Pulmonary artery reconstruction for non–small cell lung cancer: Surgical management and long-term outcomes

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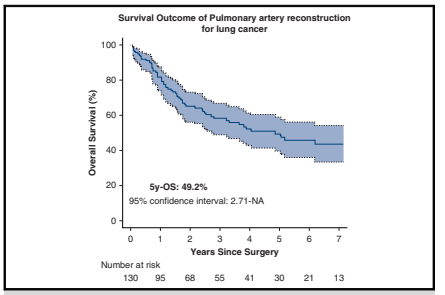
ABSTRACT

Objective: Pulmonary artery (PA) reconstruction is performed to avoid pneumonectomy for non–small cell lung cancer (NSCLC). Our objective was to assess the safety and efficacy of performing PA reconstruction without systemic heparinization during resections of NSCLC.

Methods: Among 3537 patients with resected NSCLC between 2008 and 2019, 130 (3.7%) patients underwent PA reconstruction to avoid pneumonectomy without intraoperative systemic heparinization. We investigated surgical outcome. The median follow-up time was 37 months.

Results: As to PA reconstruction, tangential suture, patch closure (autologous pericardium), end-to-end anastomosis, and conduit were performed in 56, 26, 32, and 16 patients (autologous pericardium, 13; resected pulmonary vein, 3), respectively. Combined bronchial sleeve resection was performed in 68 (52%) patients. The mean operative time was 261 minutes. The procedure-related complications were 2 PA thromboses with pericardial conduit requiring completion pneumonectomy and 2 massive hemoptysis of a bronchopulmonary fistula leading to death (operative mortality, 1.5%). PA bending and mechanical stenosis were due to the lengthening by the conduit. Seventy-five patients had other complications, the most frequent being arrhythmia. One patient was at stage 0 after induction chemoradiotherapy; 26, stage I (9 IA and 17 IB); 43, stage II (19 IA and 24 IB), 55 stage III (49 IIIA and 6 IIIB); and 5, stage IV. Five-year overall survival, cancer-specific survival, and recurrence-free survival rates were 49.2%, 61.8%, and 37.1%, respectively.

Conclusions: PA reconstruction without intraoperative systemic heparinization during resections of NSCLC was performed with a very low risk of thrombosis as well as perioperative bleeding. (J Thorac Cardiovasc Surg 2022;164:1200-7)



Overall survival of patients who underwent any pulmonary reconstruction for lung cancer.

CENTRAL MESSAGE

Pulmonary artery reconstruction without heparinization avoided pneumonectomy in more than 98% of the patients, with a low risk of bleeding and thrombosis compared with using intraoperative heparin.

PERSPECTIVE

Pulmonary artery (PA) reconstruction without systemic heparinization during resections of non–small cell lung cancer should be one of the options for thoracic surgeons. The length of PA reconstructed would be a key to a successful procedure. Postoperative PA thrombosis can occur if the reconstructed PA is too long.

See Commentary on page 1208.

Pulmonary artery (PA) reconstruction to avoid pneumonectomy is often required for thoracic surgeons. A standard bronchoplastic procedure including reconstruction of the PA for non–small cell lung cancer (NSCLC) has been established, and its short- and long-term outcomes are better than those of pneumonectomy.[1] PA reconstruction is mainly used for functional preservation and has various technical aspects such as central or peripheral vascular clamping,

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Abbreviations and Acronyms
CT = computed tomography
NSCLC = non–small cell lung cancer
PA = pulmonary artery
PET = positron emission tomography

suturing, and air removal. PA-reconstruction techniques include simple tangential suture, pericardial or artificial patch closure, and end-to-end anastomosis.[2,3] Recently, a method of interposition of the pericardial conduit or the pulmonary vein of the resected lung during end-to-end anastomosis has been reported.[4,5] PA reconstruction is often performed with left upper lobectomy. The long PA compared with bronchus makes it easy to reconstruct it. Previous studies have reported that arterioplasty is performed frequently for left-sided tumors.[3,6]

