PULMONARY FUNCTION AFTER SEGMENTECTOMY FOR SMALL PERIPHERAL CARCINOMA OF THE LUNG

Tsuneyo Takizawa, MD^a
Manabu Haga, MD^a
Nobuo Yagi, MD^a
Masanori Terashima, MD^a
Hiroko Uehara, MD^b
Akira Yokoyama, MD^b
Yuzo Kurita, MD^b

Objective: The aim of this study is to compare the pulmonary function after a segmentectomy with that after a lobectomy for small peripheral carcinoma of the lung. **Patients and methods:** Between 1993 and 1996, segmentectomy and lobectomy were performed on 48 and 133 good-risk patients, respectively. Lymph node metastases were detected after the operation in 6 and 24 patients of the segmentectomy and lobectomy groups, respectively. For bias reduction in comparison with a nonrandomized control group, we paired 40 segmentectomy patients with 40 lobectomy patients using nearest available matching method on the estimated propensity score. **Results:** Twelve months after the operation, the segmentectomy and lobectomy groups had forced vital capacities of 2.67 ± 0.73 L (mean $\pm$ standard deviation) and 2.57 ± 0.59 L, which were calculated to be $94.9\% \pm 10.6\%$ and $91.0\% \pm 13.2\%$ of the preoperative values ($P = .14$), respectively. The segmentectomy and lobectomy groups had postoperative 1-second forced expiratory volumes of 1.99 ± 0.63 L and 1.95 ± 0.49 L, which were calculated to be $93.3\% \pm 10.3\%$ and $87.3\% \pm 14.0\%$ of the preoperative values, respectively ($P = .03$). The multiple linear regression analysis showed that the alternative of segmentectomy or lobectomy was not a determinant for postoperative forced vital capacity but did affect postoperative 1-second forced expiratory volume. **Conclusion:** Pulmonary function after a segmentectomy for a good-risk patient is slightly better than that after a lobectomy. However, segmentectomy should be still the surgical procedure for only poor-risk patients because of the difficulty in excluding patients with metastatic lymph nodes from the candidates for the procedure. (J Thorac Cardiovasc Surg 1999;118:536-41)

The extent of resection has been discussed for small peripheral carcinoma of the lung, because these tumors are regarded as possibly being amenable to lesser resections (segmentectomy and wedge resection) than lobectomy. Although survival, recurrence, mortality, and morbidity after lesser resections have been investigated in several studies,¹⁻⁶ postoperative pulmonary function has been evaluated only rarely.⁵ Some lobar segments that are removed by a lobectomy are not

removed by lesser resections. Lesser resections apparently have an anatomic advantage over lobectomy. However, it is unclear whether the functional advantage of lesser resections is as great as the anatomic advantage over lobectomy.

Several authors have noted that local recurrence is more prevalent after lesser resections than after lobectomy.^{1-3,5} Is the functional benefit of lesser resections great enough for patients to risk having a local recurrence if they can tolerate a lobectomy? The aim of this study is to compare pulmonary function after segmentectomy with that after lobectomy in patients with small peripheral carcinoma of the lung.

Patients and methods

Segmentectomy. The study was conducted between January 1993 and December 1996 with the approval of our institutional ethics board. We performed segmentectomies on patients who had a small peripheral tumor and who were

From the Departments of Thoracic Surgery^a and Clinical Oncology,^b Niigata Cancer Hospital, Niigata, Japan.

Received for publication Dec 10, 1998; revisions requested March 4, 1999; final revisions received June 1, 1999; accepted for publication May 4, 1999.

Address for reprints: Tsuneyo Takizawa, MD, Department of Thoracic Surgery, Niigata Cancer Center Hospital, 2 Kawagishi-cho, 951-1388 Niigata, Japan.

Copyright © 1999 by Mosby, Inc.

