed an anterior transcervical approach for cancers infiltrating the anterior part of the inlet and the subclavian vessels. Subsequently, several modifications of this technique were reported (26-28). Radical surgery with acceptable local tumor control became a real possibility thanks to new surgical techniques such as laminectomy, partial or hemivertebrectomy, complete resection of vertebral body, and vascular by-pass, as well as the common practice of working in a multidisciplinary team (thoracic surgeon, neurosurgeon, orthopedic surgeon, vascular surgeon) (24,29-33). During the 1990s, the increasing experience with combined modality therapy suggested that induction chemo-radiotherapy followed by resection could become an effective treatment strategy for stage III NSCLC (34). These new findings, associated with the need to improve systemic as well as local control, acted as a base for the development of two trials for Pancoast tumor treatment: the Southwest Oncology Group (SWOG 9416) prospective, multi-institutional, phase II trial (35) and the Japan Clinical Oncology group (JCO 9806) phase II trial (36). In both studies, improvements in completeness of resection and pathological response rates to chemo-radiotherapy were reported. Even long-term (5-year) survival rates resulted improved reaching 44% (SWOG

9416) and 56% (JCO 9806), respectively. Based on these data, the modern standard treatment for sulcus superior tumors has become the combination of induction CT/RT followed by radical surgical resection (25,29,35-43) (Table 1).

### Surgical approaches

The complex anatomy of the thoracic inlet led to the development of various surgical approaches to properly expose the tumor and the involved structures.

#### *High postero-lateral approach (Figure 5)*

This was the first surgical approach described by Shaw and Paulson (10). The incision extends around the tip of the scapula and reaches midway between the posterior edge of the scapula and the spinous processes, up to the level of C7. Posterior thoracotomy allows a wide exposure of the posterior chest wall, transverse processes, vertebrae and roots of the thoracic nerves and the plexus.

#### *Anterior transcervical-thoracic approach*

This approach was described and popularized by Darteville *et al.* (23). The incision runs along the anterior border of the sternocleidomastoid muscle and continues laterally above the clavicle, the medial portion of the clavicle has to be excised. This anterior approach allows an excellent exposure of the entire thoracic inlet and particularly of the subclavian vessels and brachial plexus. Transection of the clavicle, however, causes postoperative alterations in the shoulder anatomy, mobility and cervical posture (44).

Transmanubrial L-shaped approach (Figure 6). Grunewald and colleagues (27) developed this technique to overcome the superior girdle instability due to the clavicle transection in the Darteville approach. The transclavicular incision evolved into a transmanubrial incision preserving the integrity of the clavicle and its muscular insertions and raising both as an osteomuscular flap.

#### *Anterior trans-sternal approach*

Introduced in 1979 by Masaoka (45), it consists of an upper median sternotomy with an extension into the anterior fourth intercostal space, and a transverse incision above the clavicle at the base of the neck. It provides excellent exposure of the anterior upper chest wall, particularly when the tumor involves subclavian artery, brachial plexus or the