Potential issues after PA reconstruction include PA bending and mechanical stenosis after closing the chest. Careful attention should be paid to the factors related to PA thrombosis and postoperative bleeding. Long PAs tend to kink, so if the reconstructed PA is too long compared with the bronchus, PA thrombosis can occur.[7] Procedure-related major lethal complications are massive hemoptysis or bronchovascular fistula.[6,8] However, the choice of method for intraoperative and postoperative management is left to the discretion of each facility worldwide. Rendina and colleagues[8] initially recommended an intraoperative dose of 3000 to 5000 units of intravenous heparin, followed by 10,000 to 15,000 units/day of subcutaneous heparin for 10 days. Later, the authors reduced the intraoperative dose of 1500 units heparin intravenously without reversal by protamine sulfate at the end of the PA suture, followed by 6000 units/day low-molecular-weight heparin subcutaneously administered for 7 days after surgery.[2] Reduced anticoagulation contributes to reducing the risk of bleeding, especially from the lymphadenectomy sites. In contrast, we do not believe in intraoperative systemic heparinization during resections of NSCLC and have performed PA reconstruction with this policy for 10 years.

Our objective of this investigation was to assess the safety and efficacy of performing PA reconstruction without systemic heparinization during resections of lung cancer, with a particular focus on the morbidity, mortality, and oncologic outcomes.

METHODS

Study Population

Between March 2008 and December 2019, 3537 patients with NSCLC underwent surgical resection at our institute. Among them, 130 (3.7%) patients needed concomitant PA reconstruction to avoid pneumonectomy. The study design, which included a retrospective review of patient medical records, was approved by the institutional review board of Juntendo University School of Medicine, Tokyo, Japan (institutional review board number: 20-401, March 18, 2021). Informed consent was waivered.

Preoperative Evaluations

Preoperative evaluation included chest radiography, total-body computed tomography (CT), CT or magnetic resonance imaging of the brain, and/or F-18 fluorodeoxyglucose whole-body positron emission tomography (PET) to determine the tumor size and location. We performed a detailed review of the preoperative thin-section CT scans of all patients. Tumor size was determined preoperatively based on a thin-section CT scan with 2-mm collimation.

Regarding the clinical nodal assessment, clinical N0 was classified by nonenlarged lymph nodes on the CT scan or negative uptake of F-18 fluorodeoxyglucose by the lymph nodes on PET. Invasive modalities for mediastinal lymph node staging, such as mediastinoscopy or endobronchial ultrasound-guided transbronchial needle aspiration, were routinely used preoperatively if N2 disease was suspected. Whenever N2 disease was confirmed, as assessed by the most appropriate invasive methods, neoadjuvant radiation (45-60 Gy) and chemotherapy were delivered to the tumor and mediastinal targets. All patients were considered operable based on the clinical response to treatment as assessed by CT or PET. All patients underwent systemic hilar and mediastinal lymphadenectomy. Moreover, respiratory function tests and blood gas analysis were also considered when determining the operability. Tolerance for pneumonectomy was always confirmed.

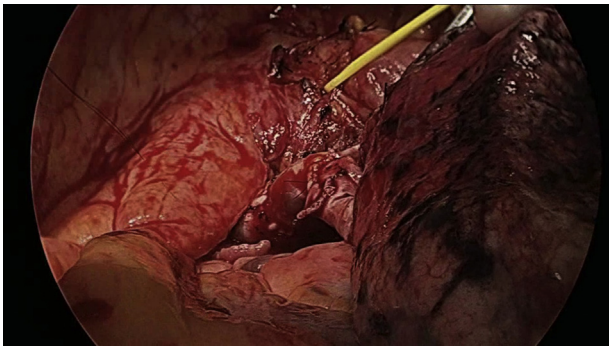
Surgical Technique for PA Reconstruction

All patients underwent double-lumen endotracheal intubation. We used a standard posterolateral thoracotomy. After the vessel was clamped proximally and distally to the area infiltrated by the tumor, the oncologic and technical feasibility of sleeve resection and modality of PA reconstruction were assessed by the surgeon (K.S.) based on the intraoperative findings. We did not use systemic heparinization before arterial clamping as a standard practice in all reconstructive procedures. For all arterial sutures, we washed the anastomosis sites with diluted heparin to prevent intraluminal thrombosis. PA reconstruction was performed with running sutures, pericardial patch closing, end-to-end direct anastomosis, or interposition of pericardial conduit or pulmonary vein with 6-0 nonabsorbable monofilament stitches (Video 1). Frozen section analysis was routinely performed to check for negative PA margins. For cases of conduit interposition, proximal anastomosis was performed first. After the conduit length was checked during re-expansion of the residual lung, distal anastomosis was performed. If combined bronchoplasty using 4-0 nonabsorbable monofilament stitches in a hybrid manner was performed, PA reconstruction was conducted after the end of bronchial anastomosis to avoid vessel kinking. We do not cover PA reconstruction routinely, and a pericardial fat pad is used for covering in case of bronchovascular sleeve resection.