0022-5223/99 \$8.00 + 0 12/1/100611

Fig 1. Patients eligible for the comparative study of postoperative pulmonary function. *NSCLC*, Non-small cell lung cancer.

believed able to tolerate a lobectomy, so long as no nodal metastases were identified during the operation. The choice of the operation was left to the discretion of the surgeon. In each segmentectomy, the pulmonary artery, pulmonary vein, and segmental bronchus were isolated. After the vessels were divided, the lobe was inflated and the segmental bronchus was closed to trap the air in the segment. We thereafter resected this segment, which remained inflated, whereas the other lobar parenchyma became deflated within several minutes. The intersegmental plane was not stripped. We always used a surgical stapler to divide the intersegmental planes. Two segments were removed when the tumor was localized beyond the segment or when bi-segmentectomy was easier than seg-

mentectomy. Systematic hilar and mediastinal lymphadenectomy were done as previously described.⁷ If necessary, a few lymph nodes were sampled during the operation and examined pathologically to determine whether they contained tumor metastasis. When the sampled node was metastatic, we converted the segmentectomy to a lobectomy during the operation.

Patients. During the period, 184 good-risk patients had peripheral non-small cell lung cancer, in which the stage appeared to be T1 N0 intraoperatively; these patients were eligible for this study (Fig 1). Patients were excluded when they had a tumor in the right middle lobe. The alternative choice in the 2 operative procedures was left to the discretion

Table I. Segmentectomy and lobectomy groups paired by nearest available matching method on the estimated propensity score

Variables	Segmentectomy	Lobectomy	P value
No.	40	40	
Male/female	22/18	21/19	.8
Age (y)	65.0 ± 6.4	64.0 ± 7.3	.5
Tumor			
Histology			
Squamous cell	6	9	.6
Adenocarcinoma	33	30	
Others	1	1	
Size (cm)	1.7 ± 0.4	1.9 ± 0.5	.08
Location			
Right upper lobe	11	15	.7
Right lower lobe	6	6	
Left upper lobe	14	13	
Left lower lobe	9	6	
Pulmonary function			
FVC			
Liters	2.81 ± 0.70	2.85 ± 0.63	.8
% of std.	101.4 ± 16.5	102.0 ± 13.1	.9
FEV ₁			
Liters	2.13 ± 0.61	2.25 ± 0.63	.3
% of std.	105.0 ± 24.6	109.4 ± 18.3	.4
Logit of the propensity score	1.12 ± 0.58	1.17 ± 0.55	.7

FVC, Forced vital capacity; FEV₁, 1-second forced expiratory volume; % of std., the ratio of actual volume to standard volume that is determined by age, sex, and height of the patient according to Baldwin's formula for FVC and Berglund's formula for FEV₁. The distribution is represented by the mean value ± standard deviation.

of the surgeon. Lobectomies were performed in 133 patients. Segmentectomies were intended for 51 good-risk patients. Three segmentectomies were converted to lobectomies because metastatic lymph nodes were identified during the operation. Lymph node metastases were revealed after the operation in 24 and 6 patients of the lobectomy and segmentectomy groups, respectively. Of the 6 patients with metastatic lymph nodes in the segmentectomy group, 4 had N1 disease and 2 had N2 disease. One patient underwent a completion lobectomy. Two patients underwent adjuvant irradiations. Three patients had no adjuvant therapy. Postoperative pulmonary function testing was scheduled for 109 and 42 patients who had a pathologic T1 N0 tumor resected by lobectomy and segmentectomy, respectively. For 101 and 40 patients who underwent lobectomy and segmentectomy, the testing was done 2 weeks and 12 months after the operation. The testing was not done in 10 patients because of refusal in 2 patients, postoperative persistent air leakage in 4 patients, and diseases that developed in the postoperative period in 4 patients: cancer recurrence in 2 patients, gastric cancer in 1 patient, and depression in 1 patient. One patient who was eligible for this study died in the perioperative period. This patient had nodal metastases resected by lobectomy.

