Journal of Surgical Oncology 2013;108:315–319

Maximizing the Benefit of Minimally Invasive Surgery

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Minimal invasive surgery is an excellent approach for the diagnosis and treatment of a wide range of thoracic disorders that previously required sternotomy or open thoracotomy. The notable benefits of minimal invasive surgery to patients include less postoperative pain, fewer operative and post-operative major complications, shortened hospital stay, faster recovery times, less scarring, less stress on the immune system, smaller incision, and for some procedures reduced operating time and reduced costs.
J. Surg. Oncol. 2013;108:315–319.

KEY WORDS: minimally invasive surgery; lung cancer; MIS benefits

INTRODUCTION

Lung cancer is the leading cause of death from cancer in the United States. For patients with a diagnosis of lung cancer, there are a number of options, including chemotherapy, radiation therapy, and surgery. Many patients with early-stage lung cancer benefit from upfront surgery because the tumor appears confined to an area of the body that is resectable. Surgery is an important part of the treatment plan for early-stage lung cancer. Historically, surgical intervention has been performed through traditional, open incisions; with the advent of minimally invasive surgery (MIS), procedures across almost all surgical specialties are now being performed through much smaller incisions. Today, this is increasingly the case with thoracic surgery, and MIS is fast becoming the norm for many types of thoracic procedures that were typically performed through large incisions. The recent growth in the use of minimally invasive techniques is due to major improvements in optics for video thorascopes, better instrumentation, and improved anesthesia. Correspondingly, the number of thoracic MIS procedures continues to increase, since this technique offers distinct benefits for the patient over traditional, open thoracotomy. Two techniques can be used to allow the surgeon to see inside the chest cavity: video-assisted thoracic surgery (VATS) and robotic thoracic surgery. VATS currently is the best of the two with a longer track record, easier application and less expensive than the robotic approach. MIS offers notable benefits to patients, including shorter hospital stays, shorter recovery times, less postoperative pain and scarring, and less stress on the immune system. This review will provide an overview of current trends in thoracic MIS, beginning with a review of its historical evolution.

BACKGROUND

Over the past decade there has been a shift from traditional open thoracic surgery to minimally invasive surgery. Video-assisted thoracoscopic surgery (VATS), began in the early 1990's. This approach offered several advantages over open surgery; a reduction in the inflammatory response, improved of post-operative pulmonary function, decreased post-operative pain, and a faster return to normal activity. Most early VATS studies reported on small T1 or T2N0M0 lesions (usually less than 3 cm). Now most lung cancers can be removed using a VATS approach.

Robots are the newest advancement in the field of thoracic surgery to facilitate minimally invasive thoracic surgery [1].The application of robotic surgical technology was shown to be technically feasible and safe for resection of selected mediastinal masses. Robots make it feasible to access remote and difficult-to-reach areas in the thorax, as in thymectomy procedures. Bonatti et al. [2] reported that the use of robotic thoracic surgery has proved safe for heart surgery programs in which a left internal thoracic artery takedown and total endoscopic coronary-artery bypass grafting was performed successfully in 50 patients. Robotic surgery clearly takes longer to set up, has higher initial capital costs and involves more specialized equipment when compared to VATS.

Stereotactic body radiation therapy (SBRT) is a technique that utilizes precisely targeted radiation to a tumor while minimizing radiation to adjacent normal tissue. It is a minimally invasive treatment for cancer and allows treatment of small- or moderate-sized tumors in either a single or limited number of dose fractions. The radiation is focused on the tumor with millimeter precision. The result is that radiation damages less healthy tissue. Preserving healthy tissue is important for cancer patients whose tumors are near or in essential organs. Surgical resection remains the standard therapy for patients with stage I non-small cell lung cancer (NSCLC). SBRT for lung cancer may offer a treatment option to patients who are not candidates for surgical resection surgery, because of tumor size or location, emphysema or heart disease.

