Thoracic Cancer Open Access

Thoracic Cancer ISSN 1759-7706

ORIGINAL ARTICLE

Three-dimensional (3D)- computed tomography bronchography and angiography combined with 3D-video-assisted thoracic surgery (VATS) versus conventional 2D-VATS anatomic pulmonary segmentectomy for the treatment of non-small cell lung cancer

Xiao-wei She[1,2*], Yun-bin Gu[3*], Chun Xu[1], Chang Li[1], Cheng Ding[1], Jun Chen[1] & Jun Zhao[1]

1 Department of Thoracic Surgery, The First Affiliated Hospital of Soochow University, Suzhou, China
2 Department of Thoracic Surgery, Suzhou Municipal Hospital North District, Nanjing Medical University, Suzhou, China
3 Department of Radiology, The First Affiliated Hospital of Soochow University, Suzhou, China

Keywords
3D; bronchography and angiography; non-small cell lung cancer; segmentectomy; VATS.

Correspondence
Jun Zhao, Department of Thoracic Surgery, The First Affiliated Hospital of Soochow University, 899 Ping Hai Road, Suzhou 215006, China.
Tel: +86 185 5039 9999
Fax: +86 512 6523 8350
Email: zhaojia0327@126.com

*These authors contributed equally to this work.

Received: 6 November 2017;
Accepted: 1 December 2017.

doi: 10.1111/1759-7714.12585

Thoracic Cancer **9** (2018) 305–309

Abstract

Background: Compared to the pulmonary lobe, the anatomical structure of the pulmonary segment is relatively complex and prone to variation, thus the risk and difficulty of segmentectomy is increased. We compared three-dimensional computed tomography bronchography and angiography (3D-CTBA) combined with 3D video-assisted thoracic surgery (3D-VATS) to perform segmentectomy to conventional two-dimensional (2D)-VATS for the treatment of non-small cell lung cancer (NSCLC).

Methods: We retrospectively reviewed the data of randomly selected patients who underwent 3D-CTBA combined with 3D-VATS (3D-CTBA-VATS) or 2D-VATS at the Department of Thoracic Surgery, The First Affiliated Hospital of Soochow University Hospital, from January 2014 to May 2017.

Results: The operative duration of 3D group was significantly shorter than the 2D group ($P < 0.05$). There was no significant difference in the number of dissected lymph nodes between the two groups ($P > 0.05$). The extent of intraoperative bleeding and postoperative drainage in the 3D group was significantly lower than in the 2D group ($P < 0.05$). Chest tube duration in the 3D group was shorter than in the 2D group ($P < 0.05$). Incidences of pulmonary infection, atelectasis, and arrhythmia were not statistically different between the two groups ($P > 0.05$). However, hemoptysis and pulmonary air leakage (>3d) occurred significantly less frequently in the 3D than in the 2D group ($P < 0.05$).

Conclusion: 3D-CTBA-VATS is a more accurate and smooth technique and leads to reduced intraoperative and postoperative complications.

Introduction

The increased popularity of physical examinations and the wide use of low-dose chest computed tomography (CT) scans for chest examinations in China have led to an increase in the early detection rate of lung cancer each year.[1] The use of anatomic pulmonary segmentectomy has gradually increased for the treatment of early non-small cell lung cancer (NSCLC). Anatomic segmentectomy can maximally preserve healthy lung tissue and avoid unnecessary loss of lung function, and is the best treatment option for lung metastatic tumors or patients with poor lung function who cannot tolerate lobectomy.[2] Compared to the pulmonary lobe, the anatomical structure of the segment is relatively complex and prone to variation, thus the risk and difficulty of segmentectomy is increased. We use three-dimensional computed tomography bronchography and angiography (3D-CTBA) to ascertain the location of the lung nodule and its relationship to the surrounding blood vessels and bronchi, to detect anatomical variation,[3] and design a sound procedure and strategy before surgery. We use three-dimensional video-assisted thoracic surgery (3D-VATS) to perform segmentectomy because it provides 3D surgical vision and allows for greater accuracy, therefore reducing the risk of intraoperative injury.