**Table 1** Recent studies on the use of induction chemoradiation followed by surgery in Pancoast tumors

First author	No. of patients [operated patients]	cTNM [%]	CT/RT (Gy)	Surgery [%]	R0 (%)	PCR (%)	Operative mortality (%)	Morbidity (%)	Recurrence [%]	5-year survival (%)
Wright, 2002 (25)	15	T4 [47], N+ [0]	PFV, PE: 51 [40-66]	Lob [87]	93	67	NS	NS	Total [15], local [0], distant [100]	93 (2-year), 84 (4-year)
Kwong, 2005 (41)	37	T4 [13], N+ [27]	P, PE, PV, C: 56.9 [30-70.2]	Lob [92], Pne [8]	97	40	2.7	27	Total [50], brain [50], local [28], distant [22]	50
Rusch, 2007 (35)	110 [88]	T4 [29], N+ NS	PE: 45	Lob [81], Pne [3], Wed [16]	94	36	2.3	52	Total [52], brain [33], local [18], distant [49]	44
Marra, 2007 (39)	31 [29]	T4 [19], N+ [32]	PE, CP: 45	Lob [76], Wed [21], Pne [3]	100	45	6.9	21	Total [29], brain [45], local [11], distant [45]	46
Pourel, 2008 (40)	107 [72]	T4 [29], N+ [74]	PE: 45	Lob [70], Pne [29], Expl [1]	90	39†	3.0	47	Total [52], local [19], distant [81]	55 (2-year), 40 (3-year)
Fischer, 2008 (37)	44	T4 [32], N+ [11]	PE: 45	Lob [90], Pne [29], other [5]	89	30	0	45	Total [36], local [31], distant [69]	59
Kunitoh, 2008 (36)	76 [57]	T4 [26], N+ [22]	MVP: 45	Lob [93], Wed [5], Expl [2]	89	21	3.0	14	Total [51], local [26], brain [13], other [61]	56
Kappers, 2009 (43)	22	NS	P: 66	Lob [100]	100	62	0	41	Total [45], distant [100]	37
Li, 2010 (38)	22	T4 [18], N+ [45]	PE: 45	Lob [73], Pne [27]	91	45	0	18	Total [59], local [23], distant [77]	36
Favaretto, 2010 (42)	38 [34]	T4 [32], N+ [23]	MVC, NC: 30-44	Lob [88], Wed [12]	74	15	6.0	29	Total [47], local [33], distant [67]	40
Marulli, 2015 (29)	56	T4 [43], N+ [16]	MVC, NC: 30-44	Lob [75], Seg [23], Wed [2]	86	18	5.4	11	Total [59], local [23], distant [77]	38

†, PCR + microscopic residual foci. Lob, lobectomy; Pne, pneumonectomy; Seg, anatomical segmentectomy; Wed, wedge resection; PFV, cisplatin fluorouracil vinblastine; PE, cisplatin etoposide; CP, carboplatin paclitaxel; PV, cisplatin vinorelbine; C, carboplatin; MVP, mitomycin vindesine cisplatin; P, cisplatin; MVC, carboplatin mitomycin vinblastine; NC, carboplatin navelbine; NS, not stated; CPR, complete pathological response; PCR, pathological complete response; cTNM, clinical TNM.

superior vena cava.

### **Hemiclambell or trapdoor approach (28)**

This incision includes a partial sternotomy prolonged into an anterior thoracotomy usually in the fourth intercostal space. It allows the exposure of the same structures as in the Masaoka approach.

In the event of a complex superior sulcus tumor with the involvement of anterior and posterior inlet structures, a combination of the two surgical accesses could be used (i.e., anterior approach and thoracotomy). A double incision could allow a radical tumor resection but may increase the complication rate concerning wound healing and respiratory failure.

### **Videoscopic assistance**

Although the anterior transmanubrial approach provides good exposure of the apical structures, an upper lobe



