Table 4 Accuracy of preoperative radiographic staging

	CT/PET group ($N = 79$)			CT group ($N = 40$)
	Clinical stage			
	cIA	cIIA	cIIIA	cIA
Pathological stage				
pIA	**58**	4	4	**28**
pIB	8[a]	0	0	8[a]
pIIA	0	**1**	0	0
pIIIA	0	1	**2**	4
Accuracy of preoperative staging (%)				*P* value
Accurate	61 (78)		28 (70)	0.370
Underestimated	9 (12)		12 (30)	
Overestimated	8 (10)		0 (0)	

Bold indicates the number of patients who had been correctly diagnosed preoperative stage

[a] Tumor 2 cm or less in greatest dimension with visceral pleural invasion

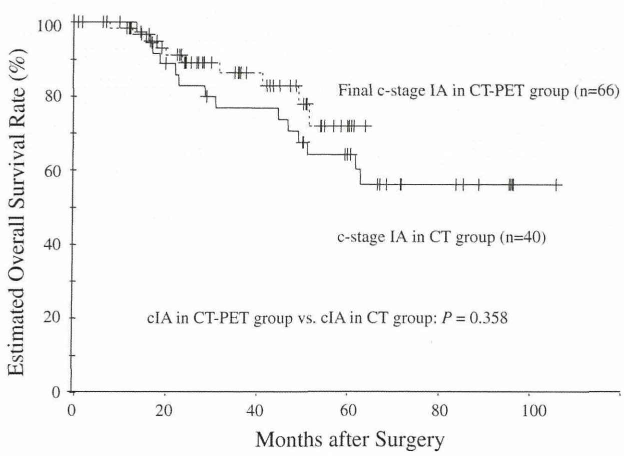

Fig. 3 Survival curves illustrating overall survival for the 66 patients in the CT–PET group diagnosed with final cIA disease and the 40 patients in the CT group diagnosed with cIA disease. The *curves* did not differ significantly for both groups ($P = 0.358$)

based on FDG-PET (CT/PET group), the 3-year overall survival rate was 76.8, 86.3, and 66.7 %, respectively. Although patients who were up-staged based on FDG-PET seemed to show poor survival, the postoperative outcome was similar in both cIA patients in the CT/PET group and cIA patients in the CT group ($P = 0.358$) (Fig. 3).

Discussion

FDG-PET is widely used for the differential diagnosis of benign and malignant pulmonary nodular lesions, the clinical staging of primary lung cancer (e.g., lymph node metastasis, distant metastasis), the evaluation of treatment response, and to assist with prognostic considerations [1–4]. The multi-purpose nature of FDG-PET can, therefore, simplify patient evaluation [14]. Many studies have investigated the utility of FDG-PET for the characterization of lung cancer. Indeed, several randomized controlled trials (RCTs) have shown that preoperative FDG-PET resulted in a reduction in the number of futile thoracotomies, as FDG-PET enables a more accurate staging [15–17]. However, other studies have shown the opposite result [18], as well as a lack of improvement in outcomes even if FDG-PET did result in a reduction in the number of futile thoracotomies [16]. However, these RCTs included a large numbers of stage III–IV advanced cancer cases, and it is impossible to use these results to characterize the utility of FDG-PET for stage I lung cancer.

Small-sized lung cancers are more common in Japan than in Western countries. Of 13,010 resected lung cancers in 2004, 37.5 % were small-sized lung cancers measuring 2 cm or less (cT1a) [7]. Accordingly, the American College of Chest Physicians Guidelines [19] state: "PET to evaluate for mediastinal and extrathoracic staging should be considered in patients with clinical 1A lung cancer being treated with curative intent. (Grade of recommendation, 2C)", and FDG-PET is recommended as a standard modality for evaluating cIA disease before treatment. Recent studies have shown that PET can provide high specificity and positive predict value in lymph node staging even in T1-2N0 NSCLC [6, 8, 9]. However, several studies have concluded that FDG-PET adds little value to CT in the lymph node staging of cT1 NSCLC [5, 7]. The clinical utility of FDG-PET for the staging of small-sized lung cancer (2 cm or less in diameter) diagnosed with cT1aN0 has not been sufficiently studied.