The use of MIS for thoracic procedures is expected to grow. Figure 1 outlines the volume projections for VATS procedures for 2005 through 2014 [3]. Approximately 26,000 thoracoscopies were performed in the United States in 2005; the number of these procedures is expected to increase over the forecast period at a compound annual rate of 5.6% to reach an estimated 43,000 procedures in the year 2014. As noted, the expected increase in lung procedures using MIS techniques is due to improved instrumentation, better understanding, and the broader

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Received 10 January 2013; Accepted 12 July 2013

DOI 10.1002/jso.23398

Published online 23 August 2013 in Wiley Online Library (wileyonlinelibrary.com).

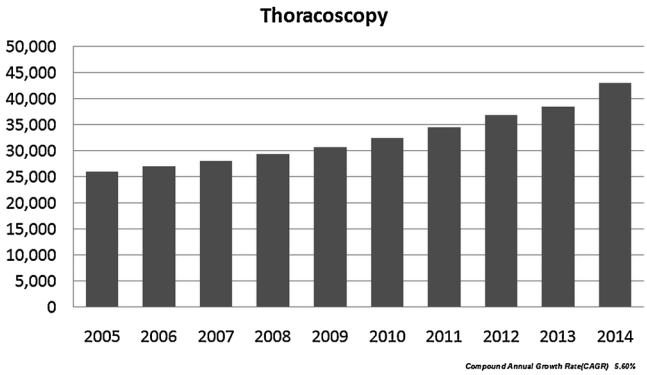

Fig. 1. VATS procedure volumes forecast: 2005 through 2014 [3]

acceptance of thoracoscopy by chest surgeons. The population in which minimally invasive surgery is preferable and beneficial are listed in (Table I) [4].

CURRENT PERSPECTIVE OF MINIMALLY INVASIVE THORACIC SURGERY

Minimally Invasive surgery was initially used for simple diagnostic and therapeutic procedures involving the pleura, lungs, and mediastinum [5]. However, minimally invasive surgery continues to replace many procedures that formerly required thoracotomy [6]. Pulmonary operations using minimally invasive technique have evolved from simple wedge resections to lobectomy, segmentectomy, and pneumonectomy. In most patients a VATS lobectomy is best treatment option compared with a thoracotomy and lobectomy [7,8]. Minimally invasive surgery can be used for many structures in the chest and is not just limited to the lungs, pleura, and mediastinum. The heart and great vessels, the esophagus and diaphragm, the spinal column and nerves can all be approached using a minimally invasive technique [9–17]. Each year has seen new, innovative applications of the technique. The current indications and relative contraindications for minimally invasive thoracic procedures are shown in Table II [18]. The most common surgical procedures for lung cancer performed are briefly described below [19].

Lobectomy

Most lobectomies can be performed by VATS. A lobectomy performed by VATS should be a standard, anatomic resection, just as the procedure performed through a thoracotomy. In CALGB 39802, a prospective, multi-institution study Swanson et al. [20] evaluated the feasibility and safety of VATS lobectomy in 128 patients. Their results demonstrated that a VATS lobectomy has a lower complication rate and shorter chest tube duration as compared to open thoracotomy. The indications for VATS lobectomy include early stage lung cancer, a tumor smaller than 6 cm in diameter, and benign disease (e.g., bronchiectasis). Relative contraindications include a tumor greater than 6 cm in diameter, preoperative irradiation or chemotherapy, sleeve resections, and chest-wall invasion. Although in experienced hands, each of these can be safely and effectively accomplished using a thoracoscopic technique.

The initial reports of minimally invasive lobectomy were focused on the technical aspects and the immediate perioperative outcomes. The total numbers of patients in any series were relatively very small. Later, a number of authors reported on several hundred consecutive patients who underwent minimally invasive lobectomy with morbidity rates ranging from 3% to 13% and operative mortality rates from 0% to 2% [21–25]. These results were comparable with a thoracotomy approach [26]. In fact, with respect to morbidity, the minimally invasive approach in these reports, despite their being retrospective and uncontrolled, appeared to have potentially lower complication rates that seen previously with open thoracotomy.