After the bronchial anastomosis was performed, we checked the PA suture line, length, and position after re-expansion of the residual lung. In the postoperative period, low-dose anticoagulation therapy was not administered. Our routine protocol for preventing postoperative venous thromboembolism is intraoperative intermittent pneumatic compressions for both lower extremities, which is until the time the patient walks for the first time after surgery, ie, mostly the first postoperative day. Postoperative low-dose anticoagulation is not routinely used. Moreover, routine anticoagulant therapy was not performed for all patients after discharge.

Follow-up Policy

Based on a routine follow-up protocol, CT, basically plain, and tumor markers are evaluated every 6 months for 5 years. After 5 years, CT is evaluated annually up to 10 years after surgery. Contrast-enhanced CT to detect PA obstruction or decreased flow was not performed routinely. If any symptoms or signs of recurrence were observed, further evaluation was



VIDEO 1. Reconstruction of the pulmonary artery with pericardial conduit is shown. The pericardium was harvested and trimmed with Metzenbaum scissors, Supercut. Pericardial conduit was made with the trimmed pericardium using a 28F chest tube. Nonabsorbable monofilament 6-0 strings were used for the conduit in an interrupted manner. The proximal side was selected for the first anastomosis with a 6-0 nonabsorbable monofilament string with needle on both ends. The pulmonary artery was sutured carefully in a continuous manner, so as not to become bottleneck. After the procedure is done, the lung is inflated to make sure that the pulmonary artery is not bent. Video available at: https://www.jtcvs.org/article/S0022-5223(22)00087-3/fulltext.

performed. Locoregional recurrence was defined as occurrence within the same lobe or in the ipsilateral thoracic cavity, hilum, or mediastinal lymph nodes.

Statistical Analysis

Data were collected and stored in an Excel database (Microsoft Corp, Redmond, Wash). Frequencies and percentages are provided for categorical data. Medians with standard deviations are reported for continuous data. Overall survival, recurrence-free survival, and cancer-specific survival were estimated with the Kaplan–Meier method using EZR, version 1.52 (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R version 4.02 (The R Foundation for Statistical Computing, Vienna, Austria). More precisely, it is a modified version of R commander designed to add statistical functions frequently used in biostatistics.[9]

RESULTS

The overall clinical characteristics of all patients are summarized in Table 1. The median age of patients was 69 (range: 44-88) years, and 102 (78%) were male. In addition, 110 patients (83.9%) were current or former smokers. The mean preoperative forced expiratory volume in 1 second and diffusing lung capacity for carbon monoxide were 68.6% ± 12.1% (median, 69.2%; range, 27.2%-97.0%) and 55.5% ± 17.1% (median, 55.3%; range, 9.8%-89.0%), respectively. Comorbidities, which were duplicated in some patients, included previous cerebral infarction (11 patients, 8.4%), cardiovascular disease (31 patients, 24%), diabetes (20 patients, 15%), and pulmonary disease (27 patients, 21%). Twelve (9.2%) patients were taking antiplatelet drugs and/or anticoagulant drugs preoperatively. Perioperative heparin bridging was performed in 7 patients (5.3%). Fifteen patients (11%) received