The results of FDG-PET can alter management in patients with NSCLC and predict outcomes more accurately than conventional CT staging. Gregory et al. [20] suggested that there was an association between FDG-PET use and improved lung cancer outcomes. However, these studies were limited and potentially biased. Indeed, Dinan et al. [21] concluded that any association between FDG-PET use and improved outcomes likely reflected stage migration resulting from reallocation of patients to different stage categories on the basis of the application of FDG-PET.

In our study, no significant differences were observed in the accuracy of preoperative staging (CT/PET group, 79.5 % versus CT group, 70.0 %) or outcomes (3-year overall survival rate: "cIA" patients in the CT/PET group, 85.5 % versus "cIA" patients in the CT group, 76.8 %) according to whether or not FDG-PET had been performed. FDG-PET findings were positive in all four patients in which lymph node metastasis was observed in hilar/mediastinal lymph nodes, but there were eight patients in which hilar/mediastinal lymph nodes showed false-positive results using FDG-PET; in other words, these cases were incorrectly upstaged based on FDG-PET results. On the other hand, based on FDG-PET findings, distant metastasis was detected in any of the patients, which renders futile thoracotomies unnecessary. However, the rate of preoperative underdiagnosis was significantly lower in the CT–PET group than in the CT group (CT/PET group, 10.3 % versus CT group, 30.0 %, $P = 0.010$), and, except for the T-stage accuracy (presence or absence of visceral pleural invasion), a significant difference was noted in the rate of underdiagnosis when comparing the groups (CT/PET group, 0 % versus CT group, 10.0 %, $P = 0.012$). Further, patients who were up-staged by FDG-PET were likely to show poor prognosis, even though this difference did not reach the level of statistical significance. Thus, further evaluation is needed to definitely determine the significance of FDG-PET for small-sized lung cancer.

FDG-PET is also very valuable for the identification of second primary cancers or pre-malignant lesions in patients with primary lung cancer [22, 23]. Lin et al. [23] reported that PET–CT revealed a second primary or pre-malignant lesion in 20 (3.1 %) of 649 patients with NSCLC. In our study, FDG-PET identified three patients (3.8 %) with synchronous double malignancies, and all of these patients subsequently underwent curatively treatment. This clinical impact of unexpected pre-malignant lesions or second malignancy detected on FDG-PET during preoperative staging of patients with primary lung cancer on overall management would benefit from further investigation.

The present study demonstrated little benefit performing FDG-PET in every patient with a solid-type small-sized lung cancer (2 cm or less in diameter) staged as N0M0 based on CT findings. However, this study also possesses several limitations. In addition to the fact that this study was a small-sized retrospective analysis, comparative assessment was hampered by the fact that there were different numbers of patients in each group (CT/PET group, 78; CT group, 40). Further, our results could be impacted by the fact that lymph nodes were not evaluated sufficiently histologically in 20 of 78 patients (25.6 %) in the CT–PET group, which may have affected the determination of diagnostic accuracy of preoperative FDG-PET.

Although these limitations must be considered, the present study demonstrated that FDG-PET did not offer clear benefit in terms of the diagnostic accuracy of preoperative staging or prediction of postoperative survival of patients with solid-type small-sized lung cancer (2 cm or less in diameter). Accumulation of additional cases is needed for definitive determination of the utility and cost-benefit of preoperative FDG-PET in patients with solid-type small-sized lung cancers.

Conflict of interest All authors declare that they have no competing interests.

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Case Report

Three-dimensional simulation, surgical navigation and thoracoscopic lung resection

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This report describes a 3-dimensional (3-D) video-assisted thoracoscopic lung resection guided by a 3-D video navigation system having a patient-specific 3-D reconstructed pulmonary model obtained by preoperative simulation. A 78-year-old man was found to have a small solitary pulmonary nodule in the left upper lobe in chest computed tomography. By a virtual 3-D pulmonary model the tumor was found to be involved in two subsegments (S1 + 2c and S3a). Complete video-assisted thoracoscopic surgery bi-subsegmentectomy was selected in simulation and was performed with lymph node dissection. A 3-D digital vision system was used for 3-D thoracoscopic performance. Wearing 3-D glasses, the patient's actual reconstructed 3-D model on 3-D liquid-crystal displays was observed, and the 3-D intraoperative field and the picture of 3-D reconstructed pulmonary model were compared.