**Figure 5** High postero-lateral approach (Shaw-Paulson's thoracotomy).

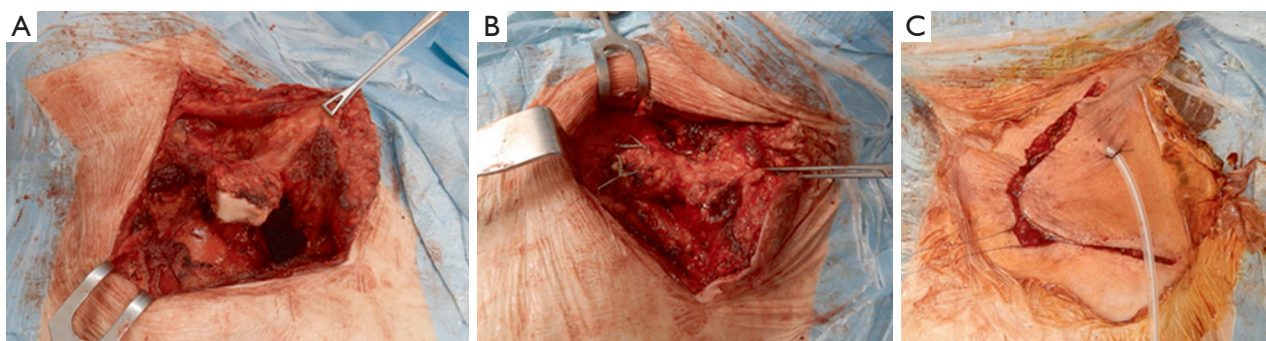
lobectomy with hilar and mediastinal lymph node dissection may be difficult without a wide incision or an additional thoracotomy. Therefore, some authors propose to combine the anterior transmanubrial approach with video-assisted thoracic surgery (VATS) lobectomy (46-48). The VATS use may support the surgical procedure and improve surgical outcome (49) providing:

- (I) Good overview of the superior sulcus area;
- (II) Aid to confirm or change the surgical strategy intraoperatively;
- (III) Aid to determine the appropriate chest wall resection level, avoiding the resection of extra ribs;
- (IV) Possibility to complete lobectomy and lymph node dissection avoiding a second incision;
- (V) Less post-surgical pain due to less rib injury, less inter-costal nerve injury, less rib spreading, less length of skin incision and preservation of latissimus dorsi;
- (VI) Prompter recovery of pulmonary function;
- (VII) Reduction in opioid and analgesic consumption.

### **Limits to resectability**

Pancoast tumor unresectability criteria remained unchanged for a long time (6,9,11,15,50,51), in recent years, however, some restrictions have been revised and absolute and relative contraindications to surgery have begun to change (Table 2).

Concerning lymph node involvement, there is no agreement about N2 disease and surgical treatment. Some authors (25,35) excluded all N2 disease patients from surgical treatment. Others, like Kwong and colleagues (41), accepted well-defined mediastinal lymph nodes disease and subdued those patients to surgery only in case of chemotherapy response. No difference in survival between N2 and



**Figure 6** Transmanubrial L-shaped approach (Grunenwald's incision). Intraoperative views of the transmanubrial incision (A) and manubrial suture with steel stitches (B). Final view of the skin incision (C).

**Table 2** Absolute and relative contraindications to surgery in Pancoast tumors

Absolute contraindications to surgery	
Distant metastases	
N2 (mediastinal) or N3 (contralateral supraclavicular) nodal disease	
>50% vertebral body involvement	
Brachial plexus involvement above T1 nerve	
Invasion of esophagus/trachea	
Relative contraindications to surgery	
N1 or N3 (ipsilateral supraclavicular) nodal disease	
Invasion of the subclavian artery	
<50% vertebral body involvement	
Intraforaminal extension	
Invasion of common carotid or vertebral artery	

N0/N1 tumor involvement was found. In most papers (17,21,39,52-55), however, N+ disease is considered as a negative prognostic factor in terms of overall and disease-free survival. As previously stated, ipsilateral supraclavicular lymph node disease (N3 disease) is a peculiar finding and its biological behavior could be equalized to local nodes due to the anatomy of the region where Pancoast tumor occurs.

Vertebral body involvement greater than 50% was historically considered an absolute contraindication to surgery and a relative contraindication with an involvement lower than 50%. This limitation was caused by the lack of proper surgical techniques to achieve a radical resection and no multimodality treatment. At present, surgical procedures such as laminectomy, partial or hemivertebrectomy or complete resection of vertebral body can be performed in the context of a triple modality therapy, with high rates of complete surgical resection, good long-term survival, and acceptable morbidity and mortality (24,32,33,56,57) (*Figure 7*). The careful selection of patients and of specialized centers with interdisciplinary teams of thoracic and spine surgeons is indispensable.