TABLE 1. Clinical characteristics of the patients

Variables	n = 130
Age, y	69 (44-88)
Sex, male	101 (78%)
Pack-year smoking	47.7 ± 39.4
FEV1, %	68.6 ± 12.1
VC, %	96.2 ± 15.9
DLco, %*	55.5 ± 17.1
CEA, ng/mL	3.9 (0.4-141.3)
Maximum tumor size, mm	38 (9-127)
Comorbidities, cerebral infarction/ cardiovascular disease/diabetes/ pulmonary disease	11 (8.4%)/31 (24%)/ 20(15%)/27 (21%)
Preoperative antiplatelet drugs and/or anticoagulant drugs, yes	12 (9.2%)
Perioperative heparin bridging, yes	7 (5.3%)
Neoadjuvant therapy, chemoradiotherapy/ chemotherapy alone/radiotherapy alone	9 (6.9%)/5 (3.8%)/1 (0.8%)
Salvage surgery	4 (3.0%)
Side, left	94 (72%)
Reason for PA reconstruction, tumor invasion/lymph node invasion/others	115 (89%)/14 (10%)/1 (1%)
Surgical resection	
Segmentectomy	2
Lobectomy	102
Lobectomy + wedge resection	10
Lobectomy + segmentectomy	7
Bilobectomy	9
Procedure, PA with bronchoplasty	68 (52%)
PA-reconstruction technique, TS/P/EE/C	56 (44%)/26 (20%)/ 32 (24%)/16 (12%)
Systematic nodal dissection, yes	115 (88%)
Operative time, min, mean	261 ± 86
Blood loss, mL, median (range)	180 (10-1970)
Pathologic stage, 0 (CR)/I/II/III/IV	1 (1%)/26 (19%)/ 43 (33%)/55 (43%)/5 (4%)
Histologic types, Ad/Sq/others	54 (42%)/58 (44%)/18 (14%)
Pathologic N2 status, yes	37 (28%)
Pathologic ly and/or v invasion, yes	99 (76%)
Adjuvant chemotherapy, yes	31 (24%)
30-d/90-d mortality	2 (1.5%)/7 (5.3%)
Recurrence, local/distance/multiorgan	7 (5.3%)/6 (4.6%)/40 (30%)

Categorial data are shown as numbers (%) and continuous data as mean ± standard deviation if normally distributed, and median ± interquartile range if not normally distributed (range). *FEV1*, Forced expiratory volume in 1 second; *VC*, vital capacity; *DLco*, diffusing lung capacity for carbon monoxide; *CEA*, carcinoembryonic antigen; *PA*, pulmonary artery; *TS*, tangential suture; *P*, patch closure; *EE*, end-to-end anastomosis; *C*, conduit; *CR*, complete responder; *Ad*, adenocarcinoma; *Sq*, squamous cell carcinoma; *ly*, lymphatic; *v*, vascular. *There were 26 missing data.

preoperative treatment: chemoradiation therapy (9 patients, 6.9%), chemotherapy (5 patients, 3.8%), and radiotherapy (1 patient, 0.8%). Salvage surgery was performed in 4 patients (3.0%). Ninety-five procedures (73%) were performed on the left side. Combined bronchial sleeve resection was performed in 68 (51.9%) patients.

The PA was resected because of direct invasion of the main tumor in 116 (89%) patients, extranodal invasion of a metastatic hilar node in 14 (10%) patients, and others in 1 (1%) patient. As for the other reasons, one case was of repairing an injury of the PA. The following surgical methods were performed: bilobectomy (9 patients), lobectomy (102 patients), lobectomy + segmentectomy (7 patients), lobectomy + wedge resection (10 patients), and segmentectomy (2 patients). PA reconstruction was performed in 130 (3.7%) patients: 56 (44%) by tangential suture, 26 (20%) by patch closure (autologous pericardium), 32 (24%) by end-to-end anastomosis, and 16 (12%) by conduit (autologous pericardium, 13; resected pulmonary vein, 3). The mean operative time and median blood loss were 261 ± 86 minutes and 180 (10-1970) mL, respectively. Transfusion was needed in 14 (10.7%) patients.