INTRODUCTION

Although conventional open thoracotomy has been replaced with video-assisted thoracoscopic surgery (VATS) for many pleuro-pulmonary diseases, video-assisted thoracoscopic lung resection such as segmentectomy and subsegmentectomy requires surgeons to have much experience and skill for performing the procedure safely. Recently, 3-dimensional (3-D) images, which help surgeons, have been used in preoperative simulation for VATS lung resection [1].

Previously, our department has reported a patient-specific virtual 3-D pulmonary model for thoracoscopic lung resections [2, 3]. This report describes 3-D video-assisted thoracoscopic lung resection guided by a 3-D video navigation system having a patient-specific 3-D reconstructed pulmonary model obtained by preoperative 3-D simulation.

CASE REPORT

A 78-year-old man with a history of pulmonary tuberculosis and gastric cancer was found to have a small solitary pulmonary nodule in the left upper lobe 4 months ago in chest computed tomography (CT) done for postoperative follow-up for gastric cancer (Fig. 1A). Routine laboratory study results, including the tumor markers carcinoembryonic antigen, sialyl Lewis X-1, and squamous cell carcinoma antigen, were within normal limits. He was preoperatively staged as N0 by positron emission tomography, high-resolution CT (HRCT) of the chest and abdomen, and the magnetic resonance imaging of brain. He was also examined by thin-sliced chest CT scan. Based on thin-sliced plain chest CT scan, based on the data of which a virtual 3-D pulmonary model was designed for him on a personal computer (PC) before operation. Patient-specific 3-D pulmonary model was created by the following methods. Homemade software, called CTTRY (Tokyo Women's Medical University, Tokyo, Japan), was used [2]. By using 120 of 1-mm thin-sliced CT scan images of the tumor and the hilum in digital imaging and communications in medicine format, CTTRY allowed us to mark pulmonary arteries, veins, bronchi and tumor in the thin-sliced CT scan images. CTTRY attempted to reconstruct an anatomical model with the help of anatomically correct

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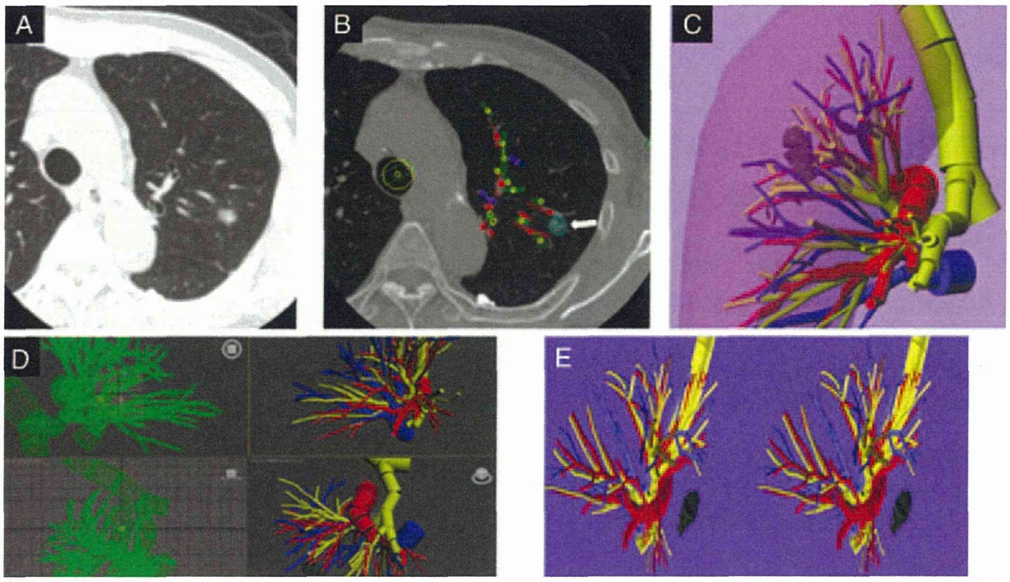

