SURGICAL CLINICS OF NORTH AMERICA

Surg Clin N Am 82 (2002) 541–559

Video-assisted thoracic surgery (VATS) resection for lung cancer

Scott J. Swanson, MD*, Hasan F. Batirel, MD

Division of Thoracic Surgery, Brigham and Women's Hospital, 75 Francis Street, Boston, MA 02115, USA

In 1910, Jacobaeus, in a procedure to lyse pleural adhesions, was the first to use a thoracoscope [1]. With the advent of selective bronchial intubation, use of thoracoscopy was expanded to pleural biopsies, drainage of pleural effusion, and pleurodesis. Improvement in videotechnology in the mid 1980s led to video-assisted thoracic surgery (VATS) for apical bullectomies, wedge resections, and mediastinal lymph node evaluation [2–4]. In 1993, the first experimental report of VATS lobectomy using a pig model came from Japan [5]. In the same year, initial reports of VATS lobectomy for lung cancer in humans were published by Kirby from the United States and Walker from the United Kingdom [6,7].

Background

Complete surgical resection is the only curative option in the treatment of lung cancer [8,9]. An anatomic resection, preferably lobectomy or pneumonectomy and in rare instances segmentectomy, is the standard treatment for stage I or II lung cancer [8,10]. Wedge resections are used for diagnosis, and in rare instances for local control of lung cancer.

Initially, VATS was used for diagnostic purposes. Currently, VATS is the technique of choice for many thoracic procedures and is controversial for anatomic lung resection [11–20]. VATS has the advantage of small incisions and the avoidance of rib spreading. Following standard thoracotomy for lung resection, postoperative morbidity and mortality are low [8,10]. However, post-thoracotomy pain, directly related to the size of the incision and spreading of the ribs, can lengthen hospital stay and prolong recuperation. Recent reports suggest an improvement in recovery when a VATS approach

* Corresponding author.
E-mail address: sjswanson@partners.org (S.J. Swanson).

PII: S0039-6109(02)00015-4

is used [21–26]. However, widespread use of VATS for lung cancer resection has raised oncologic concerns that include the adequacy of lymph node dissection.

Indications

Wedge resection

Wedge resection using VATS is not a standard oncologic operation for lung cancer. Wedge resections for lung nodules are most commonly performed to achieve a pathologic diagnosis that has not been reached with other methods [27,28]. The local recurrence rate has been reported to be three times greater following wedge resections and segmentectomies than following lobectomy [8]. If the wedge resection demonstrates a primary lung cancer, one should proceed with lobectomy.

However, in patients with severely limited lung function (forced expiratory volume in one second [FEV_1] less than 40%) or multiple risk factors, wedge resection may be the only surgical option to treat a small, peripheral lung cancer. Asamura et al showed that in tumors less than 2 cm in size and of squamous histology, lymph node metastasis was seen in 6.3% (1 of 16) [29]. All of the patients in their series underwent radical lymph node dissection. It is also known that intra- or peritumoral blood vessel invasion in small tumors is rare and relates to distant recurrence [30]. The results of a phase II study, Cancer and Leukemia Group B (CALGB) 9335 (on the feasibility of wedge resection and postoperative radiation therapy in high-risk patients) demonstrate that wedge resection is a safe approach for patients with T1 tumors [31]. Swanson et al reported a series of 40 patients with subcentimeter lung cancer who were treated with either wedge resection or lobectomy [32]. Five-year cancer-free survival was 90% with low local recurrence rates, demonstrating that in select cases, wedge resection can be justified if the patient's respiratory reserve does not allow an anatomic resection.

Anatomic resections

A VATS lobectomy should achieve the same result as a lobectomy performed through an open incision. Both open lobectomy and VATS lobectomy include complete removal of the tumor with individual ligation of lobar vessels and bronchus, as well as a hilar lymph node dissection or sampling. The indications for a VATS lobectomy for lung cancer are the same as for an open lobectomy, except that central hilar tumors may be difficult to resect using VATS [33–35].

Mediastinoscopy should be performed using the same indications regardless of the technique of lobectomy performed. If at the time of a diagnostic VATS wedge resection the lesion is found to be malignant, then ipsilateral mediastinal lymph node sampling should be carried out to rule out stage III disease before completing the lobectomy. General contraindications to a

VATS lobectomy are bulky mediastinal lymphadenopathy, endobronchial tumor presence, chest wall or mediastinal invasion, or use of neoadjuvant therapy [34,35].

A pneumonectomy may be performed using VATS, but the indications are unusual. An anatomic segmentectomy is not an operation that is easily adapted to a VATS approach.

Technique

Wedge resection

Three port sites are typically required to perform a VATS wedge resection. One port is used for the camera and is placed in the mid or anterior axillary line in the seventh intercostal space. The positions of the other ports are individualized according to the location of the lesion. As a basic principle, the ports should triangulate the lesion, with the camera port positioned inferiorly. Most commonly, the anterior port incision is placed lateral to the submammary line in the fourth intercostal space. For lower lobe lesions, the fifth intercostal space may be preferred. The posterior port is placed in the fifth or sixth intercostal space, posterior or inferior to the tip of the scapula, depending on the surgeon's preference. The anterior port generally permits placement of the stapler and the posterior post is used to retract and manipulate the lung.

The lesion is located by digital palpation and loosely grasped with a Babcock or ring forceps. With serial firings of endoscopic staplers, a triangular piece of lung tissue is cut. The specimen is than placed in an endoscopic bag and removed from the anterior port.

This technique can be used for peripherally located (outer half of the lung seen on chest computed tomography), small lesions (less than 3 cm) [16,33].

Lobectomy

There are three major types of VATS lobectomy described in the literature: video-assisted mini-thoracotomy (VAMT) [18,22], video-assisted simultaneously stapled lobectomy (VASSL) [11,14,36], and video-assisted non-rib spreading lobectomy (VNRSL) [6,7,33,35,37]. A true VATS lobectomy should include the individual ligation of lobar vessels and bronchus, and avoid rib spreading [6,7,33,38]. Lymph nodes should be removed in the same manner as with an open technique.

Video-assisted minithoracotomy (VAMT)

VAMT is probably the most widespread applied technique for performing a VATS lobectomy [18,22,39]. Standard camera and port incisions are made. The anterior or posterior port incision is enlarged to 6 to 8 cm. After the subcutaneous tissues and muscle are divided, the chest is entered. Preference of the surgeon determines the length of intercostal muscle division.