Pulmonary function testing. Pulmonary function was

Table II. The distribution of resected segments in the segmentectomy group

Tumor location	No.	Resected segment(s)	No. of patients
Right upper lobe	11	Apical	2
		Anterior	4
		Posterior	3
		Apicoposterior (bi-segmentectomy)	2
Right lower lobe	6	Superior (apical)	3
		Anterior basal	1
		Apicoposterior basal (bi-segmentectomy)	1
		Anterolateral basal (bi-segmentectomy)	1
Left upper lobe	14	Apicoposterior	1
		Anterior	1
		Superior-inferior lingula (bi-segmentectomy)	4
		Superior division (bi-segmentectomy)	8
Left lower lobe	9	Superior (apical)	8
		Anterior basal	1

tested with a spirometer (Chestac-55V, Chest M. I. Inc, Japan) according to American Thoracic Society standards.⁸ The forced vital capacity (FVC) and the 1-second forced expiratory volume (FEV₁) were measured in all patients. The measurements were documented in the form of the actual volume and the ratio of the actual volume to the standard volume that is determined by age, sex, and height of a patient according to Baldwin's formula for FVC and Berglund's formula for FEV₁.^{9,10} To compare the actual postoperative pulmonary function with the predicted function, we calculated the predicted postoperative pulmonary function according to the formula described in an earlier study.¹¹ In brief, the calculation was based on the number of segments that remained after the operation. The lower lobes were considered to have 5 pulmonary segments each, the right upper lobe had 3 segments, and the left upper lobe had 4 segments. Each segment was supposed to represent 1/9 or 0.0526 of the preoperative function.

Statistical analysis. To reduce the bias in the comparison of a nonrandomized control group, we paired the segmentectomy group with the lobectomy group using the nearest available matching method on the estimated propensity score.¹² To compare the frequencies of the categorical data in the 2 groups, we used the χ^2 tests with Yates' correction for continuity. To compare the distribution of tumor size, number of resected segments, and spirometric values in the 2 groups, we used the 2-sample *t* test. To compare the distribution of the actual postoperative pulmonary function with the predicted function, we used the paired *t* test. To examine determinants for postoperative pulmonary function, we used multiple linear regression. All statistical analyses were performed with the SPSS software package (SPSS Inc, Chicago, Ill).

Table III. Postoperative pulmonary function

	Segmentectomy	Lobectomy	P value
No.	40	40	
No. of resected segments	1.4 ± 0.5	3.9 ± 0.8	<.01
Predicted FEV ₁			
% of pre.	92.8 ± 2.5	79.3 ± 4.4	<.01
FVC			
Two weeks			
Liters	2.05 ± 0.66	1.91 ± 0.51	.3
% of std.	71.9 ± 19.7	67.4 ± 10.0	.2
% of pre.	72.7 ± 12.5	67.2 ± 9.7	.03
Twelve months			
Liters	2.67 ± 0.73	2.57 ± 0.59	.5
% of std.	95.3 ± 20.0	92.4 ± 16.7	.5
% of pre.	94.9 ± 10.6	91.0 ± 13.2	.14
FEV ₁			
Two weeks			
Liters	1.54 ± 0.51	1.50 ± 0.44	.7
% of std.	75.5 ± 22.3	73.3 ± 16.4	.6
% of pre.	73.0 ± 13.5	66.6 ± 11.4	.03
Twelve months			
Liters	1.99 ± 0.63	1.95 ± 0.49	.8
% of std.	100.2 ± 25.0	96.5 ± 21.1	.5
% of pre.	93.3 ± 10.3	87.3 ± 14.0	.03

FVC, Forced vital capacity; FEV₁, 1-second forced expiratory volume; % of std., the ratio of actual volume to the standard volume; % of pre., the ratio of postoperative volume to preoperative volume. The distribution is represented by the mean value ± standard deviation.

Results

Table I shows the characteristics of segmentectomy and lobectomy groups paired by nearest available matching method on the estimated propensity score. Tumor size in the original lobectomy group was 2.2 ± 0.5 cm (mean ± standard deviation), significantly larger than that in the segmentectomy group ($P < .01$). The distribution of tumor types and locations was also different between the 2 groups, although the difference was not statistically significant. Logit of the propensity score was 1.53 ± 0.55 for the original lobectomy group, significantly different from that for the segmentectomy group ($P < .01$). As shown in Table I, no significant difference between the 2 groups was observed in the categorical and sequential variables including logit of the propensity score after matching.

