ORIGINAL ARTICLE

Surgical outcome of pulmonary artery reconstruction using the expanded polytetrafluoroethylene patch in patients with lung cancer

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Abstract

Purpose Pulmonary artery reconstruction is sometimes utilized as an alternative to pneumonectomy in lung cancer surgery. We herein report our experience of pulmonary artery reconstruction using an expanded polytetrafluoroethylene (ePTFE) patch based on the surgical results and long-term outcome.

Methods Clinical records of lung cancer patients who underwent patch plasty were reviewed retrospectively.

Results Between 2003 and 2017, pulmonary artery patch plasty were performed in 21 patients [18 males, 3 females; mean age 65 (range 47–79) years]. Induction chemoradiotherapy was performed in three patients. Bronchoplasty was performed in five patients. The pathologic stages were stage I in 3 patients, stage II in 6 and stage III in 12. Pneumonectomy, lobectomy and segmentectomy were performed in 2, 18 and 1 patient, respectively. The left upper lobe was the most frequent origin of lung cancer (15 patients). There was no reconstruction-related morbidity or mortality. The overall survival rate at 5 years was 64.1% with a mean follow-up of 39.5 months, and the survival rates for N0–1 and N2–3 were 80.8% and 28.6%, respectively.

Conclusion Patch angioplasty using the ePTFE sheet is a reliable procedure in radical surgery for lung cancer.

Keywords Lung cancer · Surgery · Pulmonary artery reconstruction · ePTFE patch

Introduction

Lung cancer patients who undergo lung resection suffer from a loss of their respiratory function in exchange for a possible survival benefit. In particular, pneumonectomy significantly reduces the quality of life [1, 2]. Combined resection and reconstruction of the pulmonary artery (PA) for lung cancer is a useful technique for both achieving curative surgery and avoiding pneumonectomy when the tumor invades the stem of the PA. PA reconstruction techniques include primary closure of defects by direct suturing, patch closure with autologous or bovine pericardium, end-to-end anastomosis and conduit interposition with polytetrafluoroethylene (PTFE) or hand-made pericardium after sleeve resection. Although direct suturing is the simplest approach and may not be included in PA reconstruction, there are concerns about PA stenosis due to reconstruction if the defect is large. Patch closure is effective when the resection range of PA is relatively wide but does not include the whole circumference. When patch angioplasty is performed, a biological patch (autologous or bovine pericardium) is often used as a material, and there are few reports about the use of artifacts [3–7]. We have used the expanded PTFE (ePTFE) patch at our facility because it is very easy to handle.

The purpose of the present study was to review our experience with PA reconstruction using the ePTFE patch during lung resection by analyzing morbidity, mortality and long-term results.

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Methods

This study was approved by the institutional review boards of the National Hospital Organization Chiba Medical Center and the collaborating hospitals. Informed consent was waived because it was a retrospective analysis. Between January 2003 and December 2017, 21 patients underwent lung cancer surgery with PA patch plasty using an ePTFE sheet. We retrospectively reviewed the medical records in terms of the patients' background and postoperative outcomes. The following data were collected: sex, age, location of tumor, operative method, site of PA reconstruction, tumor histology, pathologic staging, postoperative morbidity, mortality and prognosis.

Surgical technique

PA reconstruction was performed as follows: reconstruction was started after the treatment of the pulmonary veins and bronchus. If primary tumor or lymph node invasion into the PA was suspected, we adequately detached the central and peripheral sites of invasion and clamped the proximal and distal sites of the PA using forceps. After wide wedge resection of the PA, the prosthetic ePTFE patch was trimmed to be slightly larger than the resecting range and continuously sutured over using 5-0 monofilament nonabsorbable sutures (5-0 polypropylene). We performed PA reconstruction using a 0.4-mm ePTFE patch (Gore-Tex Cardiovascular Patch; W.L. Gore & Associates, Inc., Flagstaff, AZ, USA) (Fig. 1). Before tying the arterial suture, we washed the anastomosis sites with diluted heparin to prevent intraluminal thrombosis, and the distal clamp was removed in order to help remove air from the PA. Thereafter, the proximal vascular clamp was removed in order to ensure hemostasis of the sutured line. We avoided tightening the thread too tightly when ligating the suture. Oozing from the needle hole of the patch was stopped naturally by lightly pressing it with gauze, and the tension of the suture was equalized. In the case of combined bronchoplasty, the PA and bronchus were dissected after clamping the PA, and, in general, the bronchus was sutured before the PA was sutured.