A small rib retractor is placed. The hilar dissection is performed under direct vision through this utility thoracotomy, with the illumination of the videothoracoscope. The lobectomy specimen is delivered from the same incision. One or two pericostal sutures are used to approximate the ribs. This is not significantly different from a standard muscle-sparing thoracotomy.

Video-assisted simultaneously stapled lobectomy (VASSL)

A linear stapler is used to create the lobar fissure. The pulmonary artery, vein, and the bronchus are then stapled and divided simultaneously. The procedure is performed without any rib spreading, and the specimen is removed in a bag. VASSL has been reported by Lewis in 250 patients [36].

Video-assisted non-rib spreading lobectomy (VANRSL)

The surgical approach is planned according to the location of the lesion. To achieve improvement in outcome, rib spreading should be avoided. The technique of VANRSL has been described elsewhere in the literature [6,7,33,35]. Our technique [33] for a right upper lobectomy is as follows (Fig. 1). The dissection is performed in a similar manner to an open technique. The lung is retracted posteriorly, using a ring forceps through the posterior port, and the pulmonary vein is dissected via the anterior port. To facilitate and safely divide the vascular structures, we attach one anvil of the stapler to an 8-mm red rubber catheter (Rob-Nel catheter, The Kendall

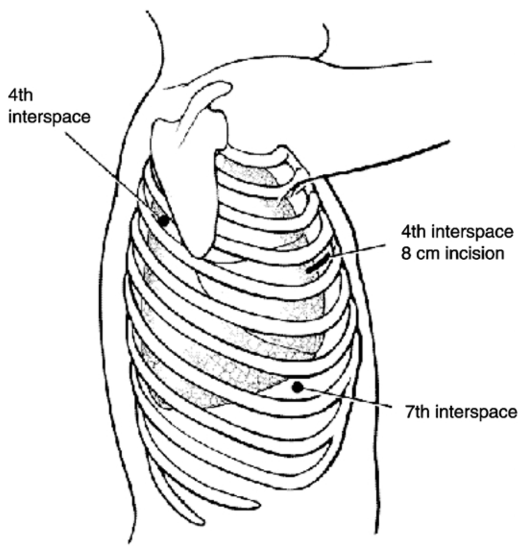

Fig. 1. The three thoracoscopic port incisions for dissection of the right upper lobe. The access incision is in the fourth intercostal space, anterior axillary line, and is 8 cm or less. The camera port is in the seventh space, the posterior port in the fourth. (Courtesy of Scott J. Swanson, MD, Boston, MA.)

Company, Mansfield, MA) (Fig. 2) [40]. This allows safe passage of the stapler around the structure of intent. Then the vessel is divided with the endovascular 30-mm stapler (United States Surgical Corporation, Norwalk, CT). Similarly, the pulmonary artery and bronchus are dissected and divided (Fig. 3). The bronchus is freed together with the lymph nodes and divided with a 30-mm linear cutter (Fig. 4). Last, the fissure is completed with an endoscopic 30-mm linear stapler (United States Surgical Corporation). The anterior port incision is elongated to an 8-cm access incision to allow removal of the specimen (Fig. 5). The resected lobe is then placed in a sac and removed without any rib spreading (Fig. 6).

To resect the other lobes of the lung, different access and port incisions are performed. The dissection and division principles for the pulmonary vein, artery, and the bronchus are the same [33].

There is currently a national trial assessing the feasibility of VANRSL for solitary, peripheral pulmonary nodules (less than 3 cm) either suspected or histologically documented to be non-small cell lung cancer. The trial has recently closed, and early data suggest the technique is feasible (CALGB 39802).

Other anatomic resections

Pneumonectomy

A pneumonectomy is rarely performed using VATS, because most tumors needing a pneumonectomy are either T3 or large hilar tumors [16]. The technique is similar to that for an open procedure, with stapling and dividing of vessels in the order of the superior and inferior pulmonary veins and the main pulmonary artery. We suggest considering use of a TA

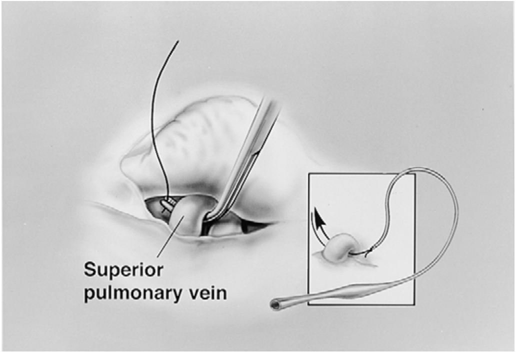

Fig. 2. The guidance catheter is being placed under the superior pulmonary vein to facilitate safe thoracoscopic stapling of the vessel. To allow safe placement of the stapler, one jaw of the endoscopic stapler fits into the end of the pliable plastic self-dilating catheter. (*From* Garcia JP, Richards WG, Sugarbaker DJ. Surgical treatment of malignant mesothelioma. In: Kaiser LR, Kron IL, Spray TL, editors. Mastery of cardiothoracic surgery. Philadelphia: Lippincott-Raven; 1997; with permission.)

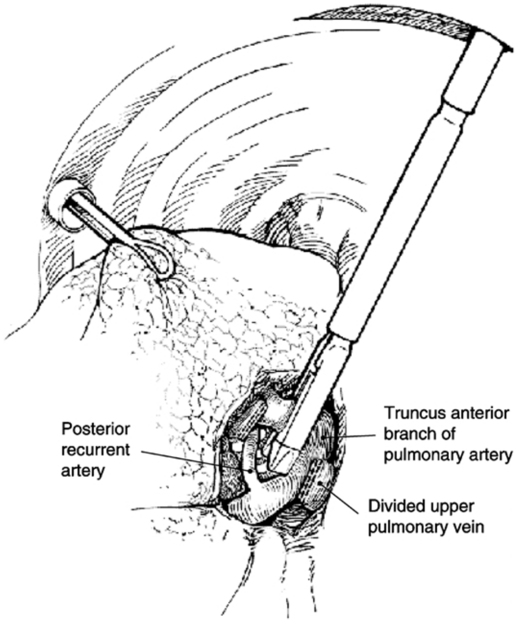

Fig. 3. Through the posterior port, the ring forceps retract the upper lobe. The truncus anterior branch of the right pulmonary artery is divided using the endostapler through the access incision. (Courtesy of Scott J. Swanson, MD, Boston, MA.)