Vascular involvement, thanks to new surgical techniques and to the current multimodality therapy, is no longer a contraindication to resection. The subclavian vein can be resected with ligation of the vessel. The involved part of a subclavian artery can be resected and reconstructed (11,15,58) (*Figure 8*). Even the invasion of the common

carotid and vertebral arteries are no longer considered absolute contraindications to surgery even if the resectability is strictly dependent on patient's vessel state in term of atherosclerotic changes and patency of the contralateral vessels (11,51).

## Complications

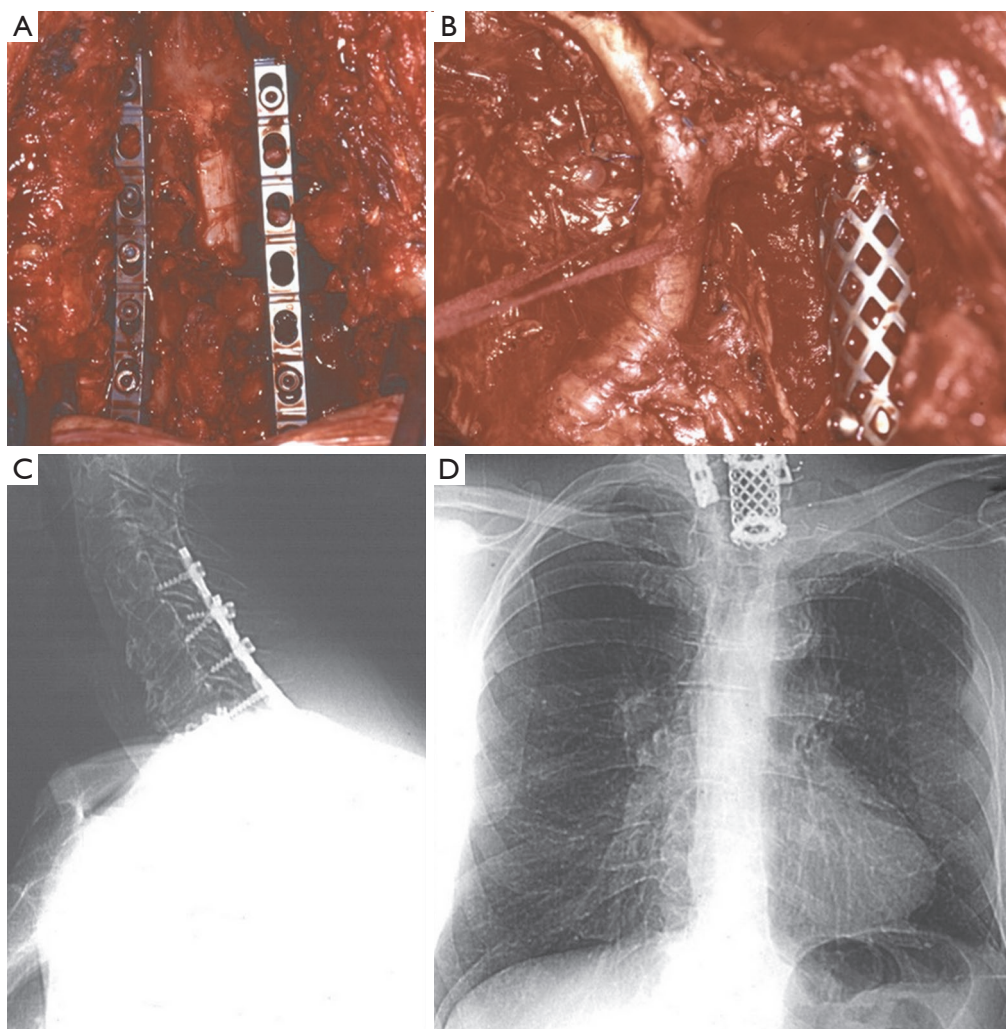
Heterogeneous mortality and morbidity rates are available in operative series of Pancoast tumors undergoing multimodality treatment. Operative mortality rate ranges from 0% to 6.9% and morbidity from 11% to 47% (25,29,35-43). In particular, the SWOG 9416 (35) and JCO 9806 (36) phase II trials showed operative mortality rates of 2.3% and 3% and morbidity rates of 52% and 14%, respectively.