Bolus injection of heparin (2000–5000 units) was performed when the PA clamping time exceeded 30 min, such as with simultaneous bronchoplasty, with a reference activated clotting time of 200 s. Routine anticoagulant therapy was not performed after surgery.

Statistical analyses

The survival and tumor recurrence were assessed by patient follow-up. Survival probabilities were calculated using the
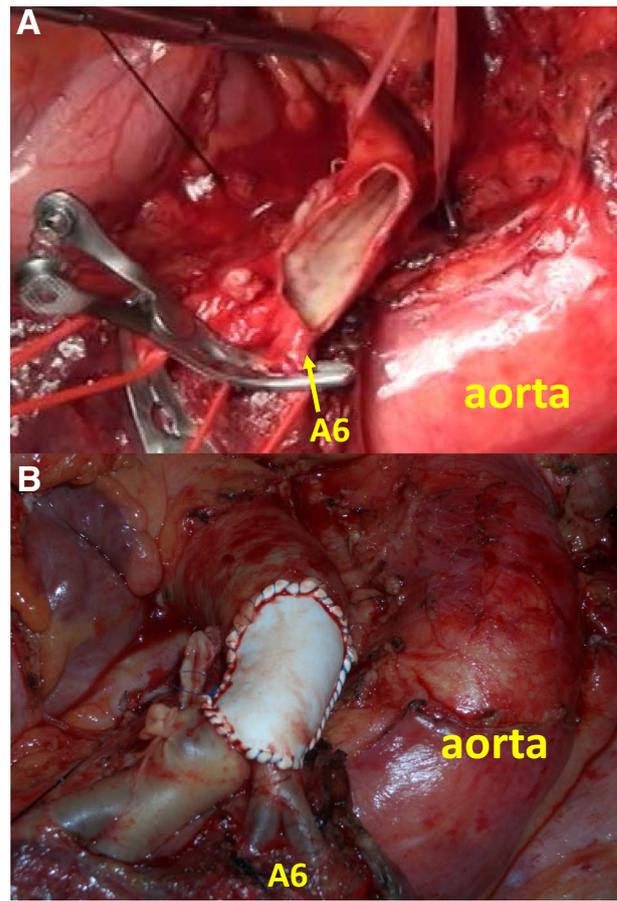
Fig. 1 Intraoperative view of a case of left pulmonary artery reconstruction. **a** After clamping the proximal and distal parts of the left pulmonary artery, the pulmonary artery was dissected. **b** The pulmonary artery defect was repaired with the ePTFE patch. Patch anastomosis was performed with one running suture with non-absorbable monofilament (5-0 polypropylene)

Kaplan–Meier method from the date of the surgery until death or loss to follow-up. Significant differences between the individual curves were assessed with the log-rank test. A value of $p < 0.05$ was considered to indicate statistical significance.

Results

The clinical parameters of the patients are summarized in Table 1. There were 18 males and 3 females. The mean age was 65 (range 47–79) years. A definitive pathologic evaluation revealed the following histologic types: 10 squamous cell carcinomas (47.6%), 5 adenocarcinomas (23.8%) and 6 other primary lung cancers (28.6%). The pathologic stages were stage I in 3 patients (14.3%; 1 IA and 2 IB), stage II in 6 (28.6%; 3 IIA and 3 IIB) and stage III in 12 (57.1%; 11

Table 1 Clinical characteristics of the patients

Variables	Number of patients ($N=21$)	(%)	5-year survival (%)	p value
Age, median (range) years	65 (47–79)			
Gender				NA
Male	18	85.7	59.0	
Female	3	14.3	100.0	
Histologic type				0.5400[b]
Squamous	10	47.6	75.0	
Adenocarcinoma	5	23.8	100.0	
Others	6	28.6	33.3	
Pathological stage				0.1389
I or II	9	42.9	85.7	
III	12	57.1	50.0	
Nodal status				0.0076
N0–1	14	66.7	80.8	
N2–3	7	33.3	28.6	
Induction therapy (preoperative treatment)				0.7295
Yes	3	14.3	66.7	
No	18	85.7	64.8	
Surgical resection				0.2027[c]
Segmentectomy	1	4.8		
Lobectomy	15	71.4		
Lobectomy + segmentectomy	2	9.5		
Bilobectomy	1	4.8		
Pneumonectomy	2	9.5		
Bronchoplasty				0.3639
Wedge	5	23.8	50.0	
None	16	76.2	66.8	
Reason for PA reconstruction				
Tumor invasion	10	47.6	74.1	0.1393[d]
Lymph node invasion	9	42.9	37.5	
Others	2	9.5	100.0	
Recurrence[a]				
Yes	12	60	100.0	NA
No	8	40	42.9	