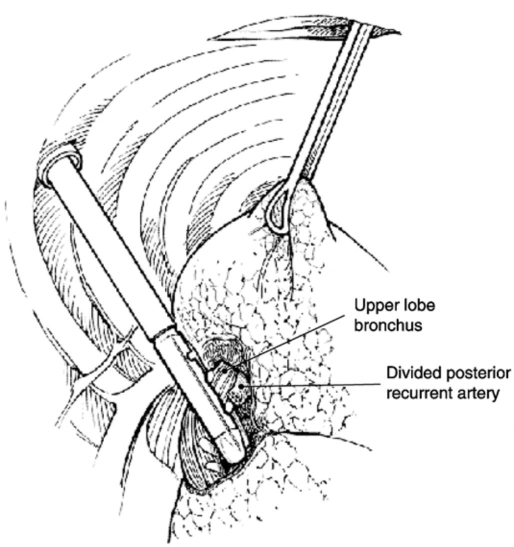

Fig. 4. Through the access port, the ringed forceps retract the right upper lobe anteriorly. Through the posterior port, the endoscopic 30-mm linear cutter divides the upper lobe bronchus. (Courtesy of Scott J. Swanson, MD, Boston, MA.)

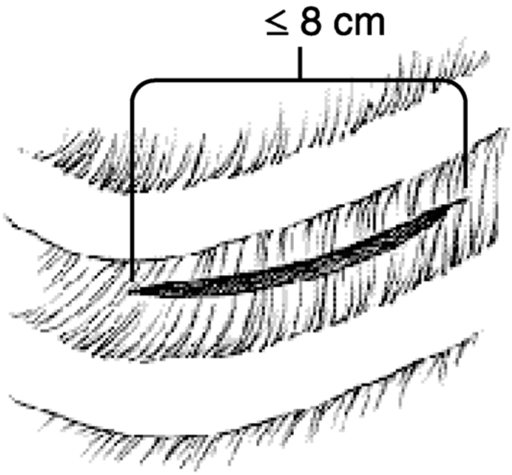

Fig. 5. The 8-cm or less access incision is made to aid in the hilar dissection and to remove the specimen. (Courtesy of Scott J. Swanson, MD, Boston, MA.)

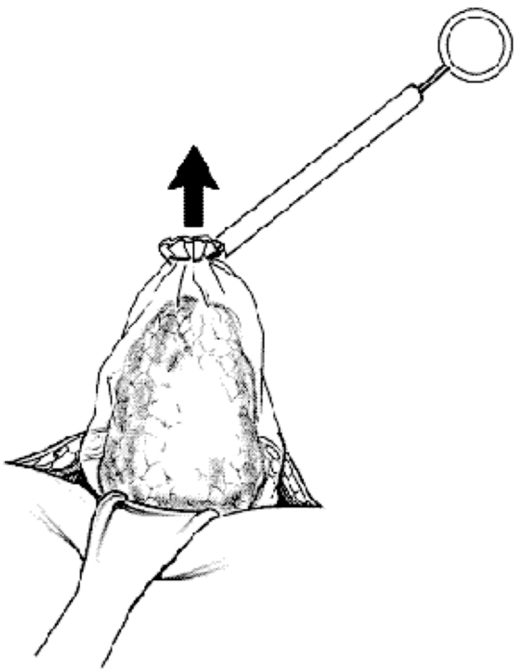

Fig. 6. Specimen in sac, ready for removal through the access incision. Sacking is done to prevent port site seeding. (Courtesy of Scott J. Swanson, MD, Boston, MA.)

stapler (United States Surgical Corporation) for the main pulmonary artery because there have been reports of stapler failures with the smaller stapler [41,42]. For the bronchus, a 30-mm TA stapler can be fired using the access incision.

Segmentectomy

Segmentectomy is a conditionally acceptable operation for lung cancer; its utility in lung cancer management is limited to patients with poor pulmonary function. Creating the segmental fissure and dissecting out the segmental vessels can be challenging using VATS. The most amenable segments are the superior segments of the lower lobe and lingula.

Outcome

Morbidity and mortality following VATS resection

Morbidity and mortality following VATS wedge resection or lobectomy compares favorably to open surgery, as seen in published series [9,11,12,18,20,21,26,36,43–45].

Wedge resection

VATS wedge resection has a very low perioperative morbidity and mortality. Because indications for performing it are limited, VATS wedge resection is generally performed in high-risk patients. Shennib et al reported 30 high-risk (FEV_1<35%, PaO_2 <60 mm Hg in room air, DLCO <40%) patients who had wedge resection for the treatment of lung cancer [45]. Perioperative mortality was 3% (1 of 30) and morbidity was 23% (7 of 30). In patients over the age of 65, Jaklitsch et al showed that non-anatomic lung resections were safe, with a mortality of 0.6% (1 of 156) and morbidity of 9% (14 of 156) [43]. This series was a mixed group of patients and not all resections were for lung cancer. The most common morbidity in these series was prolonged air leak. Landreneau et al reported a lower postoperative morbidity rate after VATS wedge resections (16%) when compared with open wedge resections (28%) or lobectomy (31%) for lung cancer ($P<0.05$) [9].

Lobectomy

In a prospective, non-randomized, multicenter study, Landreneau et al reported 6% (5 of 81) morbidity in a mixed group of patients who had either lobectomy using VAMT or thoracoscopic wedge resections [9]. The morbidity rate for VAMT was 27% (12 of 44). In another study in the extreme elderly (>age of 80, $n = 9$), no mortality was observed after VANRSL and two patients had minor morbidity [38]. Walker et al reported a 33.7% (28 of 83) morbidity rate following VATS lobectomy, with only four patients having major complications [19]. The most common morbidity in the series shown in Table 1 was prolonged air leak. Other complications in these series ranged

Table 1
Morbidity and mortality following VATS lobectomy

First author	Year	No. of patients	Lung cancer patients (%)	Technique/type of resection (n = lobe)	Morbidity (%)	Mortality (%)
Lewis	1999	250	214/250 (86)	VASSL/Lobe	28/250 (11.2)	0
Demmy	1999	22	22/22 (100)	VAMT/Lobe	3/22 (14.0)	3/22 (14.0)
McKenna	1998	298	298/298 (100)	VANRSL/Lobe (290)	38/298 (12.4)	1/298 (0.3)
Hermansson	1998	30	22/30 (73)	VASSL/Lobe	1/30 (3.0)	0
Walker	1998	150	123/150 (83)	VANRSL/Lobe	48/150 (32.0)	1/150 (0.7)
Kesada	1998	128	103/128 (80)	VANRSL/Lobe (119)	4/128 (3.0)	1/128 (0.8)
Roviaro	1998	171	142/171 (83)	VAMT/Lobe (163)	26/171 (15.0)	0
Yim	1998	214	168/214 (79)	VANRSL/Lobe (203)	47/214 (22.0)	1/214 (0.5)

Abbreviations: VATS, video-assisted thoracic surgery; VASSL, video-assisted simultaneously stapled lobectomy; VAMT, video-assisted minithoracotomy; VANRSL, video-assisted non-rib spreading lobectomy; Lobe, lobectomy.

from empyema, respiratory failure, and bronchopleural fistula to minor complications such as subcutaneous emphysema.