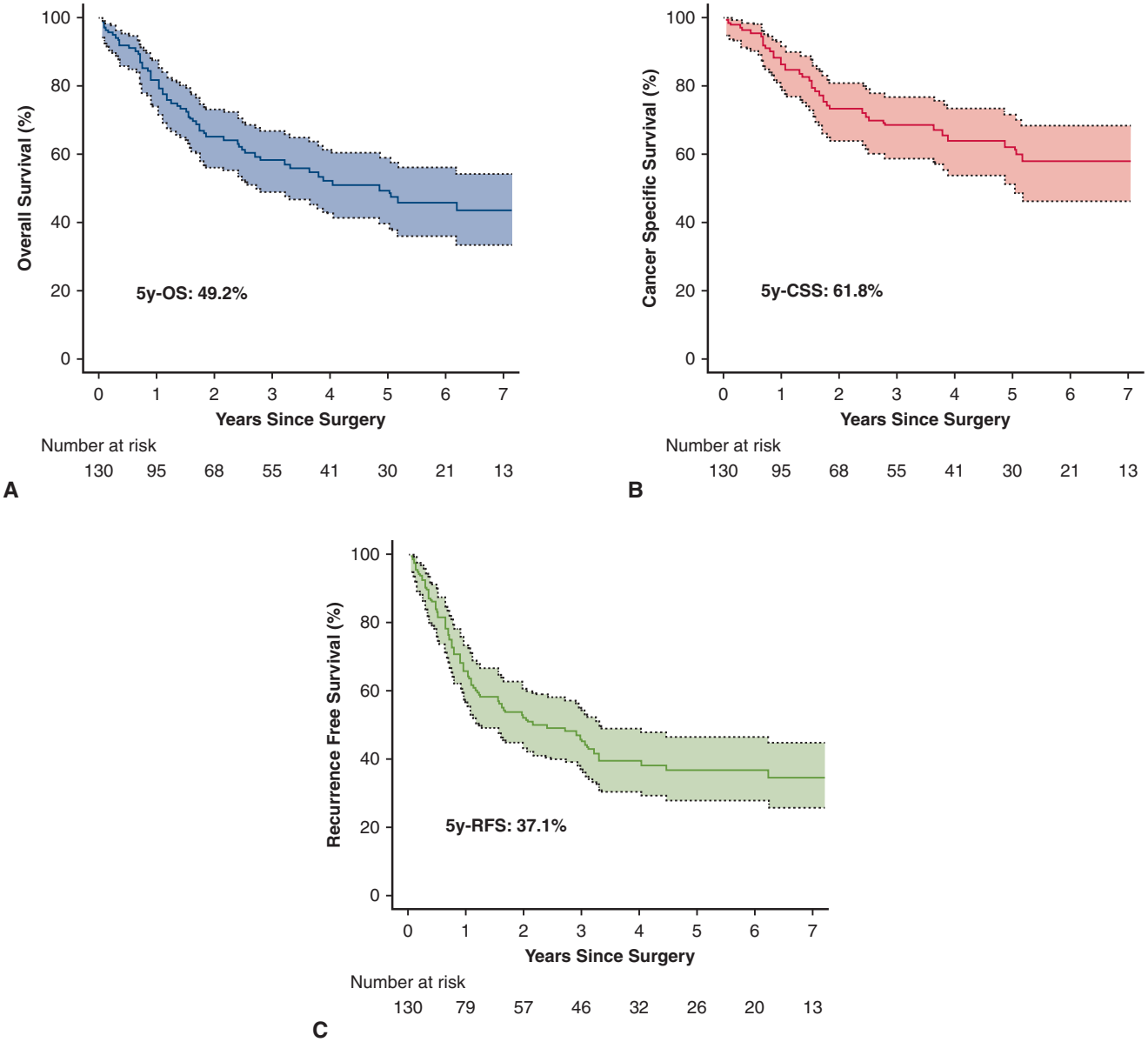


FIGURE 1. Five-year OS (A), CSS (B), and RFS (C) for 130 patients who underwent PA reconstruction for NSCLC are shown. Five-year OS, CSS, and RFS rates are 49.2%, 61.8%, and 37.1%, respectively. In CSS, patients who die from other diseases than cancer are censored. In RFS, death or recurrence are both recorded as events. The range is 95% CI. *OS*, Overall survival; *CSS*, cancer-specific survival; *RFS*, recurrence-free survival.

Based on histologic features, 58 (44%) tumors were squamous cell carcinomas; 55 (42%), adenocarcinomas; and 18 (14%), others (adenosquamous and neuroendocrine carcinomas). The pathologic stages were stage 0 in 1 (1%) patient after induction chemoradiotherapy, stage I in 26 (19.8%; 9 IA and 17 IB), stage II in 43 (32.8%; 19 IIA and 24 IIB), stage III in 56 (42.7%; 50 IIIA and 6 IIIB), and stage IV in 5 (3.8%). Adjuvant postoperative therapy was performed in 32 patients (24%). No intraoperative deaths occurred. Thirty-day and 90-day mortalities were 1.5% and 5.3%, respectively. Five-year overall survival, cancer-specific survival, and recurrence-free survival rates were 49.2%, 61.8% and 37.1%, respectively (Figure 1, *A-C*), at a median follow-up time of 37 (range 8-127) months. No evidence of local recurrence along the PA suture line was found. Recurrence occurred in 53 (40.4%) patients: locoregional relapse was recorded in 7 patients (lymph node metastasis, 6; bronchial anastomosis, 1), distant recurrence in 6 (brain relapse, 2; bone, 4), and multiorgan in 40.