In this study, we retrospectively analyzed the clinical features of segmentectomy cases in our department and compared 3D-CTBA combined with 3D-VATS (3D-CTBA-VATS) to conventional two-dimensional video-assisted thoracic surgery (2D-VATS). We analyzed and summarized the advantages of the 3D-CTBA-VATS technique for anatomical segmentectomy for the treatment of NSCLC.

Methods

Patient selection

We retrospectively analyzed the records of patients who underwent anatomical segmentectomy via 3D-CTBA-VATS or 2D-VATS in our department from January 2014 to May 2017. Patients were divided into randomly selected groups (Table 1). The eligibility criteria were as follows: (i) clinical diagnosis of NSCLC and clinical staging of $T_{1a}N_0M_0$ or $T_{1b}N_0M_0$; (ii) each patient underwent anatomical segmentectomy using 3D-CTBA-VATS or 2D-VATS; (iii) no limitation on age or gender; (iv) preoperative definitive diagnosis by chest CT, head magnetic resonance imaging, abdominal B-ultrasound and bone scan excluding distant metastasis, and routine assessment of cardiopulmonary function excluding surgery contraindications; and (v) no neoadjuvant chemotherapy or radiotherapy treatment had been administered.

Table 1 Clinical characteristics

Characteristics	3D (*n* = 51)	2D (*n* = 51)	t/χ^2	*P*
Gender, *n* (%)			0.358	0.550
Male	21 (41.1)	24 (47.0)		
Female	30 (58.8)	27 (52.9)		
Age, y, mean (SD)	59.3 ± 10.4	58.5 ± 9.7	0.431	0.667
Preoperative smoker, *n* (%)			0.729	0.393
Yes	18 (35.2)	14 (27.4)		
No	33 (64.7)	37 (72.5)		
Tumor location, *n* (%)			0.982	0.322
Right lung	27 (52.9)	22 (43.1)		
Left lung	24 (47.0)	29 (56.8)		
Comorbidity *n* (%)				
Hypertension	10 (19.6)	13 (25.4)	0.505	0.477
Diabetes mellitus	7 (13.7)	5 (9.8)	0.378	0.539
COPD	4 (7.8)	6 (11.7)	-	0.741
Arrhythmia	2 (3.9)	3 (5.8)	-	0.678

COPD, chronic obstructive pulmonary disease; 2D, two-dimensional; 3D, three-dimensional; SD, standard deviation.

The Ethics Committee of the First Affiliated Hospital of Soochow University approved the study. Written informed consent was obtained from all patients before surgery.

Surgical procedures

DeepInsight software (Northeastern University, Shenyang, China) was used preoperatively to construct a 3D-CTBA image to ascertain the location of the nodule. According to 3D-CTBA imaging, the position and structure of targeted segmental blood vessels and bronchi were analyzed, anatomical variation located, and the surgical procedure planned. Because of the relative complexity of each basal segment, complete preoperative evaluation is required to design the appropriate surgical procedure. For cases with smaller nodules, a hook wire was positioned intraoperatively through CT into adjacent parts of the smaller nodule.

The procedure is as follows. Patients are administered general anesthesia with double-lumen ventilation and lie on their healthy side at a 90° position. A 1 cm incision at the seventh or eighth intercostal midaxillary line is marked for the endoscopic hole, and a 3 cm incision at the fourth intercostal (nodule in the upper or middle lobe) or fifth intercostal (nodule in the lower lobe) axillary line for the operating hole. The surgeon stands on the ventral side of the patient, and the assistants on the contralateral side, all wearing 3D polarized glasses. The German KARL STORZ 3D thoracoscopic system (Karl Storz, Tuttlingen, Germany) is used. Surgery is conducted according to preoperative 3D-CTBA imaging and the designed surgical program, combined with intraoperative practical 3D imaging.