The perioperative mortality rate associated with a VATS lobectomy is less than 1%, which compares favorably with the open approach (2%–3%) (see Table 1). The causes of mortality in the series in Table 1 were mesenteric venous infarct, massive pulmonary embolism, severe respiratory failure, and unknown. None of the deaths in these series were due to major intraoperative bleeding.

In a review by McKenna of 1560 VATS lobectomies, only one intraoperative death occurred due to bleeding [34]. In 11.6% (119 of 1239) of VATS lobectomies the incision was converted to a thoracotomy [34]. The majority of the conversions were oncologic, such as T3 tumor or close proximity of the tumor to the pulmonary artery. Thirty percent of the conversions were due to technical causes such as pleural symphysis or poor visualization [34].

There also have been three reported cases of stapler failure in which the stapler cut the vessel, but did not fire the staples. Two were reported by Craig [41] and one by Yim [42]. Each led to significant bleeding; none were fatal.

Long-term survival and recurrence

Conclusions regarding the validity of VATS in lung cancer management will be based on cancer recurrence data. Up to now, there are few reports that have significant numbers of patients and five-year survival figures (Table 2) [12,26,44,46].

Wedge resection

In 1995, the Lung Cancer Study Group (LCSG) published the results of a randomized study of limited resection versus lobectomy in clinical T1N0 lung cancer patients. The study showed that limited resection (82 segmental

Table 2
VATS lobectomy: survival and recurrence

Author	Year	Type of study	No of patients	Stage I survival		Stage II survival		Follow-up (mo)	Locoregional recurrence (%)
				3 yr	5 yr	3 yr	5 yr		
Sugi	2000	Randomized	48	90%	90%	N/A	N/A	Median (60)	3/48 (6%)
McKenna	1998	Retrospective	298	80%	60%	66%	66%	Mean (29)	N/A
Walker	1998	Retrospective	101	94%	75%	57%	N/A	Mean (27)	4/101 (4%)
Kaseda	1998	Retrospective	103	94%	N/A	N/A	N/A	Median (22)	N/A

Abbreviations: VATS, video-assisted thoracic surgery; N/A, not available; yr: year; mo; months.

resections, 40 wedge resections in 122 patients) was associated with a 17% (21 of 122) local recurrence rate [8]. Lobectomy had a local recurrence rate of 6% (8 of 125; $P = 0.008$). Wedge resection was associated with a fourfold and segmentectomy with a twofold increase in locoregional recurrence when compared with lobectomy. In this study, all resections were performed through posterolateral thoracotomy. Survival was worse in the limited resection group of patients (five-year survival was 46% in wedge resection versus 68% in lobectomy group; $P = 0.09$) [8].

Landreneau and colleagues reported a retrospective review of 219 patients from several institutions who had pathologic T1N0 lung cancer [9]. Of the 219 patients, 117 had a lobectomy, 42 had an open wedge resection through a muscle-sparing thoracotomy, and 60 had a VATS wedge resection. Local recurrence was higher in the two groups of patients who underwent wedge resection than in those who underwent lobectomy (39% [40 of 102 combined] versus 8% [9 of 117]), but the difference did not reach statistical significance ($P = 0.07$) [9]. Although the survival rate was lower in patients who had an open wedge resection, the survival rate for patients who underwent a VATS wedge resection for lung cancer was almost the same as for those who underwent a lobectomy (73% and 77% at four years, respectively).

Multiple study data demonstrate that lesser resections have higher local recurrence rates. Therefore, VATS wedge resection for lung cancer should be reserved for patients with multiple morbidities and poor pulmonary function.

Lobectomy

VATS lobectomy is a less invasive operation than a posterolateral thoracotomy. There are no adequate prospective, phase III studies to assess long-term survival following VATS versus open lobectomy (see Table 2).

In a recently published study by Sugi et al, 100 consecutive patients with clinical stage IA lung cancer were randomized to a VATS lobectomy (technique not specified) ($n = 48$) or open thoracotomy and conventional lobectomy ($n = 52$) [46]. A radical lymphadenectomy was performed in both groups. The survival was 90% at both three and five years for the VATS lobectomy group and 93% and 85%, respectively, in the conventional lobectomy group ($P = 0.91$). Locoregional recurrence was equivalent in both groups (3 of 48 and 3 of 52). The median follow-up was 60 months [46].

In 1998, McKenna et al also reported a retrospective series with 298 patients treated for lung cancer [44]. All patients underwent a VANRSL technique. Three-year survival for patients with stage I ($n = 233$) disease was 80% and for those with stage II ($n = 27$) was 66%. Mean follow-up was 29 months [44].

There are reports in 1998 by Walker [19] and Kaseda [12] with similar survival figures. Local recurrence rates were less than 6% in these series.

Currently, a phase III, multi-institutional, national trial is being drafted to compare a VANRSL against a muscle-sparing thoracotomy. This trial should determine whether the operations have similar survival and whether there is any benefit to a VATS approach.

Critical issues in VATS lung surgery

Perioperative course and acute pain

Posterolateral thoracotomy is associated with significant pain and limitation in function. A VATS approach is aimed at minimizing these conditions.

Perioperative course

Operative time was longer for VATS lobectomy in most studies (Table 3) [21–24,26,47–49]. A VATS approach, however, improved perioperative recovery, which subsequently decreased length of hospital stay [21–23,47–50]. Although duration of chest tube drainage was the same with VATS and open surgery groups (see Table 3), improved pain and pulmonary function shortened the hospital stay and hastened the recovery. In 895 consecutive VATS patients, DeCamp et al showed that average hospital stay was three days following any VATS procedure and five days following VATS lung resection [51].