McKenna et al. [26] and Onaitis et al. [27] reported the two largest case series of minimally invasive lobectomy that demonstrated its feasibility and safety as a procedure. McKenna et al. [26] reported in his largest series of minimally invasive lobectomies to date with 1,048 cases out of 1,100 minimally invasive anatomic resections, the majority of which (92.3%) were for primary lung cancer.

The mean age of the patients was 72 years with a slight female predominance (54%). The median length of stay was 3 days, and the morbidity rate was 15%. Only 4% of patients required blood transfusion and readmission rate was (1%). Perioperative mortality was (0.8%) with no intraoperative deaths. Similarly, Onaitis et al. [27] reported the Duke University experience with 500 consecutive patients undergoing minimally invasive lobectomy to determine safety and efficacy. In this retrospective review, 83% of procedures were performed for NSCLC. Ninenty-eight percentage had successful thoracoscopic lobectomy with a conversion rate of 1.6%. The length of hospital stay and median chest tube were both 3 days. Operative mortality was 1%, and 24% had complications. The most common complication was atrial fibrillation (10%).

For primary surgical treatment of NSCLC, the most important issue is whether the long-term survival outcome is equivalent using a VATS approach. There have been no large, randomized controlled trials of minimally invasive versus thoracotomy lobectomy designed to evaluate oncologic equivalence in NSCLC. Lack of standardized approach and inability to randomize, due to patient preference are barriers to the development of a randomized control trial. There are few single

TABLE I. Populations for Which Minimally Invasive Surgery is Preferable [4]

Special population	Examples
Pulmonary compromise	Poor[a] FEV1/Dlco, heavy smoking, sleep apnea, recent pneumonia
Cardiac dysfunction	Congestive heart failure, severe coronary artery disease, recent myocardial infarction, valvular disease
Extra-thoracic malignancy	Solitary brain metastasis from lung cancer, deep pulmonary metastases requiring lobectomy
Poor physical performance	Performance status 2–3, morbid obesity
Rheumatologic/orthopedic	Spinal disease, severe rheumatoid arthritis, severe kyphosis, lupus, osteomyelitis
Advanced age	Older than 70
Vascular problems	Aneurysm, severe peripheral vascular disease
Recent or impending major operations	Urgent abdominal operations, joint replacement requiring crutches, contralateral thoracotomy needed
Psychologic/neurologic	Substance abuse, poor command following, pain syndromes
Immuno-suppression/impaired wound healing	Recent transplant, diabetes

[a]dlco, lung diffusing capacity of carbon monoxide; FEV1, forced vital capacity in first second.

TABLE II. Indications for Minimally Invasive Thoracic Surgery [18]

General intra-thoracic cavity	Lungs
Diagnosis or biopsy of intra-thoracic structure	Wedge resection
Laser application for treatment of tumor	Segmentectomy
Diagnosis and drainage of pleural effusion	Lobectomy
Treat chylothorax	Sleeve Lobectomy
Debride empyema	Pneumonectomy
Retrieval of intrathoracic foreign body	Closure of persistent/recurrent pneumothorax
	Identification of broncho-pleural fistula
Pleura	**Mediastinum**
Lysis of adhesions	Mediastinal lymph node dissection
Pleurodesis	Removal of mediastinal cysts
Decortication	Thymectomy
	Resection of posterior mediastinal neurogenic tumors
Relative contraindications for minimally invasive thoracic surgery	
Extensive intrapleural adhesions	
The inability to sustain single-lung ventilation	
Extensive involvement of hilar structures	
Preoperative induction of chemotherapy or chemoradiation	
Severe coagulopathy	