Figure 1: (**A**) Chest CT image shows a primary lesion as ground glass opacity in 2 segments (S1 + 2 and S3) of the left upper division. (**B**) Locations and thicknesses of tumor. Yellow dots indicate the bronchi; red dots, the pulmonary arteries; blue dots, the pulmonary veins; white, tumor, which were rendered as different-sized cylinders by the home-made software program (CTTRY). The striped rectangles of each color were a trace of the dots of each color. (**C**) Virtual 3-D image was reconstructed using shareware (Metasequoia). Yellow indicates the trachea and bronchi; red, pulmonry arteries; blue, pulmonary veins; the veiled area, the lung. (**D**) Data of the reconstructed 3-D images were converted with Autodesk® 3ds Max® 2012. (**E**) REMO Exporter®, which reproduces Autodesk 3ds Max data with real-time CG, can indicate with a stereoscopic vision display by 3-DCG data. On a PC, reconstructed 3-D pulmonary images were provided side-by-side and were output to a monitor. Dark yellow indicates the stapled bronchi; dark blue, resected pulmonary veins.

images (Fig. 1B). After feeding the reconstructed model images into a PC, the pulmonary arteries, veins and bronchi of patient were traced and marked by an experienced thoracic surgeon for the anatomic structure on the images. The location and thickness of the bronchi and pulmonary vascular were rendered as various-sized cylinders. Then, based on the resulting numerical data, a 3-D image, which was converted by the surface-rendering technique, was reconstructed using software (Metasequoia, http://www.metaseq.net/) (Fig. 1C). When his virtual 3-D pulmonary model was reconstructed by CTTRY, the tumor was found to be involved in two subsegments [horizontal subsegment of apicoposterior segment (S1 + 2c) and posterior subsegment of anterior segment (S3a)] (Fig. 1E). Further, the data of the reconstructed 3-D images by Metasequoia were converted with Autodesk® 3ds Max® 2012 (Autodesk, San Rafael, CA, USA) (Fig. 1D). Finally, image software, REMO Exporter® (3D Incorporated, Kanagawa, Japan), which reproduced Autodesk data with real-time computer graphics (CG), was able to indicate with a stereoscopic vision display by 3-DCG data. On a PC, reconstructed 3-D pulmonary images were provided side by side and were output to a monitor. Surgeons were able to watch the 3-DCG of the reconstructed 3-D pulmonary model with a 3-D liquid-crystal (LC) monitor by REMO Viewer® (3D Incorporated). The reconstructed 3-D images on a 3-D LC monitor were able to be manipulated by virtual surgical procedures such as reshaping, cutting and moving (Fig. 1E). The simulation result was able to allow the subsegmentectomy of S1 + 2c and S3a to be performed with a sufficient surgical margin.

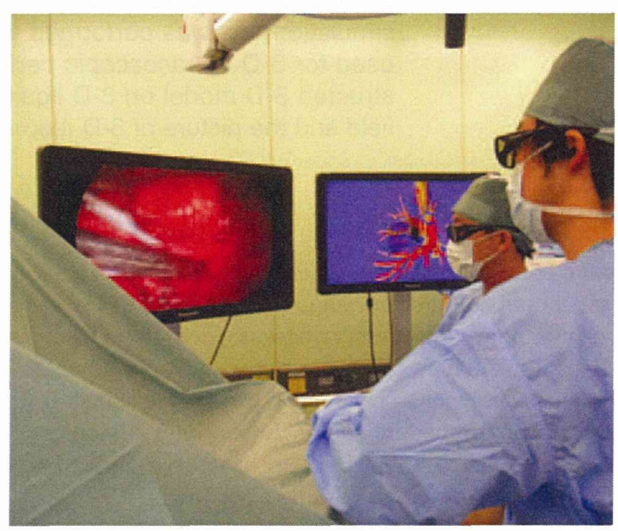

Figure 2: In 3-D thoracoscopic surgery with 3-D navigation, wearing glasses, comparing 3-D intraoperative field during VATS and the picture of 3-D reconstructed pulmonary model, with 3-D LC displays, the surgeons performed thoracoscopic procedures.