Acute pain

Post-thoracotomy pain is thought to be caused by rib spreading. Benedetti et al analyzed the presence of superficial abdominal reflexes at day one, one week and two to three months following posterolateral thoracotomy [52]. They found absence of ipsi- and contralateral superficial abdominal reflexes at day one and one week following surgery. This absence had an inverse correlation with the intensity of pain and was attributed to the intercostal nerve trauma [52].

There are many studies evaluating the intensity of acute pain following minimally invasive surgery (see Table 3). In all of these studies, VATS was associated with less pain than the open approach. In the randomized study

Table 3
VATS lobectomy versus standard lobectomy: perioperative outcome data

Author	Year	Type of study	No of patients		Operation time (min)		CT drainage (days)		LOS (days)		Acute Pain[1,2]
			VATS	Thoracotomy	VATS	Thoracotomy	VATS	Thoracotomy	VATS	Thoracotomy	
Nagahiro	2001	Non-randomized	13	9	250[2]	186	3.6	3.8	N/A	N/A	Less pain at POD 1, 7, 14
Demmy	1999	Non-randomized	23	31	229	215	4.0	8.3	5.3[2]	12.2	Less pain med at 3 weeks
Ohbuchi	1998	Non-randomized	35	35	217[2]	195	5.3	7.6	15.0[2]	24.0	Less pain med
Walker	1996	Non-randomized	70	110	135	N/A	N/A	N/A	7.0	N/A	Less pain med
Tschernko	1996	Randomized[1]	22	25	N/A	N/A	N/A	N/A	5.1	9.2	Less pain at POD 3
Kirby	1995	Randomized	30	31 (MST)	161	175	4.6	6.5	7.1	8.3	No data
Giudicelli	1994	Non-randomized	44	23 (MST)	133[2]	110	8.0	10.0	12.0	15.0	Less pain at POD 1–4
Landreneau	1993	Non-randomized	81	57 (52 MST)	N/A	N/A	N/A	N/A	5.0[2]	7.5	Less pain at POD 1, 2

[1] Less pain refers to VATS groups.
[2] $p<0.05$.
Abbreviations: VATS, video-assisted thoracic surgery; LOS, length of stay; CT, chest tube; POD, post-operative day; N/A, not available; med, medication; MST, muscle-sparing thoracotomy.

by Kirby, comparing lobectomy through muscle-sparing thoracotomy to VATS lobectomy, post-thoracotomy pain was the same in both groups [47]. The study, however, did not examine acute pain, and rib spreading was carried out in many of the VATS patients. Giudicelli et al showed that VAMT resulted in less pain than muscle-sparing thoracotomy at postoperative days one, two, and four [22]. Landreneau reported less pain in the first three weeks following surgery in the VATS group of patients than in the thoracotomy group [23].

Early and late quality of life

Chronic post-thoracotomy pain, shoulder function, and return to work are important issues following thoracic surgery. Most of the patients are restricted in their regular physical activities for six to eight weeks following standard posterolateral thoracotomy. Demmy et al [21] showed that in high-risk patients [53] who had VATS lobectomy, the recovery time and return to full activity was shorter.

Stammberger et al assessed the long-term quality of life following VATS procedures in 173 patients [25]. Fifty-three percent stated that their pain was insignificant two weeks after surgery. Seventy-five percent of the patients had no complaints six months following VATS; the remaining 25% had minimal to moderate discomfort. After two years, only 4% of the patients had mild to moderate discomfort. Most of the patients in this group had pleurectomy, wedge resection, or biopsies. There were 16 lobectomies [39]. In the same series, 89% of the patients returned to work in two weeks. In 70 VATS lobectomy patients, Walker et al showed that there was mild port site discomfort three to six weeks following surgery [26]. The overall incidence of chronic pain was 1.2% (1 of 70).

In a questionnaire study evaluating acute pain and shoulder dysfunction, Landreneau et al showed that shoulder dysfunction was the same in both VATS and muscle-sparing thoracotomy groups in the first three days after surgery. However, in the VATS group, shoulder function returned to normal in three weeks, whereas it was significantly impaired in the muscle-sparing thoracotomy group [23]. A follow-up to this study performed at one year compared 165 patients who had a lung resection through lateral thoracotomy with 178 who had a VATS resection [54]. The results showed that within the first year there was a significant difference in overall pain, pain intensity scores, and shoulder function between the groups, favoring a VATS approach (shoulder dysfunction: 25% open group, 10% VATS group [$P = 0.001$]) [54].

Pulmonary function

Several studies have compared pulmonary function following VATS lobectomy and thoracotomy (Table 4) [22–24,49,55,56]. Other than a single

Table 4
VATS versus thoracotomy: pulmonary function tests

Author	Year	FEV_1 [1,2]	FVC [1,2]	PaO_2 [1,2]
Nagahiro	2001	Improved at POD 14	Improved at POD 7, 14	N/A
Kaseda	2000	Improved at 3 months	Improved at 3 months	N/A
Nakata	2000	No statistical difference	No statistical difference	Improved at POD 7
Tschernko	1996	N/A	N/A	Improved at POD1-3
Giudicelli	1994	No statistical difference	No statistical difference	N/A
Landreneau	1993	Improved at POD 3	N/A	N/A

[1] Improvement refers to VATS group.
[2] Statistically significant ($p < 0.05$) unless otherwise denoted.
Abbreviations: VATS, video-assisted thoracic surgery; FEV_1, forced expiratory volume in one second; FVC, forced vital capacity; PaO_2, partial pressure of oxygen; POD, postoperative day; N/A, not available.

study (Giudicelli et al) that compared VAMT with muscle-sparing thoracotomy, all other studies showed improved postoperative pulmonary function following VATS [22]. In one study, long-term (>1 year) pulmonary function was evaluated and no difference was found between VATS and thoracotomy groups [56]. Nomori et al evaluated respiratory muscle strength using maximum inspiratory and expiratory pressures. Their data showed that VATS resulted in a more rapid recovery of respiratory muscle strength compared with posterolateral thoracotomy [57].