In cases where the position of the nodule is deep and close to the segmental blood vessels or bronchi, segmentectomy is performed. If the nodule is on the lung surface, wedge resection is performed and the specimen is sent for rapid-freezing pathology. In cases of well-developed pulmonary fissures, blood vessels are dealt with from the pulmonary fissure, otherwise from the pulmonary hilum. Careful identification of the targeted segmental blood vessels according to preoperative 3D-CTBA imaging (which has confirmed any anatomic structure variation) is required to avoid accidental damage to segmental blood vessels and bronchi.

The smaller sub-branch of segmental blood vessels can be directly resected using an ultrasonic knife, while larger branches should be ligated or a linear cutting stapler should be used. We routinely use the "lung expansion-collapse method" to ascertain segmental borders: the targeted segmental bronchus is blocked and resected; the lung is manually inflated until the lung tissue completely expands and then single lung ventilation is maintained on the healthy side of the lung for about 15 minutes, most segments of the affected side lung will collapse, but the targeted segment still expend. A high frequency electric knife, ultrasonic knife, or linear cutting stapler is used to resect the targeted segment at the tissue boundary between the expansion and collapse. The surgical margins of all malignant nodules must be ≥ 2 cm or at least equal to the diameter of the tumor, and if necessary, multiple segmental resection is performed. N1 (group 10–13) and N2 lymph nodes should be routinely sampled and sent for rapid-freezing pathology during surgery. In patients with pathology positive for malignancy, lobectomy and systemic lymph node dissection should be performed.

In the 2D group, preoperative chest radiograph CT scans were used to ascertain the location of the nodule, and the German KARL STORZ 2D thoracoscopic system was used. The procedure followed was similar to the 3D group.

Statistical analysis

SPSS version 22.0 (IBM Corp., Armonk, NY, USA) was used to analyze the data. Data were presented as mean ± standard deviation ($\pm s$) for continuous variables and percentages for dichotomous variables. Continuous variables were analyzed using the *t*-test, and categorical variables using χ^2 or Fisher's exact test. A P value of < 0.05 was considered statistically significant.

Results

Segment distribution and postoperative pathology is shown in Tables 2 and 3. All thoracoscopy procedures were successfully completed without conversion to thoracotomy. The operative duration was shorter in the 3D than the 2D group, and the difference was statistically significant ($P < 0.05$). There was no significant difference in the number of dissected lymph nodes between the two groups ($P > 0.05$). Intraoperative bleeding, postoperative drainage, and chest tube duration in the 3D group were all significantly lower than in the 2D group ($P < 0.05$). There was no statistically significant difference in postoperative complications, such as pulmonary infection, atelectasis, and arrhythmia, between the two groups ($P > 0.05$). Postoperative complications of hemoptysis and pulmonary air leakage (>3d) occurred significantly less frequently in the 3D compared to the 2D group ($P < 0.05$), as shown in Table 4. After 12 months of follow-up, no bronchial pleural fistula, chylothorax, encapsulated pleural effusion, recurrence or distant metastasis occurred in patients in either group.

Table 2 Segmentectomy position and number of cases

Segmentectomy position	3D-L (*n* = 23)	3D-R (*n* = 28)	2D-L (*n* = 26)	2D-R (*n* = 25)
S1	–	2	–	4
S2	–	3	–	3
S3	2	5	2	3
S1 + 2	3	3	4	2
S1 + 2 + 3	3	–	2	–
S4 + 5	5	–	5	–
S6	6	9	8	10
S7 + 8	1	2	1	1
S9 + 10	1	1	1	1
S7 + 8 + 9 + 10	2	3	3	2

2D, two-dimensional; 3D, three-dimensional; L, left lung; R, right lung.

Table 3 Postoperative pathology and number of cases

Pathological category	3D (*n* = 51)	2D (*n* = 51)
Benign	8 (15.6%)	7 (13.7%)
Benign nodule	3 (5.8%)	4 (7.8%)
Atypical adenomatous hyperplasia	5 (9.8%)	3 (5.8%)
Malignant	43 (84.3%)	44 (86.2%)
Adenocarcinoma in situ	23 (45.0%)	20 (39.2%)
Minimally invasive adenocarcinoma	17 (33.3%)	19 (37.2%)
Other types and metastatic tumor	3 (5.8%)	5 (9.8%)

2D, two-dimensional; 3D, three-dimensional.