A 3-D digital vision system (Shinko Optical, Tokyo, Japan) was used for 3-D thoracoscopic performance. This system included a 11-mm, 30° stereo digital scope and a 3-D data-processing unit. Wearing glasses, thoracoscopic procedures were performed by the surgeons and by means of intraoperative navigation, the patient's actual reconstructed 3-D pulmonary model was able to be watched with 3-D LC displays (Fig. 2). Complete VATS bi-subsegmentectomy was selected

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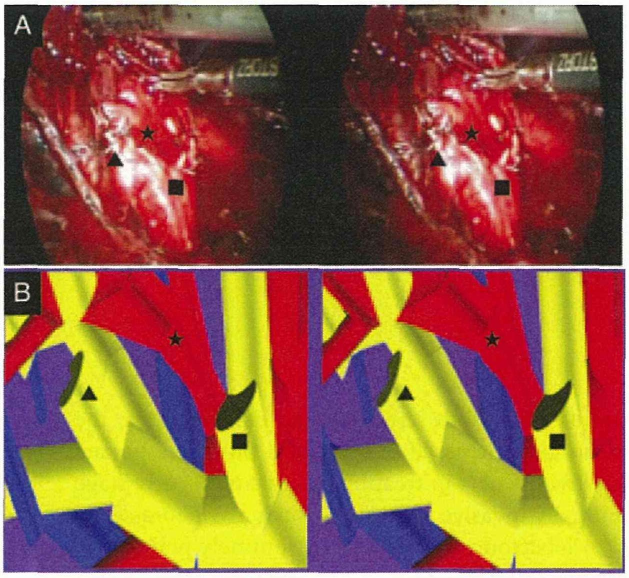

Figure 3: Comparison between the 3-D navigation of patient-specific 3-D reconstructed pulmonary model and the operative view. (**A**) The operative view of the patient was extracted from digital video data taken during the operation and was provided on a PC after operation. (**B**) In patient-specific 3-D image, the target bronchus and vascular branching pattern were similar to intraoperative findings. B1 + 2c (Filled Square) and B3a (Filled Triangle) were dissected and stapled separately. A1 + 2c (Filled Star) was detected.

in preoperative simulation and was performed with intraoperative assessment of lymph nodes; hilar node dissection with mediastinal lymph node sampling was done using conventional thoracoscopic instruments (Fig. 3A and B). Final histologic examination revealed T1aN0M0 pulmonary adenocarcinoma. The patient's postoperative course was uneventful.

DISCUSSION

Recently, smaller size lung cancers in a peripheral location are detected by HRCT. For these lung cancers, lung segmentectomy/subsegmentectomy has become a good option and has been reported to be able to yield promising outcomes comparable with those of lobectomy. On the other hand, video-assisted thoracoscopic lung resection such as segmentectomy and subsegmentectomy requires surgeons to have much experience and skill for performing the procedure safely.

Advances in HRCT scans have enabled reconstitution of fine virtual 3-D pulmonary models. Virtual reconstructed 3-D models can show easily the positional relationship among the target nodule, pulmonary vessels and bronchi, and allow surgeons to access more peripheral vascular branches and target segmental/subsegmenatal bronchi with an accurate detection during a thoracoscopic procedure [1]. As a result, reconstructed 3D pulmonary models guide surgeons in avoiding vascular injury in complete VATS lung resections. Further, simulation using a patient-specific 3-D pulmonary model helps surgeons to select the most suitable type of VATS lung resection [2–4].

In 3-D thoracoscopic surgery with 3-D navigation onto a 3-D LC display, depth perception is improved, compared with a conventional thoracoscopic surgery, and 3-D surgery is similar to an operative field vision of open thoracotomy [5]. Although 3-D vision was hampered by technical and financial limitations previously, a 3-D thoracoscopic system has been improved to real-time transmission. There is no study that performs 3-D endoscopic surgery using both presurgical 3-D simulation and actual navigation with a reconstructed patient pulmonary model. In our 3-D thoracoscopic surgery under 3-D navigation, comparing 3-D intraoperative field and the picture of 3-D reconstructed pulmonary model, surgeons simply wore glasses and were able to perform thoracoscopic surgery, such as segmentectomy and subsegementectomy, more easily and precisely. This technique can be applied to tumor <2 cm. We ensured that the safety surgical margin was >2 cm from the tumor.