Biologic effects

Various inflammatory mediators and cytokines have been studied to evaluate the biologic mechanism for differences in VATS versus thoracotomy approaches (Table 5) [24,58,59]. A prospective, randomized study was performed by Gebhard et al to evaluate the inflammatory response

Table 5
VATS versus thoracotomy: cytokines and inflammatory mediators

Author	Year	IL-6 [1,2]	IL-8 [1,2]	IL-10 [1,2]	CRP [1,2]
Nagahiro	2001	Less at POD 0	N/A	Inverse linear correlation with pain	N/A
Yim	2000	Less at immediate postoperative period	Less at immediate postoperative period	Less at postoperative 4 and 8 hr	N/A
Sugi	2000	No difference in serum. Less in pleural fluid	No difference	N/A	Less at POD 1

[1] The reference point is the VATS group.
[2] All statistically significant ($p < 0.05$) unless otherwise denoted.
Abbreviations: VATS, video-assisted thoracic surgery; IL, interleukin; CRP, C-reactive protein; POD, post-operative day; N/A, not available; Hr, hour.

following minimally invasive surgery for pneumothorax [60]. VATS was compared with axillary thoracotomy. Serum levels of C-reactive protein, polymorphonuclear elastase, prostacyclin, and thromboxane A2 were less in the VATS group at the time of lung resection and chest closure [60].

In other studies, postoperative C-reactive protein and interlukin (IL)-6, IL-8, and IL-10 levels were less in VATS groups of patients than in patients who underwent thoracotomy (see Table 5) [24,58,59].

Leaver et al showed that the number of circulating T (CD4) cells was higher at postoperative day two following VATS [61]. Natural killer cells were also higher when compared with the thoracotomy group of patients at postoperative day seven. Lymphocyte oxidation was less suppressed in the VATS group [61].

Oncologic outcome

The oncologic outcome is critical in determining the validity of VATS. The oncologic adequacy of the operation is particularly important because lung cancer patients who are candidates for a VATS lobectomy constitute a potentially curable population.

Three major points are important in determining adequacy. A surgeon performing VATS lobectomy should (1) be able to either sample or dissect the lymph nodes, (2) be able to resect the tumor completely, (3) not contaminate the pleural space with tumor cells.

Several studies showed that VATS lobectomy was oncologically the same operation as a lobectomy through a thoracotomy [14,21,26,44,46,48,62]. The number of dissected lymph nodes in these series ranged from 10 to 23. There was no difference in the number of lymph nodes dissected or sampled between VATS lobectomy or thoracotomy groups of patients [21,48,62].

Kondo et al performed a study to assess the efficacy of the VATS approach in radical lymph node dissection [63]. Six patients underwent VATS lobectomy and radical lymph node dissection. Upon completion of the VATS session of the operation, another surgeon extended the incision to a posterolateral thoracotomy and performed a radical lymphadenectomy. The second surgeon found no other lymph nodes in four out of six patients. In two of the patients, two and three lymph nodes were found and were not in a dependent drainage location of the resected lobe [63].

A majority of the studies included stage I tumors, which were completely resected. Locoregional recurrence rates were less than 6% (see Table 2). There have been several reports regarding the dissemination of tumor cells into the pleural space during VATS [64–66]. Large series, however, demonstrated low pleural space or incisional recurrences (0.3%–2%) [14,21, 26,44,46,67].

Long-term survival figures for patients with stage I lung cancer following VATS are similar to treatment following an open approach; however, larger prospective studies are currently recruiting patients to address this issue.

Other issues and future directions

Training young surgeons to perform anatomic lung resections using VATS is a complex process. Animal laboratory sessions are helpful. Another option is a computer-based simulation. Familiarity with simpler VATS procedures is required to perform more complicated procedures such as a lobectomy. The best plan should start with wedge resection, proceed to video-assisted lobectomy via a small thoracotomy, and finish with a non-rib spreading lobectomy.

The technique of VATS should use a standard approach, which has been outlined above and should not include rib spreading [33].

Currently, technology limits the breadth of VATS surgery. Lack of three-dimensional feedback and staplers without multiple degrees of freedom are issues that need to be resolved. Robotic surgery is a potential way to address these issues, but needs further refinement. Further improvement in the technology of vascular ligation and division will also be a major advance.

Summary

VATS is a relatively new technology that has become the standard of care for basic procedures such as drainage of pleural effusion and blebectomy. VATS anatomic lung resection is more controversial. Published studies demonstrate several advantages of VATS over a standard posterolateral thoracotomy. A minimally invasive approach causes less inflammatory reaction. Acute and chronic pain are diminished. As a result, the length of hospitalization is shorter. Early and late shoulder dysfunction is less and return to work time is shorter. Taken together, these factors suggest a better overall outcome using a VATS approach.

From an oncologic standpoint, lymph node dissection can be accomplished and locoregional recurrence is low. The validity of VATS for lung cancer will be determined by long-term data. A phase III national (intergroup) protocol is being drafted and will help to answer these questions.

Acknowledgement

The authors wish to thank Mary S. Visciano for editorial assistance.

References

[1] Jacobeus HC. Ueber die Moglichkeit die Zystoskopie bei Untersuchung seroser hohlungen Anzuwenden. Munchen Med Wochenschur 1910;57:2090–2.

[2] Landreneau RJ, Hazelrigg SR, Mack MJ. Thoracoscopic mediastinal lymph node sampling: a useful approach to mediastinal lymph node stations inaccesible to cervical mediastinoscopy. J Thorac Cardiovasc Surg 1993;106:554–8.

[3] Landreneau RJ, Mack MJ, Dowling RD, et al. The role of thoracoscopy in lung cancer management. Chest 1998;113(1 Suppl):6S–12S.