The two groups were followed up for 12 months, there were no bronchial pleural fistula, chylothorax, encapsulated pleural effusion and other complications, two groups of patients with malignant nodules without recurrence and distant metastasis cases.

Discussion

Churchill and Belsey reported the first case of pulmonary segmentectomy for the treatment of bronchiectasis in 1939.[4] Over the following decades, surgeons have attempted to use segmentectomy to treat lung cancer. However, in 1995, a randomized controlled study by Ginsberg and Rubenstein showed that the recurrence rate after localized pulmonary resection was significantly higher than after lobectomy for lung cancer.[5] Subsequently, the use of localized pulmonary resection was limited in many countries and medical centers. In recent years, improvements in diagnostic imaging technology and the popularity of low dose CT scanning for chest examination have led to a significant increase in the early detection rate of lung cancer. However, some studies have indicated that there is no significant difference in postoperative overall survival between patients with an NSCLC nodule ≤ 2 cm who underwent anatomic pulmonary segmentectomy or standard lobectomy.[6–8] The patient sample in the Ginsberg and Rubenstein study included a higher number of patients with nodules ≥ 2 cm who underwent wedge resection and thus there were significant differences between the results

Table 4 Intraoperative and postoperative data

Variable	3D (*n* = 51)	2D (*n* = 51)	t/χ^2	*P*
Operative duration, min, mean (SD)	141.9 ± 29.1	160.9 ± 31.5	−3.162	0.002
Blood loss, ml, mean (SD)	96.4 ± 47.5	131.7 ± 48.5	−3.709	0.000
Number of DLN, *n*, mean (SD)	9.2 ± 2.3	9.4 ± 2.3	−0.423	0.674
Postoperative drainage, mL, mean (SD)	425.4 ± 163.5	664.7 ± 245.6	−5.790	0.000
Chest tube duration, days, mean (SD)	2.7 ± 1.0	4.2 ± 1.6	−5.796	0.000
Postoperative complications, *n* (%)				
Pulmonary air leakage	2 (3.9)	10 (19.6)	-	0.028
Pneumonia	3 (5.8)	2 (3.9)	-	1.000
Arrhythmia	4 (7.8)	6 (11.7)	-	0.741
Atelectasis	1 (1.9)	2 (3.9)	-	1.000
Hemoptysis	1 (1.9)	8 (15.6)	-	0.031
Hospital length of stay, days, mean (SD)	5.1 ± 1.3	5.5 ± 1.5	−1.411	0.161
Average cost of surgery, CNY, mean (SD)	5,5532.2	5,4751.7	0.842	0.402

2D, two-dimensional; 3D, three-dimensional; CNY, China Yuan; DLN, dissected lymph nodes; SD, standard deviation.

of localized pulmonary resection and lobectomy. Therefore, the current surgical approach for early lung cancer has gradually converted from the standard anatomical lobectomy to segmentectomy.

Anatomical pulmonary segmentectomy has attracted attention for the treatment of early lung cancer, although controversy remains over whether the oncological efficacy of segmentectomy is equal to standard lobectomy. A series of recent studies showed no significant difference between segmentectomy and standard lobectomy in patients with an NSCLC nodule diameter ≤ 2 cm, especially those with carcinoma in situ or micro invasive adenocarcinoma.[9,10] Nevertheless, we are cautious when treating patients with pulmonary nodules via segmentectomy. We regularly observe nodules with a diameter < 8 mm and choose segmentectomy for nodules sized from between ≥ 8 and ≤ 20 mm in diameter, with malignant characteristics on CT imaging, or in which the tumor size has not significant changed after 1–3 months. According to the literature and considering our experience, we perform segmentectomy in the following cases: (i) adenocarcinoma in situ or minimally invasive adenocarcinoma nodules with peripheral diameter ≤ 2 cm; (ii) ground glass density nodule component is ≥ 50% and nodal doubling time is ≥ 400 days; (iii) the nodule is in a deep position and difficult to locate; (iv) solitary lung metastatic tumor or multiple nodules require multiple segmental resection; and (v) when lobectomy is inappropriate, such as in elderly patients or those with poor cardiopulmonary function.[11,12] Lobectomy and systematic lymph node dissection are performed in patients with invasive adenocarcinoma or positive lymph nodes.