PA pulmonary artery, *NA* not available

[a]One case could not be confirmed

[b]Squamous vs. non-squamous(adenocarcinoma and others)

[c]Segmentectomy + lobectomy vs. others

[d]Tumor vs. lymph nodes

Table 2 Primary tumor and PA reconstruction site

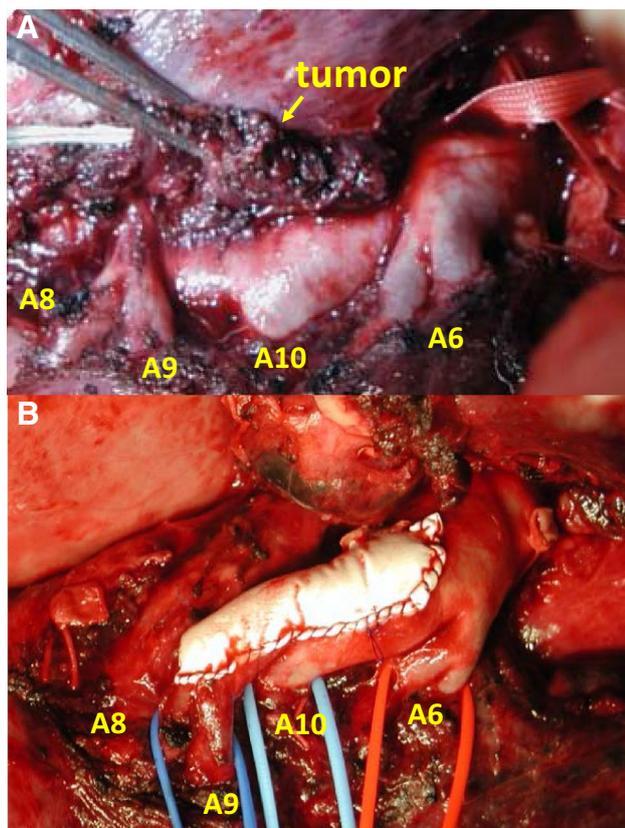| Tumor site	Right ($N=5$)	Left ($N=16$)
Upper	3	15
Upper + middle	1	–
Middle	1	–
Lower	0	1
PA reconstruction site		
Main pulmonary artery bifurcation	0	2
First branch only	1	8
Interlobar or wide range (including the first branch)	4	6

PA pulmonary artery

required reconstructing the PA bifurcation. Wedge bronchoplasty was performed in five patients, of whom two underwent right upper lobectomy and the other three left upper lobectomy. In this study, no cases of sleeve resection of the bronchus were noted.

The PA was resected because of direct invasion of the main tumor in 10 patients and extra-nodal invasion of a metastatic hilar node in 9. As to other reasons, one was a case of using a patch to repair the PA when a PA thrombus was removed, while the other was a case of using a patch to repair an injury of PA. Recurrence occurred in 12 patients. Locoregional relapse was noted in only one patient, lymph node metastasis in four and distant recurrence in seven.