Table II shows the distribution of resected segments in the segmentectomy group. The nomenclature of bronchopulmonary segments was used according to the textbook *Thoracic and Cardiovascular Surgery*.¹³ A-segmentectomy and bi-segmentectomy were performed for 24 and 16 patients, respectively.

Table III demonstrates the number of resected segments, the predicted FEV₁, and the postoperative FVC and FEV₁. The number of resected segments was sig-

Table IV. Multiple linear regression analysis for determinants of postoperative pulmonary function

Variables	Coefficient ± SD	95% CI	P value
FVC at 12 months			
(% of standard)			
Preoperative FVC	0.9 ± 0.1	(0.7, 1.1)	<.01
(% of standard)			
Segmentectomy	3.9 ± 2.8	(-1.7, 9.5)	.2
(vs lobectomy)			
Upper lobe	6.4 ± 3.0	(0.5, 12.3)	.03
(vs lower lobe)			
Intercept	7.2 ± 9.9	(-12.5, 27.0)	.5
FEV ₁ at 12 months			
(% of standard)			
Preoperative FEV ₁	0.9 ± 0.1	(0.7, 1.0)	<.01
(% of standard)			
Segmentectomy	8.0 ± 3.1	(1.9, 14.1)	.01
(vs lobectomy)			
Upper lobe	7.4 ± 3.2	(1.0, 13.7)	.03
(vs lower lobe)			
Intercept	12.2 ± 7.8	(-3.2, 27.7)	.12

FVC, Forced vital capacity; FEV₁, 1-second forced expiratory volume; SD, standard deviation; CI, confidence interval.

nificantly different between the 2 groups, as was the predicted FEV₁. Two weeks after the operation, the FVC was slightly higher in the segmentectomy group than in the lobectomy group. A statistically significant difference was observed between the 2 groups in the ratio of postoperative to preoperative FVC ($P = .03$), although the actual FVC and the percent of the standard FVC were not significantly different between the 2 groups. At 12 months, no significant difference was shown between the 2 groups in the actual FVC, the percent of the standard FVC, and the ratio of postoperative to preoperative FVC.

Both 2 weeks and 12 months after the operation, a statistically significant difference was observed between the 2 groups in the ratio of postoperative to preoperative FEV₁ ($P = .03$), although the actual FEV₁ and the percent of standard FEV₁ were not significantly different between the 2 groups. At 12 months, the lobectomy group had a significantly higher FEV₁ than the predicted FEV₁ (paired t test, $P < .01$), whereas the segmentectomy group had almost the same FEV₁ as the predicted value.

Table IV shows the results of multiple linear regression analysis for determinants of postoperative pulmonary function at 12 months. FVC and FEV₁ were represented by the ratio of the actual volume to the standard volume. Correlation coefficients of the model were 0.74 ($P < .01$) and 0.82 ($P < .01$) for FVC and FEV₁, respectively. An increase in 1% of the preopera-

tive FVC was associated with an increase in the postoperative FVC of $0.9\% \pm 0.1\%$. The 95% confidence interval (CI) ranged from 0.7% to 1.1%. The alternative surgical procedure of segmentectomy or lobectomy did not significantly influence the postoperative FVC. The postoperative FVC for patients with right or left upper lobe surgery was $6.4\% \pm 3.0\%$ higher than that for those with right or left lower lobe surgery. The 95% CI ranged from 0.5% to 12.3%. An increase in 1% in the preoperative FEV₁ was associated with an increase in the postoperative FEV₁ of $0.9\% \pm 0.1\%$. The 95% CI ranged from 0.7% to 1.0%. Patients who had undergone segmentectomies had $8.0\% \pm 3.1\%$ higher FEV₁ after the operation than those who had undergone lobectomies. The 95% CI ranged from 1.9% to 14.1%. The postoperative FEV₁ for patients with right or left upper lobe surgery was $7.4\% \pm 3.2\%$ higher than that for patients with right or left lower lobe surgery. The 95% CI ranged from 1.0% to 13.7%.