### *Surgical complications*

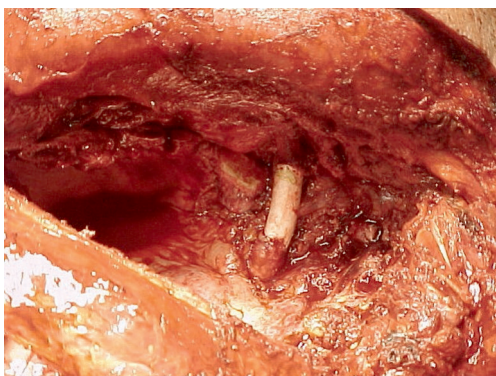
#### **Thoracic complications**

(I) Prolonged air leakage, (II) wound infection, and (III) wound dehiscence are frequent surgical complications. (IV) Bronchopleural fistula (BPF) is a challenging condition, mostly in patients receiving high dose radiotherapy. Development of sophisticated and precise (3D radiation) radiotherapy techniques and of surgical technical skills (avoiding skeletonization and devascularization of bronchial stumps and coverage with a vascularized flap) may contribute to minimize BPF incidence rate. (V) Air embolism into the subarachnoid space caused by spinal fluid leakage is a rare occurrence. (VI) Chest wall resection or pleural adhesion could results in hemothorax or (VII) bleeding. Several pulmonary complications are caused by incomplete lung expansion (VIII) lung atelectasis due to the accumulation of pulmonary secretions may evolve in (IX) pneumonia complicated or not by (X) empyema. Chest wall dyskinesia, phrenic nerve dissection, pain, air leak and ineffective drainage may also lead to incomplete lung expansion and evolve in (XI) respiratory failure associated or not with (XII) acute respiratory distress syndrome. A number of measures should be taken to achieve a complete lung expansion: adequate ventilation using mechanical support if needed, appropriate analgesia, targeted physiotherapy, secretions suction by bronchoscopy or through temporary tracheostomy. (XIII) Aesthetic or functional discomfort of the osteo-muscular compartment may occur, because of the superior girdle instability, using the transcervical anterior surgical approach. Chest wall





**Figure 7** Patient with a left-sided superior sulcus tumor with T1–T2 involvement. The patient underwent T1–T2 laminectomy, T1–T2 vertebrectomy. Intraoperative views of the posterior fixation with two mass plates and screws (A) and vertebral reconstruction with metal prosthesis (B). Lateral (C) and anteroposterior (D) radiographs of the same patient 1 month after operation.



**Figure 8** Intraoperative view of a polytetrafluoroethylene (PTFE) graft replacing a subclavian vein.

deformities and scapula entrapment can occur using the postero-lateral approach.

#### Vascular complications

(I) Intraoperative tear or injury of the subclavian artery may lead to complex surgery to correct it; (II) subclavian vein thrombosis due to radiotherapy and surgical resection is a frequent condition; (III) ipsilateral forearm edema is associated with the division of the subclavian vein without revascularization, elevation of the arm to facilitate the venous drainage must be encouraged. Rarely (IV) chylothorax can occur caused by tumors invasion or unaware surgical damn.

### Neurological complications

(I) Intrinsic hand muscle weakness (Klumpke-Déjérine syndrome) can be caused by C8 root division; while the division of T1 root affects the neural system less significantly. (II) Horner's syndrome (miosis, ptosis, and enophthalmos) may be also caused by high dorsal root sympathectomy.