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REVIEW ARTICLE

Recent advances in video-assisted thoracoscopic surgery for lung cancer

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Keywords
Lung cancer surgery; minimal invasive surgery; video-assisted thoracoscopic surgery (VATS)

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Abstract

As a result of increased use of CT in both screening and daily practice, the number of early lung cancers has increased enormously. Surgeons pursue both curativity and reduced invasiveness in treating patients with early stage lung cancer; therefore, minimally invasive operations, such as video-assisted thoracoscopic surgery (VATS) lobectomy are now being routinely performed. Most previous reports have shown that there is no difference in mortality and local recurrence between open surgery and VATS in stage I patients. However, surgeons' improved technical experience and patients' demands could soon make VATS lobectomy the operative method of choice for early stage lung cancer. Moreover, the indications for VATS are expanding to encompass complex procedures such as segmentectomy or sleeve resection. Training and dissemination of the technique and the monitoring of outcomes are necessary.

Introduction

Since CT has become commonly used in routine practice, we have been able to detect early stage lung cancers more easily. Furthermore, minimally invasive surgery has become widely performed, mainly for early stage lung cancers. In Japan, more than half of lung cancer operations are performed with video-assisted thoracoscopic surgery (VATS) (1). For some lesions, such as adenocarcinoma *in situ* or minimally invasive adenocarcinomas of a relatively non-aggressive biological nature (2), conventional operations may be overtreatment. This means that minimally invasive operations, such as VATS lobectomy or segmentectomy, are increasingly being demanded by society. In addition to meeting patient demands, minimally invasive surgery would help address issues related to the increased number of octogenarian patients. It also could be used when surgical treatment for second primary lung cancer is indicated.

Recent systematic reviews and large case studies have demonstrated that VATS lobectomy for lung cancer is associated with reduced chest tube placement duration, shorter length of hospital stay and lower rates of postoperative complications (3,4). However, the definition of VATS can vary according to individual surgeons, and we lack prospective scientific data demonstrating the superiority of VATS over thoracotomy. At present, VATS is a routine surgical procedure used mainly for early stage lung cancer. However, efforts should be made to establish a consensus regarding the indications and limitations of VATS through the collection of scientific data.

What is VATS lobectomy?

It seems that there are two kinds of VATS lobectomy, hybrid VATS and complete VATS (5), though these terms have not been standardized In hybrid VATS, the surgeon makes a small thoracotomy (8–10 cm) with rib spreading and employs both direct vision inside the chest and video monitor imaging. A thoracoscope is also used for the purpose of illumination. In contrast, when performing complete VATS, the surgeon makes three or four small incisions with no rib spreading and looks only at the video monitor during the operation. Thoracic surgeons are still debating the correct definition of VATS lobectomy. In the Cancer and Leukemia Group B 39802 prospective, multi-institutional study, Swanson *et al.* defined

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VATS lobectomy as anatomic lobectomy with individual ligation of lobar vessels and bronchi as well as hilar lymph node dissection or sampling with the video monitor used for guidance, two or three ports, and no retractor use or rib spreading (6). The Swanson *et al.* study aimed to evaluate the feasibility of performing VATS lobectomy in a standardized manner for patients with peripheral lung cancers less than 3 cm in size.

Given that there is no generally accepted definition of "VATS lobectomy," we believe that the classifications referenced above, complete VATS and hybrid VATS, should become the standard. Otherwise, varying terminology among thoracic surgeons could hinder the collection of accurate perioperative data on lung cancer.

Evidence in VATS lobectomy

Outcome

There have only been two small randomized studies concerning VATS lobectomy. Kirby *et al.* randomized 61 stage I lung cancer patients into two groups: VATS lobectomy or open surgery. This study showed reduction of postoperative complications in the VATS group (6% vs 16%), but no significant decrease in the duration of chest tube drainage, length of hospital stay or postoperative pain (7).