[4] Mack MJ, Scruggs GR, Kelly KM, et al. Video-assisted thoracic surgery: has technology found its place? Ann Thorac Surg 1997;64(1):211–5.
[5] Kohno T, Murakami T, Wakabayashi A. Anatomic lobectomy of the lung by means of thoracoscopy: an experimental study. J Thorac Cardiovasc Surg 1993;105:729–31.
[6] Kirby TJ, Rice TW. Thoracoscopic lobectomy. Ann Thorac Surg 1993;56(3):784–6.
[7] Walker WS, Carnochan FM, Pugh GC. Thoracoscopic pulmonary lobectomy. Early operative experience and preliminary clinical results. J Thorac Cardiovasc Surg 1993; 106(6):1111–7.
[8] Ginsberg R, Rubernstein L. Randomized trial of lobectomy versus limited resection for T1N0 non-small cell lung cancer. Ann Thorac Surg 1995;60:615–23.
[9] Landreneau RJ, Sugarbaker DJ, Mack MJ, et al. Wedge resection versus lobectomy for stage I (T1N0M0) non-small cell lung cancer. J Thorac Cardiovasc Surg 1997;113:691–700.
[10] Warren WH, Faber LP. Segmentectomy versus lobectomy in patients with stage I pulmonary carcinoma. J Thorac Cardiovasc Surg 1994;107:1087–94.
[11] Hermansson U, Konstantinov IE, Aren C. Video-assisted thoracic surgery (VATS) lobectomy: the initial Swedish experience. Semin Thorac Cardiovasc Surg 1998;10(4): 285–90.
[12] Kaseda S, Aoki T, Hangai N. Video-assisted thoracic surgery (VATS) lobectomy: the Japanese experience. Semin Thorac Cardiovasc Surg 1998;10(4):300–4.
[13] Kirby TJ, Mack MJ, Landreneau RJ, et al. Initial experience with video-assisted thoracoscopic lobectomy. Ann Thorac Surg 1993;56(6):1248–52.
[14] Lewis RJ, Caccavale RJ. Video-assisted thoracic surgical non-rib spreading simultaneously stapled lobectomy (VATS(n)SSL). Semin Thorac Cardiovasc Surg 1998;10(4):332–9.
[15] Liu HP, Chang CH, Lin PJ, et al. Thoracoscopic-assisted lobectomy. Preliminary experience and results. Chest 1995;107(3):853–5.
[16] McKenna Jr. RJ. Thoracoscopic evaluation and treatment of pulmonary disease. Surg Clin North Am 2000;80(5):1543–53.
[17] McKenna Jr. RJ, Fischel RJ, Wolf R, et al. Video-assisted thoracic surgery (VATS) lobectomy for bronchogenic carcinoma. Semin Thorac Cardiovasc Surg 1998;10(4):321–5.
[18] Roviaro G, Varoli F, Vergani C, et al. Video-assisted thoracoscopic surgery (VATS) major pulmonary resections: the Italian experience. Semin Thorac Cardiovasc Surg 1998;10(4): 313–20.
[19] Walker WS. Video-assisted thoracic surgery (VATS) lobectomy: the Edinburgh experience. Semin Thorac Cardiovasc Surg 1998;10(4):291–9.
[20] Yim AP, Izzat MB, Liu H, et al. Thoracoscopic major lung resections: an Asian perspective. Semin Thorac Cardiovasc Surg 1998;10(4):326–31.
[21] Demmy TL, Curtis JJ. Minimally invasive lobectomy directed toward frail and high-risk patients: a case-control study. Ann Thorac Surg 1999;68(1):194–200.
[22] Giudicelli R, Thomas P, Lonjon R, et al. Video-assisted minithoracotomy versus muscle-sparing thoracotomy for performing lobectomy. Ann Thorac Surg 1994;58:712–8.
[23] Landreneau RJ, Hazelrigg SR, Mack MJ, et al. Postoperative pain-related morbidity: video-assisted thoracic surgery versus thoracotomy. Ann Thorac Surg 1993;56(6): 1285–9.
[24] Nagahiro I, Andou A, Aoe M, et al. Pulmonary function, postoperative pain, and serum cytokine level after lobectomy: a comparison of VATS and conventional procedure. Ann Thorac Surg 2001;72:362–5.
[25] Stammberger U, Steinacher C, Hillinger S, et al. Early and long-term complaints following video-assisted thoracoscopic surgery: evaluation in 173 patients. Eur J Cardiothorac Surg 2000;18(1):7–11.
[26] Walker WS, Pugh GC, Craig SR, et al. Continued experience with thoracoscopic major pulmonary resection. Int Surg 1996;81(3):255–8.
[27] Champion JK, McKernan JB. Comparison of minimally invasive thoracoscopy versus open thoracotomy for staging lung cancer. Int Surg 1996;81(3):235–6.

[28] Roviaro G, Varoli F, Rebuffat C, et al. Videothoracoscopic staging and treatment of lung cancer. Ann Thorac Surg 1995;59(4):971–4.
[29] Asamura H, Nakayama H, Kondo H, et al. Lymph node involvement, recurrence and prognosis in resected small, peripheral, non-small cell lung carcinomas: are these carcinomas candidates for video-assisted lobectomy? J Thorac Cardiovasc Surg 1996;111: 1125–34.
[30] Macchiarini P, Fontanini G, Hardin JM, et al. Most peripheral, node-negative, non-small cell lung cancers have low proliferative rates and no intratumoral and peritumoral blood and lymphatic vessel invasion. J Thorac Cardiovasc Surg 1992;104:892–9.
[31] Shennib H, Kohman L, Herndon JE, et al. CALGB 9335: a multi-center phase II prospective study of video-assisted wedge resection followed by radiotherapy for T1N0 NSCLC in high risk patients; preliminary analysis of technical outcome. Presented at the 80th Annual Meeting of the American Association of Thoracic Surgery. Toronto, Ontario, April 29–May 3, 2000.
[32] Swanson SJ, Bueno R, Jaklitsch MT, et al. Subcentimeter non-small cell lung cancer: early detection and resection is warranted. Presented at the 80th Annual Meeting of the American Association of Thoracic Surgery. Toronto, Ontario, April 29–May 3, 2000.
[33] Mason DP, Swanson SJ. Lung cancer: diagnosis and treatment. In: Demmy TL. Video-assisted thoracic surgery (VATS). Goergetown: Landes Bioscience; 2001. p. 71–98.
[34] McKenna Jr. RJ. The current status of video-assisted thoracic surgery lobectomy. Chest Surg Clin N Am 1998;8(4):775–85.
[35] McKenna R Jr. Vats lobectomy with mediastinal lymph node sampling or dissection. Chest Surg Clin N Am 1995;5(2):223–32.
[36] Lewis RJ, Caccavale RJ, Bocage JP, et al. Video-assisted thoracic surgical non-rib spreading simultaneously stapled lobectomy: a more patient-friendly oncologic resection. Chest 1999;116(4):1119–24.
[37] Mason DP, Swanson SJ. VATS the future. In: DiFalco G, editor. Videothoracoscopic surgery (Atlante Chirurgico di Videotoracoscopia). Milan: Masson S.p.A; 1999. p. 205–211.
[38] McKenna Jr. RJ. Thoracoscopic lobectomy with mediastinal sampling in 80-year-old patients. Chest 1994;106(6):1902–4.
[39] Spaggiari L, Carbognani P, Solli P, et al. A standard muscle-sparing utility thoracotomy for VATS procedures. J Cardiovasc Surg (Torino) 1999;40(4):597–601.
[40] Garcia JP, Richards WG, Sugarbaker DJ. Surgical treatment of malignant mesothelioma. In: Kaiser LR, Kron IL, Spray TL, editors. Mastery of cardiothoracic surgery. Philadelphia: Lippincott-Raven; 1997.
[41] Craig SR, Walker WS. Potential complications of vascular stapling in thoracoscopic pulmonary resection. Ann Thorac Surg 1995;59(3):736–7.
[42] Yim AP, Ho JK. Video-assisted thoracoscopic lobectomy: a word of caution. Aust N Z J Surg 1995;65(6):438–41.
[43] Jaklitsch MT, DeCamp Jr. MM, Liptay MJ, et al. Video-assisted thoracic surgery in the elderly (a review of 307 cases). Chest 1996;110:751–8.
[44] McKenna Jr. RJ, Wolf RK, Brenner M, et al. Is lobectomy by video-assisted thoracic surgery an adequate cancer operation? Ann Thorac Surg 1998;66(6):1903–8.
[45] Shennib HAF, Landreneau R, Mulder DS, et al. Video-assisted thoracoscopic wedge resection of T1 lung cancer in high-risk patients. Ann Surg 1993;218(4):555–60.
[46] Sugi K, Kaneda Y, Esato K. Video-assisted thoracoscopic lobectomy achieves a satisfactory long-term prognosis in patients with clinical stage IA lung cancer. World J Surg 2000;24(1):27–30.
[47] Kirby TJ, Mack MJ, Landreneau RJ, et al. Lobectomy—video-assisted thoracic surgery versus muscle sparing thoracotomy a randomized trial. J Thorac Cardiovasc Surg 1995;109(5):997–1002.
[48] Ohbuchi T, Morikawa T, Takeuchi E, et al. Lobectomy: video-assisted thoracic surgery versus posterolateral thoracotomy. Jpn J Thorac Cardiovasc Surg 1998;46(6):519–22.