The tumor location and PA reconstruction site are listed in Table 2. Tumors were located on the right side in 5 patients (23.8%) and on the left in 16 (76.2%). Surgery was more frequent in the upper lobes on both sides, with 15 (71.4%) cases of left upper-lobe cancer reported. In nine cases, patch plasty was performed for only the first branch of the PA. Extensive patch plasty involving the interlobar part and the first branch was performed in 10 patients. A case of left upper lobectomy is shown in Fig. 2. The PA was excised widely and closed using an ePTFE patch in the interlobar area. In such cases, it is impossible to perform end-to-end anastomosis or conduit interposition. If patch angioplasty is not feasible, pneumonectomy is inevitable. In the two patients who underwent reconstruction of the main PA bifurcation, cardiopulmonary bypass (CPB) was required. One case in whom the tumor had invaded the left atrium and the branch of the left main PA is shown in Fig. 3. Left pneumonectomy with patch angioplasty and combined resection of the left atrium was performed under CPB. The patient in this case remains alive at 6 years after surgery, without relapse.
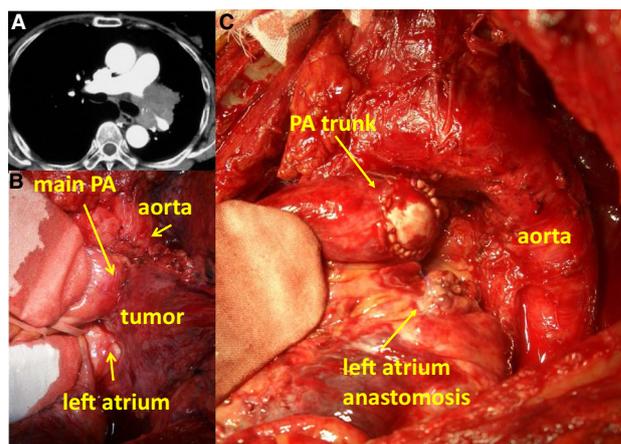
There were no intraoperative deaths and no cases of death within 30 days after surgery (Table 3). Overall, the morbidity rate was 42.9% ($n=9$), with some patients experiencing more than 1 morbidity. Cardiac morbidity occurred in

IIIA, and 1 IIIB). The cases of stage IIIB disease were due to N3 status on postoperative pathology.

Preoperative induction chemoradiotherapy was performed in 3 patients. Regarding the surgical method, pneumonectomy, lobectomy and segmentectomy were performed in 2, 18 and 1 patient, respectively. The two patients who underwent pneumonectomy were cases of left lung cancer that

Fig. 2 Intraoperative view of a case of left upper lobectomy with left pulmonary artery reconstruction. **a** Tumor infiltrates were widespread in the main pulmonary artery in the interlobar region. **b** It was possible to perform patch angioplasty, although the defects were extensive. In this case, it was impossible to perform end-to-end anastomosis or conduit interposition

Fig. 3 A case of left pneumonectomy with bifurcation reconstruction of the main pulmonary artery. **a** Computed tomography showed that the left main pulmonary artery was completely surrounded by the tumor. **b**, **c** Intraoperative view of the left pulmonary artery reconstruction. **b** The tumor invaded the left atrium and the bifurcation of the main pulmonary artery. **c** Left pneumonectomy with patch angioplasty under cardiopulmonary bypass was performed. The other side of the patch is the right main pulmonary artery

4 patients (19.0%), prolonged air leakage in 3 (14.3%), and pneumonia in 2 (9.5%). Two cases of postoperative bleeding were noted. In one case, bleeding from the aortic cannulation site for CPB was recognized. In the other, bleeding from the thoracotomy wound was recognized with the onset of postoperative heparin administration. There were no complications related to the patch plasty procedure.

The overall survival rate at 5 years after surgery was 64.1%, with a mean follow-up period of 39.5 months (Fig. 4). Nodal states had a significant effect on the survival. Patients with N0–N1 had a relatively good 5-year survival of 80.8%, whereas patients with N2–N3 had a 5-year survival of 28.6% ($p = 0.0076$; Fig. 5). There was no significant difference in the overall survival between patients who underwent PA reconstruction alone and those who received combined bronchoplasty ($p = 0.3639$). The reasons for PA patch plasty seem to affect the survival, as the 5-year survival rate for "primary tumor invasion" was 74.1%, and that for "extra-nodal invasion" was 37.5%, although there is no statistical significance ($p = 0.1393$).