institution series looking at overall survival of minimally invasive lobectomy in early stage lung cancer. Sugi et al. [28] conducted a randomized trial of 100 patients, 48 with minimally invasive versus 52 with thoracotomy for lobectomy to evaluate long-term cancer outcome with clinical stage I NSCLC. The VATS technique in the study employed an 8 cm access incision. With median follow-up of 60 months the study suggested that long-term survival outcomes were similar between the minimally invasive (90%) and thoracotomy (85%). Similarly McKenna et al. [26] in his large series of 1,015 minimally invasive lung resection for NSCLC, reported calculated 5-year survival rate (78%) for stage I patients. Thomas et al. [29] determined the prognosis of patients treated by minimally invasive (110 patients) versus open lung resections (405), for pathological stage I NSCLC. Over a 10-year period. The majority of procedure were lobectomies and overall 5-year survival between minimally invasive and thoracotomy were the same ($P = 0.6$) but for stage IA survival was 65% for patients who had a minimally invasive approach and 80% for those who had a thoracotomy ($P = 0.15$). Patients with Stage IB NSCLC had a 5-year survival of 61% using a minimally invasive technique and 58% for thoracotomy ($P = 0.4$). All of the above studies provide evidence that minimally invasive is a good option relative to a thoracotomy.

Sleeve Lobectomy

Surgeons with excellent video skills can perform a standard sleeve lobectomy by VATS. Mahtabifard et al. [30] reviewed 13 patients (median age, 59 years; range, 16–82 years) who underwent VATS sleeve lobectomy and evaluated preoperative, operative, and perioperative outcome variables, including morbidity and mortality. There were no deaths at 30 days and complications in 4 patients (31%). They concluded that VATS sleeve lobectomy with acceptable morbidity, mortality, and short length of stay is possible. This requires advanced experience.

Segmentectomy

Segmentectomy is an option for small, anatomically well-situated lung cancer. The creation of a segmental fissure and dissecting out the segmental vessels can be performed by VATS. Shapiro et al. [31] in their retrospective analysis showed that VATS segmentectomy is a safe option for experienced thoracoscopic surgeons treating patients with small stage I lung cancers. They found no significant difference in oncologic outcome between thoracoscopic segmentectomy and thoracoscopic lobectomy.

Wedge Resection

Howington et al. [32] retrospectively reviewed 2,051 patients who underwent wedge resection, 999 were performed using an open thoracotomy, and 1,052 were done with VATS. This paper compared the safety, use, and cost profile. The surgery time and length of hospital stay was longer for open thoracotomy versus VATS. MIS wedge resections are performed for non-small-cell lung cancer or pulmonary metastasis, for small (<3 cm) peripheral masses, and for patients who are not appropriate candidates for lobectomy (e.g., those with pulmonary hypertension and severe medical illnesses).

Pneumonectomy

A pneumonectomy can be performed by VATS, and the specimen usually fits through the same size of incision that is used for a VATS lobectomy, depending on the size, and location of the lesion. In general, a large central tumor is not appropriate for VATS because of involvement of the mediastinal structures. Hennon et al. [33] described in his recent article, that thoracoscopic pneumonectomy is a safe alternative to open pneumonectomy. Median blood loss, ICU length of stay, and hospital length of stay was the same. Operations were longer, and though operative blood loss was similar, transfusions were increased in the thoracoscopic pneumonectomy group. Major complications were similar for both groups. No differences in long-term survival were observed in patients undergoing pneumonectomy via thoracoscopy versus thoracotomy [34].

CT SCREENING AND MIS

The advancements in CT technology over the past decade have provided the opportunity for a more detailed evaluation of the entire lung parenchyma at higher resolution as compared to what was possible with chest X-ray. This has made making CT screening an enticing tool for the detection of small, early stage cancers. The CT technology uses low doses of radiation thus reducing the radiation exposure of the patients

significantly while preserving the resolution required to detect small, asymptomatic lung cancers that are mainly stage I. In 2006, the findings of I-ELCAP were reported [35]. In the study 31,567 asymptomatic persons at risk of lung cancer were screened using low dose CT. The screening resulted in diagnosis of lung cancer in 484 subjects with 412 (85%) out of these having clinical stage I. According to I-ELCAP regimen CT screening can detect stage I lung cancers in high proportion of persons while it is still curable by surgery.