[49] Tschernko EM, Hofer S, Bieglmayer C, et al. Early postoperative stress: video-assisted wedge resection/lobectomy vs conventional axillary thoracotomy. Chest 1996;109(6): 1636–42.
[50] Nakajima J, Takamoto S, Kohno T, et al. Costs of videothoracoscopic surgery versus open resection for patients with of lung carcinoma. Cancer 2000;89(11 Suppl):2497–501.
[51] DeCamp MM, Jaklitsch MT, Mentzer SJ, et al. The safety and versatility of video-thoracoscopy: A prospective analysis of 895 consecutive cases. J Am Coll Surg 1995;181(2):113–20.
[52] Benedetti F, Amanzio M, Casadio C, et al. Postoperative pain and superficial abdominal reflexes after posterolateral thoracotomy. Ann Thorac Surg 1997;64:207–10.
[53] Minna JD, Pass H, Glatstein E, et al. Cancer of the lung. In: Devita VT, Hellman S, Rosenberg SA, editors. Cancer: principles and practice of oncology. 3rd edition. Philadelphia: Lippincott; 1991. p. 591–705.
[54] Landreneau RJ, Mack MJ, Hazelrigg SR, et al. Prevalence of chronic pain after pulmonary resection by thoracotomy or video-assisted thoracic surgery. J Thorac Cardiovasc Surg 1994;107:1079–86.
[55] Kaseda S, Aoki T, Hangai N, et al. Better pulmonary function and prognosis with video-assisted thoracic surgery than with thoracotomy. Ann Thorac Surg 2000;70(5):1644–6.
[56] Nakata M, Saeki H, Yokoyama N, et al. Pulmonary function after lobectomy: video-assisted thoracic surgery versus thoracotomy. Ann Thorac Surg 2000;70(3):938–41.
[57] Nomori H, Horio H, Fuyuno G, et al. Respiratory muscle strength after lung resection with special reference to age and procedures of thoracotomy. Eur J Cardiothorac Surg 1996;10(5):352–8.
[58] Sugi K, Kaneda Y, Esato K. Video-assisted thoracoscopic lobectomy reduces cytokine production more than conventional open lobectomy. Jpn J Thorac Cardiovasc Surg 2000;48(3):161–5.
[59] Yim AP, Wan S, Lee TW, et al. VATS lobectomy reduces cytokine responses compared with conventional surgery. Ann Thorac Surg 2000;70(1):243–7.
[60] Gebhard FT, Becker HP, Gerngross H, et al. Reduced inflammatory response in minimal invasive surgery of pneumothorax. Arch Surg 1996;131:1079–82.
[61] Leaver HA, Craig SR, Yap PL, et al. Lymphocyte responses following open and minimally invasive thoracic surgery. Eur J Clin Invest 2000;30(3):230–8.
[62] Iwasaki A, Shirakusa T, Kawahara K, et al. Is video-assisted thoracoscopic surgery suitable for resection of primary lung cancer? Thorac Cardiovasc Surg 1997;45(1):13–5.
[63] Kondo T, Sagawa M, Tanita T, et al. Is complete systematic nodal dissection by thoracoscopic surgery possible? A prospective trial of video-assisted lobectomy for cancer of the right lung. J Thorac Cardiovasc Surg 1998;116(4):651–2.
[64] Fry WA, Siddiqui A, Pensler JM, et al. Thoracoscopic implantation of cancer with a fatal outcome. Ann Thorac Surg 1995;59(1):42–5.
[65] Lewis RJ, Caccavale RJ, Sisler GE, et al. Does VATS favor seeding of carcinoma of the lung more than a conventional operation? Int Surg 1997;82(2):127–30.
[66] Yamashita JI, Kurusu Y, Fujino N, et al. Detection of circulating tumor cells in patients with non-small cell lung cancer undergoing lobectomy by video-assisted thoracic surgery: a potential hazard for intraoperative hematogenous tumor cell dissemination. J Thorac Cardiovasc Surg 2000;119(5):899–905.
[67] Swanson SJ, DeCamp MM Jr, Mentzer SJ, Bueno R, Sugarbaker DJ. Thoracoscopic resection of lung malignancy without port site recurrence: the Brigham and Women's Hospital experience. Chest 1997;112(3):9S.