Sugi *et al.* randomized 100 stage IA lung cancer patients into VATS lobectomy or thoracotomy groups. After an average of 5 years of follow-up, there were no statistically significant differences in recurrence and survival rates. The 5-year survival in the VATS and open thoracotomy groups were 90% and 85%, respectively (8). There have been two large-scale systematic reviews to compare the performance of VATS and open surgery. Whitson *et al.* collected and analyzed 39 studies (1 randomized, 38 non-randomized) and showed that VATS lobectomy was associated with shorter chest tube drainage duration, reduced hospital stay and improved survival (at 4 years postoperative) (3). Yan *et al.* analyzed 21 eligible comparative studies (2 randomized, 19 non-randomized) and found no significant statistical differences between VATS and open thoracotomy lobectomy in terms of postoperative complications such as prolonged air leakage ($P = 0.71$), arrhythmia ($P = 0.86$), and pneumonia ($P = 0.09$). Additionally, there were no differences in mortality ($P = 0.49$) and locoregional recurrence ($P = 0.24$), but the data suggested a reduced systemic recurrence rate in VATS patients ($P = 0.03$) (4). These systematic reviews suggest that VATS lobectomy, when compared with open surgery, is an appropriate procedure for selected patients with early stage lung cancer. Gopaldas *et al.* analyzed a total of 13 619 discharge records of lung cancer patients who had been surgically treated (thoracotomy 12 860, VATS 759). The two groups had similar mortality rates (3.1% vs 3.4%, $P = 0.67$), hospital stays (9.3 vs 9.2 days, $P = 0.84$), pulmonary complications (32.2% vs 31.2%, $P = 0.55$). However, the VATS group had more complications during operation (odds ratio: 1.6, 95% confidence interval: 1.0–2.4, $P = 0.04$) (9).

Table 1 shows representative reports of VATS lobectomy from multiple studies. VATS seems to be associated with shorter chest drainage tube duration and hospital stay, which suggests that VATS lobectomy may actually be a safe operation in appropriately selected patients (3,4,9–11).

Lymph node dissection

Mediastinal lymph node dissection is a critical issue that needs to be solved in order to expand the indications of VATS in patients with lung cancer. D'Amico *et al.* evaluated patients who underwent lobectomy (VATS 199, open thoracotomy 189) and suggested that the mean number of N2 lymph node stations was similar in VATS ($n = 3.15$) and thoracotomy ($n = 2.91$). Furthermore, the difference in the total number of N1 and N2 nodes resected in each group was not statistically significant (12). Boffa *et al.* analyzed 11 531 clinical stage I lung cancer operations (7137 thoracotomy, 4394 VATS). Nodal upstaging was seen in 14.3% in the thoracotomy group and 11.6% in VATS group ($P < 0.001$). Among these, hilar or peribronchial nodal metastases were identified more often by thoracotomy than by VATS (54% vs 42%, $P = 0.002$), but upstaging from cN1 to pN2 was similar (15.6% in thoracotomy vs 15.3% in VATS). The importance of complete hilar and peribronchial dissection must be emphasized in the VATS approach (13). Denlinger *et al.* evaluated clinical stage I patients treated by VATS lobectomy ($n = 79$) and open lobectomy ($n = 464$) (14). Fewer lymph nodes (7.4 vs 8.9, $P = 0.029$) and fewer mediastinal lymph nodes (2.5 vs 3.7, $P = 0.004$) were dissected with VATS than with thoracotomy. Subset analysis revealed that there was no difference in lymph node 4R, 5 and 6, but lymph node 7 was dissected more extensively by thoracotomy (14). This fact might suggest the difficulty of subcarinal nodes, which many surgeons might encounter. Systemic lymph node dissection has not been proven to improve the prognosis of lung cancer, but it might be helpful in accurate staging (15). Standardization of the technique and expertise of VATS lymph node dissection is necessary to resolve this issue.