Discussion

In this study, the operative procedure was not chosen randomly. The alternative of segmentectomy or lobectomy was left to the discretion of the surgeon. As shown in Table II, the resected segments in the segmentectomy group were not uniformly distributed over the lung. When a tumor was localized at the apical segment in the right or left lower lobe, a segmentectomy was probably performed. When a tumor was at the posterior basal segment, a lobectomy was likely done. Our surgeons expected to observe functional benefit after apical segmentectomy, but not after posterior basal segmentectomy, which was considered to be a difficult surgical procedure. Unless a wedge resection, as well as a segmentectomy, is accepted as a procedure for limited resection, it is difficult to perform a randomized trial of lobectomy versus limited resection for small peripheral lung cancer. We had a nonrandomized control group. For bias reduction in the comparison of a nonrandomized control group, we paired the segmentectomy group with the lobectomy group using the nearest available matching method on the propensity score. We believe that the bias has been reduced enough to allow postoperative pulmonary function to be compared between the 2 groups.

The results of this study suggest that a good-risk patient will not obtain a great functional benefit if segmentectomy is performed in place of lobectomy for a small peripheral lung cancer. Some lobar segments that are removed by a lobectomy are not removed by segmental resection of a tumor. Segmentectomy apparently has an anatomic advantage over lobectomy. Why is

the functional benefit of segmentectomy slight compared with the anatomic advantage over lobectomy? Ali and colleagues¹⁴ found a disproportionate early loss, followed by significant functional improvement with time after lobectomy. Zeiher and coworkers¹¹ demonstrated the predicted postoperative FEV₁, which is based on the number of remaining segments, to consistently underestimate the actual postoperative FEV₁ by approximately 250 mL. The lobectomy group in this study showed significant functional improvement that was more than predicted. The lobectomy group in a randomized trial had a postoperative/preoperative FEV₁ ratio that is very similar to ours.⁵ The significant functional improvement after lobectomy has been demonstrated repeatedly. The remaining postoperative function is thus more than anticipated on the basis of the remaining tissue in most patients who underwent a lobectomy. This is the reason that the functional benefit by segmentectomy is slight compared with the anatomic advantage over lobectomy.

Despite our careful intraoperative nodal assessment, we could not exclude 6 patients with nodal metastasis from our candidates for segmentectomy. Five of the 6 patients had adenocarcinomas of the lung. Adenocarcinoma has a considerable potential for lymph node metastasis; even small adenocarcinomas measuring 2 cm or less in diameter do.¹⁵⁻¹⁹ An intraoperative assessment is not reliable for identifying lymph node metastasis in small peripheral adenocarcinoma of the lung.¹⁹ Patients who undergo a lesser resection run the risk of microscopic tumor cells being left in either lobar or segmental lymph nodes. A randomized study demonstrated that patients who undergo lesser resections have a higher risk of local recurrence than those who undergo a lobectomy.⁵ Segmentectomy should not be performed in place of lobectomy for good-risk patients with a small peripheral tumor because of the difficulty of identifying metastatic lymph nodes during the operation.

Who benefits from segmentectomy? Patients with limited FEV₁ may benefit if they need as great a postoperative FEV₁ as possible. Who loses? Patients with metastatic lymph nodes lose. Our patients with metastatic lymph nodes who underwent segmentectomies were subjected to completion lobectomy, irradiation, or the risk of a local recurrence developing, problems that might have been obviated had they undergone lobectomy.

We excluded poor-risk patients category and patients with secondary lung cancer from this study. However, we do not believe that the results of this study rule out the usefulness of lesser resections in such patients.

In conclusion, pulmonary function after a segmen-

ectomy for a good-risk patient is slightly better than that after a lobectomy. However, segmentectomy should still be the surgical procedure for only poor-risk patients because of the difficulty in excluding patients with metastatic lobar disease from the candidates for the procedure.

We thank Associate Professor Kazuo Endoh for his statistical support, Mrs Youko Minagawa for her physiologic assistance, and Mr Brian Quinn for his critical review.