Table 3 Postoperative complications

Complications	Number of patients (%) ($N = 21$)
30-day mortality	0 (0)
Morbidity	9 (42.9)
Arrhythmia	4 (19.0)
Prolonged air leak	3 (14.3)
Postoperative bleeding	2 (9.5)
Pneumonia	2 (9.5)
Chylothorax	1 (4.8)
Contralateral pneumothorax	1 (4.8)
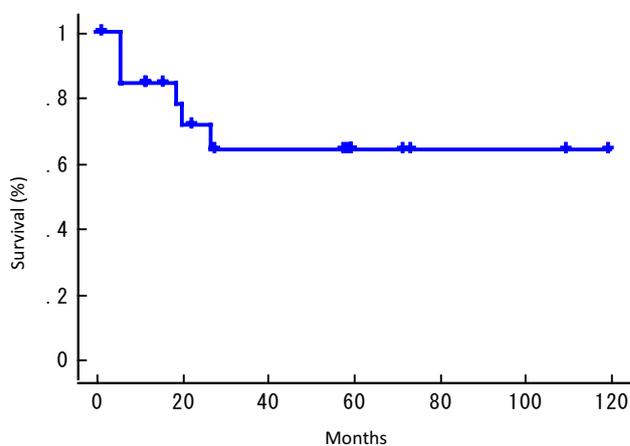
Fig. 4 The overall survival
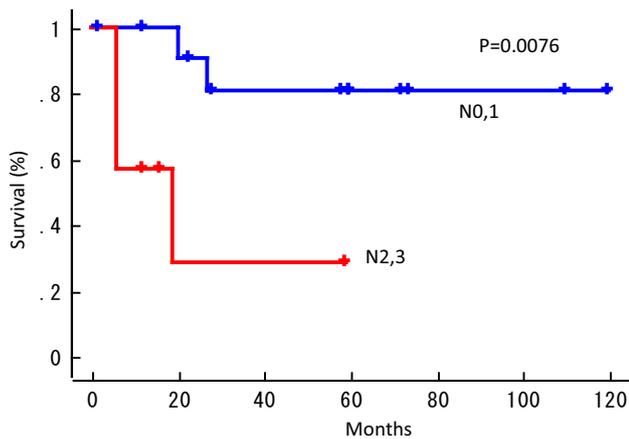
Fig. 5 The overall survival by nodal status

Discussion

Pneumonectomy is often required for managing pulmonary tumor or lymph node metastasis that directly infiltrates the PA, although this technique is also known to result in various complications and is not indicated for cases with a limited respiratory reserve. Several reconstructive techniques allow the preservation of the lung parenchyma and respiratory function. PA reconstruction techniques may involve direct suturing, which is appropriate in cases of limited tangential resection; patch closure, which is used when more than 20% of the arterial circumference has to be resected [2]; end-to-end anastomosis (sleeve resection), which is used when the defect range is > 50% of the arterial wall [3, 8, 9]; or interposition of a conduit, which is required when the whole circumference shows tumor involvement and sleeve resection cannot be performed.

When PA patch plasty is performed, a biological patch (autologous or bovine pericardium) is preferentially used as a material [3–7], and synthetic patches are used less frequently because of the associated postoperative risks, including infection and thrombosis, and there have so been few published reports describing the use of synthetic patches. However, we use the ePTFE patch in our facility because of its ease of handling and lack of shrinkage, which is sometimes observed with biological materials. In our experience, PA patch plasty using ePTFE can be performed without any difficulties. The present study indicates that PA reconstruction using the ePTFE patch for lung cancer is a valuable procedure with acceptable postoperative morbidity and mortality rates and satisfactory long-term outcomes.

In our experience and in agreement with other reports [2, 4–6, 10, 11], PA resection and reconstruction are performed more frequently for left-sided tumors (76.2% of patients) and squamous cell carcinoma (SCC) (47.6% of patients) than right-sided tumors or non-SCC. SCC often arises in

central-type non-small-cell lung carcinoma and often metastasizes early to the hilar lymph nodes. Compared with the right side, both the superior and posterior sides of the left upper bronchus are surrounded by the PA. For this anatomical reason, direct invasion by the primary tumor or extranodal invasion of metastatic lymph nodes is more likely to occur in lung cancer originating from the left upper lobe than another lobe. Reconstruction of the first branch of the left PA is performed in most cases, and this is the most frequent site for patch angioplasty. The two pneumonectomies were also on the left side because the left PA is more easily infiltrated for the same reason, and the left main PA is also anatomically shorter than the right PA, and the distance from the pulmonary trunk is shorter [12].

Various materials have been considered for patch closure. Autologous pericardium is popular [8], with bovine pericardium [4] or pulmonary veins [13, 14] serving as possible alternatives. PA patch plasty with autologous pericardium is thought to be a safe procedure in terms of thrombus formation. However, postoperative shrinkage sometimes occurs when using these materials. Rendina reported that the use of an autologous pericardial patch yielded a notably irregular artery, which caused kinking of the vessel and impairment of the blood flow. The patient in that study underwent surgery again, and completion left pneumonectomy was performed [3]. In addition, preparing these patches is time-consuming. Synthetic patches are less commonly used because of concerns about infection and thrombosis [15]. However, synthetic patches have advantages of easy availability and handling [10], features that are particularly beneficial in emergencies [16]. The ePTFE patch is superior to other artificial material in terms of its biocompatibility. It is rare for ePTFE patches to become frayed or torn, and surgeons can freely adjust their size and suture them easily. Compared with the pericardial patch, the ePTFE sheet does not shrink and is easy to use because of its adequate hardness. It can be used even in complicated locations such as near the PA branch. It is also resistant to bending and appears particularly effective for a wide range of PA plasty procedures in the interlobar areas (Fig. 2); however, careful observation may be necessary to avoid kinking due to elevation of the lower lobe after surgery when upper lobectomy is performed.