VATS segmentectomy

Lobectomy has been a standard operative procedure for lung cancer. However, given the tremendous increase in

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Table 1 Representative reports on VATS lobectomy

Author (reference)	Scott *et al.* (10)	Paul *et al.* (11)	Gopaldas *et al.* (9)	Whitson *et al.* (3)	Yan *et al.* (4)
Database	ACSOG Z0030	STS database		Meta-analysis	Meta-analysis
Number of cases					
VATS	66	1281	759	3114	1391
Thoracotomy	686	1281	12860	3256	1250
Length of stay (day)					
VATS	5	4	9.2	8.3	12
Thoracotomy	7	6	9.3	13.3	12.2
	$P < 0.001$	$P < 0.0001$	$P = 0.84$	$P = 0.016$	NA
Complication rate					
VATS	27.3%	26.2%	43.1%	16.4%	NA
Thoracotomy	47.8%	34.7%	44.1%	31.2%	NA
	$P = 0.005$	$P < 0.0001$	$P = 0.592$	$P = 0.018$	NA
Duration of chest tube drainage (day)					
VATS	1.5% > 7	3	4.2	NA	4.6
Thoracotomy	10.8% >7	4	5.7	NA	5.3
	$P = 0.029$	$P < 0.0001$	$P = 0.025$	NA	NA
Duration of air leak (day)					
VATS	1.5% > 7	7.6% > 5	NA	5%	NA
Thoracotomy	7.3% > 7	8.7% > 5	NA	8.8%	NA
	$P = 0.155$	$P = 0.35$	NA	$P = 0.27$	$P = 0.75$

ACSOG Z0030, American College of Surgeons Oncology Group Z0030; STS, Society of Thoracic Surgeons; VATS, video-assisted thoracoscopic surgery.

the number of peripheral early stage lung cancers, segmentectomy is more frequently performed for selected early stage lung cancer to pursue both curability and reduced invasiveness (16,17). There has been a debate about the indications and outcome of segmentectomy for lung cancer, and the results of an ongoing prospective randomized trial (lobectomy vs segmentectomy) should clarify the role of this procedure (18). Thoracoscopic segmentectomy is more controversial because of the procedure's complexity and the need to ensure the safety margin without palpation of the tumor. Theoretically, VATS segmentectomy can preserve the pulmonary volume and decrease the chest wall damage, and thus, it is attracting great interest with advances in VATS. VATS segmentectomy has been performed in some leading facilities, and preliminary results have shown equivalent rates of morbidity, recurrence and survival for early lung cancers less than 2 cm in diameter (19–21).

Simulation of VATS

Anatomic variations of pulmonary vessels make lung resection more difficult, especially when the separation of the interlobular fissure is incomplete. Thus, preoperative knowledge of each patient's surgical anatomy would contribute greatly to the safety of operations. The development of multi-detector CT has made it feasible to obtain 3-D images of the lung structures. These 3-D displays of anatomic structures have enabled improved decision-making on surgical methods and preoperative planning. There are several reports demonstrating the usefulness of 3-D CT for preoperative simulation and navigation during surgery (22–24).

Fukuhara *et al.* performed preoperative 3-D CT for stage I lung cancers that were scheduled for VATS lobectomy. A total of 49 patients were studied and all cases successfully underwent VATS, with 95% of pulmonary artery branches depicted on 3-D CT identified during operation (23). Oizumi *et al.* used this technique to support VATS segmentectomy in 52 patients; 3-D imaging was useful in identifying the intersegmental vein, which was the key structure in identifying the intersegmental plane (resection line) (24).

Using new generation software, we can automatically calculate the distance between the tumor and surgical margin after 3-D reconstruction of the tumor, pulmonary artery and vein, bronchial tree, and lung parenchyma. This function is useful in planning segmentectomy, engaging in preoperative virtual simulation, ensuring an accurate safety margin and gaining intraoperative guidance regarding surgical anatomy (25).

Discussion

VATS lobectomy for lung cancer has evolved over the past 20 years. There are many reports suggesting the superiority of VATS lobectomy over open thoracotomy, mainly in terms of perioperative outcome. However, most of these reports involve retrospective data obtained

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from single institutions (26). Also, analysis should differentiate between two procedures, complete VATS and hybrid VATS, rather than simply using "VATS procedure."

As this minimally invasive approach becomes more widely available, we should investigate the present status of VATS lobectomy in terms of safety and survival advantages. Robotic surgery has recently been employed in the field of thoracic surgery (27–29), and it may play a more important role in the near future. However, expanding the indications for VATS, as well as for complex procedures such as segmentectomy or sleeve resection, is currently a more pressing issue for treating advanced lung cancer. Training surgical staff, teaching the technique widely, and keeping robust databases and monitoring outcomes are essential in applying VATS to a wider range of procedures.

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