Similarly, in 2011 the findings from a large randomized controlled trial in the United States evaluating the impact of screening with low-dose CT on lung cancer morbidity and mortality were published [36]. The National Lung Screening Trial (NLST) was sponsored by the National Institutes of Health (NIH) and 53,454 current or former smokers from 33 sites in the U.S. were enrolled in this study. The incidence of lung cancer was 645 cases per 100,000 person-years in low dose CT group, as compared with 572 cases per 100,000 person-years in radiography group. Both groups had a high percentage of stage IA and stage IB lung cancer. The majority of the patients had early stage lung cancer and were treated by surgery alone or surgery with adjuvant therapy. The final analysis revealed that screening high-risk individuals with CT reduced lung cancer deaths by 20.3%. Early detection of lung cancer is an important opportunity for decreasing mortality. The impact of minimally invasive techniques will be particularly useful for these early stage lung cancers and in those patients who may have a benign lesion biopsied. The above trials were conducted at medical institutions recognized for their minimally invasive expertise in the diagnosis and treatment of lung cancer. The literature shows that for early stage lung cancer, minimally invasive surgery is one of the best approaches and the low morbidity and mortality in both of the above trials as they were conducted in high volume centers may have been due in part to the use of minimally invasive technique [20].

In 2011, after the announcement of NLST trial the International Association for the Study of Lung Cancer (IASLC) held a screening workshop. Guidelines for the successful implementation of the lung cancer CT screening implementation across the globe were created. A special panel addressed the issues of surgery in this group of patients. According to The Surgical Expert Group, surgeons should be involved in the set up and design of any screening or demonstration programs. This group also recommended that surgeons must be experienced in thoracic surgery, in evaluating pulmonary CT scans and surgery must be performed in centers with access to a full minimally invasive surgical program, including the ability to perform VATS anatomic lung resection [37].

DISCUSSION

The original impetus for the development of minimally invasive surgery was to minimize or eliminate rib spreading associated with thoracotomy and thus potentially reduce the periopeartive consequences for the patients. Like the proponents of minimally invasive cholecystectomy, advocates of minimally invasive thoracic surgery have suggested that the benefits to patients are obvious. However, it is important to be certain that the minimally invasive approach preserves oncologic principles. Long-term survival for patients who have undergone a minimally invasive technique appear at least equal to a thoracotomy approach in various comparative studies [38] and in two meta-analyses [37,39]. The National Comprehensive Cancer Network guidelines for treatment of lung cancer recognize a video assisted thoracoscopic approach as a reasonable method for the treatment of lung cancer. Thus, it is highly recommended that surgeons learn this technique. Courses are available along with preceptor-ships for those surgeons who are already out in practice. The technology continues to improve, making the surgical procedure safer and easier. As lung cancers get detected at an increasingly smaller size and more peripheral location, and in the context of a screening program minimally invasive surgical techniques become more important, particularly because other non-surgical techniques such as stereotactic radiation become more appealing.

FUTURE DIRECTION

In the United States, health care costs are climbing annually at a staggering rate. However, some medical advances, such as MIS, are critical to improving health care efficiency, enhancing the quality of care provided, and decreasing overall expenses. Savings or profits relating to technology may be difficult to measure but for less complicated cases which is seen with VATS compared with open lobectomy costs are less.

CONCLUSION

Thoracoscopic surgery has a long, fascinating history. In the last few decades, several technological advances have greatly facilitated the use of video technology in the treatment of thoracic disease. The use of VATS has greatly increased; this growth is expected to continue. Today, thoracic MIS is effective as both a diagnostic and therapeutic tool for a variety of diseases and complex problems. As with other minimally invasive techniques, VATS offers patients a number of important clinical benefits when compared to open surgical procedures, such as a significantly lower risk of overall postoperative complications, shorter recovery times, reduction in postoperative pain, and facilitation of the delivery of planned adjuvant chemotherapy.

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