REFERENCES

1. Martini N, Bains MS, Burt ME, et al. Incidence of local recurrence and second primary tumors in resected stage I lung cancer. *J Thorac Cardiovasc Surg* 1995;109:120-9.
2. Warren WH, Faber LP. Segmentectomy versus lobectomy in patients with stage I pulmonary carcinoma: five-year survival and patterns of intrathoracic recurrence. *J Thorac Cardiovasc Surg* 1994;107:1087-94.
3. Landreneau RJ, Sugarbaker DJ, Mack MJ, et al. Wedge resection versus lobectomy for stage I (T1 N0 M0) non-small-cell lung cancer. *J Thorac Cardiovasc Surg* 1997;113:691-700.
4. Kodama K, Doi O, Higashiyama M, Yokouchi H. Intentional limited resection for selected patients with T1 N0 M0 non-small-cell lung cancer: a single-institution study. *J Thorac Cardiovasc Surg* 1997;114:347-53.
5. Lung Cancer Study Group. Randomized trial of lobectomy versus limited resection for T1N0 non-small cell lung cancer. *Ann Thorac Surg* 1995;60:615-23.
6. Tubota N, Ayabe K, Doi O, et al. Ongoing prospective study of segmentectomy for small lung tumors. *Ann Thorac Surg* 1998;66:1787-90.
7. Takizawa T, Terashima M, Koike T, Akamatsu H, Kurita Y, Yokoyama A. Mediastinal lymph node metastasis in patients with clinical stage I peripheral non-small-cell lung cancer. *J Thorac Cardiovasc Surg* 1997;113:248-52.
8. American Thoracic Society. Standardization of spirometry—1987 update. *Am Rev Respir Dis* 1987;136:1285-98.
9. Baldwin D, Courmand A, Richards D Jr. Pulmonary insufficiency. I. Physiological classification, clinical methods of analysis, standard values in normal subjects. *Medicine* 1948;27:243-78.
10. Berglund E, Birath G, Bjure J, et al. Spirometric studies in normal subjects. I. Forced expirograms in subjects between 7 and 70 years of ages. *Acta Med Scand* 1963;173:185-92.
11. Zeiher BG, Gross TJ, Kern JA, Lanza LA, Peterson MW. Predicting postoperative pulmonary function in patients undergoing lung resection. *Chest* 1995;108:68-72.
12. D'Agostino RB Jr. Propensity score methods for bias reduction in the comparison of a non-randomized control group. *Stat Med* 1998;17:2265-81.
13. Glenn W, Baue A, Geha A, Hammond G, Laks H. Thoracic and cardiovascular surgery. 4th ed. East Norwalk: Appleton-Century-Crofts; 1983.
14. Ali MK, Mountain CF, Ewer MS, Johnston D, Haynie TP. Predicting loss of pulmonary function after resection for bronchogenic carcinoma. *Chest* 1980;77:337-42.
15. Takise A, Kodama T, Shimosato Y, Watanabe S, Suemasu K. Histopathological prognostic factors in adenocarcinomas of the peripheral lung less than 2 cm in diameter. *Cancer* 1988;61:2083-8.
16. Asamura H, Nakamura H, Kondo H, Tsuchiya R, Naruke T. Lymph node involvement, recurrence, and prognosis in resected peripheral, non-small-cell lung carcinomas: Are these carcinomas candidates for video-assisted lobectomy? *J Thorac Cardiovasc Surg* 1996;111:1125-34.
17. Noguchi M, Morikawa A, Kawasaki M, et al. Small adenocarcinoma of the lung. *Cancer* 1995;75:2844-52.
18. Ichinose Y, Yano T, Asoh H, Yokoyama H, Yoshino I, Katsuda Y. Prognostic factors obtained by a pathologic examination in completely resected non-small-cell lung cancer: an analysis in each pathologic stage. *J Thorac Cardiovasc Surg* 1995;110:601-5.
19. Takizawa T, Terashima M, Koike T, et al. Lymph node metastasis in small peripheral adenocarcinoma of the lung. *J Thorac Cardiovasc Surg* 1998;116:276-80.