When performing resection of the whole circumference of PA, it is possible to perform end-to-end anastomosis if sleeve bronchoplasty is also performed (so-called double-sleeve plasty). However, in cases where bronchoplasty is not performed or wedge bronchoplasty is performed, interposition using a conduit is required. In cases of interposition using biomaterials, there are concerns about the risk of PA stenosis after the surgery. The ePTFE patch enables PA reconstruction without interposition even in cases without bronchoplasty. Sleeve bronchoplasty can be performed

Table 4 Historical results of reconstruction of the PA in lung cancer surgery

References	Patients	Tangential	Patch	E–E	Interposition	Sleeve bronchoplasty	Complications (%)	Technical complications (%)	Mortality (%)	Survival (% at 5 years)
Rendina et al. [3]	52	–	34	15	3	33	13.4	1.9	0	38.3
Shrager et al. [18]	33	19	11	3	–	14	45.0	0	0	46.7[a]
Cerfolio et al. [2]	42	31	7	4	–	6	26.0	0	2.3	60.0
Venuta et al. [4]	105	–	55	47	3	65	29.4	1.9	1.0	44.0
Ma et al. [5]	118	36	51	22	–	41	52.2	0.8	0	50.2
Galetta et al. [6]	150	113	33	–	4	56	30.7	1.3	3.3	50.0
Current report	21	–	21	–	–	0[b]	42.9	0	0	64.1

Figures were calculated from data reported in articles

[a]The survival at 4 years

[b]Including five cases of wedge bronchoplasty

concomitantly with end-to-end anastomosis of PA in cases where the bronchus is intact, but the procedure is complicated. Patch angioplasty is effective in cases where the PA must be extensively resected and end-to-end anastomosis is not possible due to the tension of the PA sutures. For these reasons, sleeve bronchoplasty cases were not included in our study.

Since the ePTFE patch is a synthetic device, there is a risk of infection or thrombosis. Few other reports have described the use of prosthetic patches because of the postoperative risk of complications. However, in our study, no postoperative or intraoperative complications were caused by the ePTFE patch (bleeding, ischemia, etc.). Recent advances in automatic suturing devices have made it easier to cut and suture the bronchus, and less time is required to open the airways during surgery. Therefore, the risk of infection is believed to be reduced, allowing artificial devices (ePTFE patch) to be used safely. While we did not perform postoperative anticoagulation in the present study, no associated issues have been noted thus far. On our examination of postoperative contrast CT scans, we noted no kinking or stenosis, and the PA blood flow was maintained in all cases.

Relatively few data are available in the literature concerning the long-term outcomes of patients treated with PA resection and reconstruction [2–6, 10, 17, 18]. The 5-year survival rate of our N0 and N1 cases was 80.8%, including 9 cases of N0 and 5 cases of N1. This is the same survival rate for usual lung cancer surgery series, and PA patch plasty was an effective procedure as lung parenchyma-preserving surgery [19, 20]. Previous studies concerning PA plasty in lung cancer surgery are reviewed (Table 4), including cases of tangential resection, end-to-end anastomosis, interposition and patch plasty. In all reports except our own, the pericardium was used for patch angioplasty. The other reports included sleeve bronchoplasty cases, but ours did not for the reasons described above. Although direct comparisons

with these studies are difficult because of the differences in patient backgrounds, our study is comparable to others concerning the postoperative complications and survival outcomes.

The retrospective study design, heterogeneity of the patients and small case number represent limitations of this study; however, this study shows that PA patch plasty with ePTFE in patients with lung cancer is not only safe and feasible, but also yields a good long-term survival. The results of our experience highlight this technique as a viable and oncologically effective option for patients with lung cancer with which thoracic surgeons should be familiar.

Compliance with ethical standards

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