In patients who are elderly or have poor pulmonary function, anatomical segmentectomy can achieve maximum benefit. Because segmentectomy involves anatomical resection of the lung, preservation of healthy lung tissue is maximized, and thus the patient has better postoperative quality of life. Related studies have shown that postoperative lung function after segmentectomy is superior to lobectomy.[13] However, as a result of anatomical structure, pulmonary segmentectomy is more complex and prone to variation compared to lobectomy. Furthermore, as it is necessary to have a spatial sense of the blood vessels and bronchi, segmentectomy requires greater surgical ability and thus has a longer learning curve.

It can be difficult to ascertain nodule position via conventional CT scan because of the 2D imaging, especially when nodules are located near adjacent segments. Moreover, it is also difficult to locate variation in anatomic structure of segmental blood vessels. 3D-CTBA provides accurate segment location of the nodule, displays 3D stereoscopic images of the targeted blood vessels, and preoperatively confirms anatomical variation. Thus, it is very helpful for preparing a surgical plan. We construct a 3D image of the targeted nodule, segmental blood vessels, and bronchi, particularly for basal segments, and prepare a sound surgical plan to avoid accidental damage to normal segmental blood vessels and bronchi.

The advent of VATS has dramatically changed thoracic surgical procedure. With improvements to video imaging systems, endoscopy, and specialized surgical instruments, VATS has become an effective method for the surgical treatment of lung cancer. According to current observations, the oncological efficacy of VATS is at least equal to traditional open thoracotomy, and is a good option for high-risk thoracic surgery patients.[14] However, traditional thoracoscopy displays a 2D surgical image, resulting in a lack of 3D surgical vision and operative feeling of depth. For operators, there is often "distortion" and incongruity between idea and operation, especially for beginners. A 3D thoracoscope can present real stereoscopic surgical vision, creating harmony between surgeon and surgical instrument, and providing a similar view as traditional open thoracotomy, thus allowing for a smoother process and a lower learning curve for beginners. Compared to 2D minimally invasive surgery, some studies and experiments have also indicated that 3D can significantly reduce intraoperative errors and bleeding, and shorten operative duration and the learning curve.[15] We compared the operative duration between the two groups and found that the duration was significantly shorter in the 3D than in the 2D group ($P < 0.05$). We believe that transforming a preoperatively designed surgical procedure into real 3D stereoscopic surgery using 3D-VATS technology can allow for a simpler, shorter, and more accurate operative process. Furthermore, preoperative knowledge of anatomic structure variation reduces intraoperative damage, as demonstrated by the significantly lower rate of intraoperative bleeding in the 3D compared to the 2D group ($P < 0.05$).

While there were no significant differences in the incidence of postoperative pulmonary infection, atelectasis, or arrhythmia between the groups ($P > 0.05$), postoperative hemoptysis occurred less frequently in the 3D compared to the 2D group ($P < 0.05$). The main factors causing hemoptysis after anatomic pulmonary segmentectomy were: (i) damaged segmental vein, particularly when the vein was separated vein at the intersegmental plane; and (ii) inaccurate resection of the reserved segmental vein, leading to obstruction of pulmonary blood backflow, known as "venous infarction." The precise preoperative plan and more accurate intraoperative procedure used in the 3D group significantly reduced the probability of error, such as inaccurate resection of the segmental vein of the intersegmental plane, and therefore significantly reduced postoperative hemoptysis symptoms. Compared to the 2D group, the rate of pulmonary air leakage in the 3D group was significantly lower ($P < 0.05$). The main cause of pulmonary air leakage is that when there is no obvious boundary between each pulmonary segment, it is difficult to close up the segmental incisal margin. Preoperative 3D-CTBA can ascertain the pulmonary segment in which the nodule is located, thus the resectional range of the segment can be planned preoperatively. Use of the lung expansion-collapse method to completely excise the targeted segment can reduce postoperative complications, such as pulmonary air leakage.