### Chemo-radiotherapy complications

Chemo-radiotherapy could be associated with (I) pneumonitis; (II) peripheral neurologic dysfunctions; (III) esophagitis; (IV) infection and (V) symptomatic debilitation; (VI) hematologic toxicity and (VII) stomatitis are common chemotherapy complications.

### Prognostic factors and relapses

Defining the prognostic factors of overall and disease-free survival for superior sulcus tumors is a challenging topic. Many authors have tried to identify them and a various number of tumor characteristics seems to be involved. After reviewing the body of literature, (I) complete resection and (II) complete pathological response to therapy turned out to be positive prognostic factors in various series (17,29,35-38,40,52,55,59-62); (III) T status has been recognized as a poor prognostic factor (11,17,21,29,36,52-55,59). In particular brachial plexus invasion (59), vertebral body (11,52,53) and great vessels involvements (11,53) are correlated to an higher risk of tumor recurrence. The presence of Horner syndrome at the diagnosis of Pancoast tumor is, equally, a poor prognostic factor (17,54) implying extensive neural involvement; (IV) positive lymph node status, as in NSCLC tumor, is also a significantly poor prognostic factor in Pancoast tumor (17,21,39,52-55). In the revised series of Alifano and colleagues (60), the presence of (V) associated major illness and the completeness of resection are the two most important factors affecting the long-term outcome. Sartori and coworkers (21) found the (VI) decrease of arm pain, after irradiation, as good prognostic factor.

The relapse pattern has varied through the years, according to treatment changes. In patients treated with bimodality therapy local recurrences were 70% of all recorded relapses (43,63). The percentage reduced to less than 30% of all recurrences in patients treated with trimodality therapy (35-36,40). The decrease of local recurrence rate seems to be due to improved surgical

technique and appropriate staging. Currently, the pattern of failure has shifted to distant relapses (especially brain relapses) (40-41,44,50,64). This raises the question of prophylactic brain irradiation (PCI). There is no agreement on the possibility to perform PCI routinely on superior sulcus patients treated with trimodality therapy. Komaki and colleagues (65) reported 143 Pancoast tumor patients variously treated (radiotherapy alone, radiotherapy plus surgery and others). No statistical difference in brain metastasis rate were observed in PCI treated and non-PCI treated patients, although the PCI group was far less numerous than non-PCI group. Another study (39) analyzed 31 patients treated with chemotherapy and surgery for Pancoast tumor: of 13 patients subjected to PCI, one turned out to have brain metastasis, while 3 out of 13 non-PCI patients had the same relapse; the authors concluded that PCI seemed to offer adequate protection against brain metastases. In 2011 the RTOG 0214 trial (66) evaluated the efficacy of PCI in patients with advanced lung cancers (stage IIIA or IIIB) with a randomized study: they observed a decreased number of brain metastases in patients treated with PCI, without significant impact on survival (1-year follow-up). Taking into account the decreasing brain metastasis number trend, PCI can be considered in treatment protocols of further studies.

### Conclusions and new perspectives

Multidisciplinary approach is of paramount importance in the management of Pancoast tumors. This rare disease necessitates specialist knowledge for each different treatment proposed. Surgical treatment of T4 disease requires the participation of a multidisciplinary surgical team. The collaboration between thoracic, spine, and vascular surgeons may be needed to achieve complete resection in vertebral and vascular tumor involvement that are no longer a contraindication to resection. Surgery for extensive involvement of the brachial plexus is the new hurdle to overcome in T4 disease management. Nodal involvement represents another field of discussion. Is N2 disease still a surgical contraindication after chemo-radiotherapy downstaging? Could ipsilateral supraclavicular N3 disease be considered as N1 disease taking into account the peculiar anatomy in which these tumors grow? With regards to radiotherapy treatment, the advent of intensity-modulated radiation therapy (IMRT), allowing the radiation dose to conform more precisely to the three-dimensional shape of the chest, may allow a radiotherapy dose escalation.

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## Footnote

*Conflicts of Interest:* The authors have no conflicts of interest to declare.

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