In conclusion, 3D-CTBA combined with 3D-VATS allows for comprehensive surgical planning and adequate risk assessment, which in turn results in an accurate procedure with reduced intraoperative and postoperative complications, and a better therapeutic affect for patients.

Disclosure

No authors report any conflict of interest.

References

1 Wu N, Zhao SJ. [Positively and normatively launch screening for low dose spiral CT lung cancer]. *Chin J Radiol* 2015; **5**: 321–2 (In Chinese).

2 Yang CF, D'Amico TA. Thoracoscopic segmentectomy for lung cancer. *Ann Thorac Surg* 2012; **94**: 668–81.

3 Takamoto T, Hashimoto T, Ogata S *et al.* Planning of anatomical liver segmentectomy and subsegmentectomy with 3-dimensional simulation software. *Am J Surg* 2013; **206**: 530–8.

4 Churchill ED, Belsey R. Segmental pneumonectomy in bronchiectasis. *Ann Surg* 1939; **109**: 481–9.

5 Ginsberg RJ, Rubenstein LV. Randomized trial of lobectomy versus limited resection for T1N0 non-small cell lung cancer. *Ann Thorac Surg* 1995; **60**: 615–23.

6 Smith C, Swanson S, Mhango G, Wisnivesky JP. Survival after segmentectomy and wedge resection in stage I non-small-cell lung cancer. *J Thorac Oncol* 2013; **8**: 73–8.

7 Swanson SJ. Segmentectomy for lung cancer. *Semin Thorac Cardiovasc Surg* 2010; **22**: 244–9.

8 Galal G, Kamel M, Nasar A *et al.* Video-assisted thoracoscopic surgery is a safe and effective alternative to thoracotomy for anatomical segmentectomy in patients with clinical stage I non-small cell lung cancer. *Ann Thorac Surg* 2016; **101**: 465–72.

9 Yoshida J, Nagai K, Yokose T *et al.* Limited resection trial for pulmonary ground-glass opacity nodules: Fifty-case experience. *J Thorac Cardiovasc Surg* 2005; **129**: 991–6.

10 Koike T, Togashi K, Shirato T *et al.* Limited resection for noninvasive bronchioloalveolar carcinoma diagnosed by intraoperative pathologic examination. *Ann Thorac Surg* 2009; **88**: 1106–11.

11 Liu H, Chen L, Zhu Q *et al.* Comparison of the short-term efficacy of complete thoracoscopic anatomical segmentectomy and lobectomy in the treatment of small pulmonary nodules. *Chin J Clinicians (Electronic Edition)* 2012; **06**: 103–5.

12 Schuchert MJ, Abbas G, Awais O *et al.* Anatomic segmentectomy for the solitary pulmonary nodule and early-stage lung cancer. *Ann Thorac Surg* 2012; **93**: 1780–7.

13 Echavarria MF, Cheng AM, Velez-Cubian FO *et al.* Comparison of pulmonary function tests and perioperative outcomes after robotic-assisted pulmonary lobectomy vs segmentectomy. *Am J Surg* 2016; **212**: 1175–82.

14 Klapper J, D'Amico TA. VATS versus open surgery for lung cancer resection: Moving toward a minimally invasive approach. *J Natl Compr Canc Netw* 2015; **13**: 162–4.

15 Sorensen SM, Savran MM, Konge L, Bjerrum F. Three-dimensional versus two-dimensional vision in laparoscopy: A systematic review. *Surg Endosc* 2016; **30**: 11–23.