The overall postoperative complications are summarized in Table 2. Overall morbidity was 57% (75 patients). Morbidities were duplicated in some patients. Two cases of massive hemoptysis resulted in death because of bronchoarterial fistula, but no postoperative intrathoracic bleeding led to re-drainage or reoperation. Two cases with bronchoarterial fistula had lung cancer in the right upper lobe and the complications occurred in the 19th and 44th postoperative day. The former underwent right upper sleeve lobectomy with tangential closure of the PA and the latter did right upper lobectomy with carinal resection followed by double-barrel reconstruction of the bronchus, concomitant endo-to-endo anastomosis of the PA. In both cases, covering by pericardial fat pad was indicated. Procedure-related complications included 2 (1.5%) PA thromboses with pericardial conduit reconstruction requiring completion pneumonectomy. One case was an 81-year-old man with T3N0 adenosquamous who had undergone left upper sleeve lobectomy with pericardial conduit reconstruction of the PA. The other case was a 49-year-old man with T3N0 squamous who had undergone left upper double-sleeve lobectomy with pericardial conduit reconstruction of the PA. The chief complaint was dyspnea on the eighth and fourth postoperative days, respectively. The occlusion of the left PA due to bending of the lengthening pericardial conduit was detected on reoperation. The most frequent complication was arrhythmia (24 patients, 18%); other complications were hypoxia requiring transient home oxygen treatment (17 patients, 13%), prolonged air leak (14 patients, 11%), pulmonary vein thrombosis (2 patients), cerebral infarction (3 patients), chylothorax (4 patients), atelectasis (4 patients), and empyema or pneumonia (7 patients).

PA patency evaluation, as assessed by contrast-enhanced CT, was performed for 57 (44%) patients within 90 days of surgery. All the remaining patients underwent contrast-enhanced CT at 6 months. No PA obstruction or evidence of decreased flow was detected under asymptomatic conditions during the follow-up.

TABLE 2. Postoperative morbidity*

Complications	n = 75 (57%)
Massive hemoptysis	2 (1.5%)
Reoperation that requires completion pneumonectomy	2 (1.5%)
PA thrombosis	2 (1.5%)
PV thrombosis	2 (1.5%)
Cerebral infarction, paradoxical/atherothrombotic/cardiogenic	1 (0.8%)/1 (0.8%)/1 (0.8%)
Arrhythmia	24 (18%)
Venous thromboembolism	0 (0%)
Chylothorax	4 (3.1%)
Atelectasis	4 (3.1%)
Empyema or pneumonia	7 (5.4%)
Prolonged air leak	14 (11%)
Pleural effusion that requires redrainage	0 (0%)
Acute exacerbation of intestinal pneumonia	1 (0.8%)
Hypoxia that requires transient home oxygen treatment	17 (13%)

Categorial data are shown as numbers (%). *PA*, Pulmonary artery; *PV*, pulmonary vein. *Morbidities ware duplicated in some patients.

DISCUSSION

In Japan, 127 (0.28%) of 44,140 patients with lung cancer underwent surgery with PA reconstruction during 2018.[10] In our institute, 130 (3.7%) patients with NSCLC underwent surgery with PA reconstruction over 10 years (Figure 2). There is no previous evidence that the need for heparin can be prevented by administering heparin during or after PA reconstruction; conversely, the administration of heparin may cause resumption of bleeding. Evidence is warranted immediately because heparin management is a controversial issue. In such a clinical scenario, we focused on the surgical outcome of PA reconstruction without intraoperative systemic heparinization for NSCLC based on 10-year experience.

With respect to the feasibility and safety, intra- and postoperative management and the prevention and treatment of early complications have been reviewed in the last decade (Table 3).[3,6,11-17] The main concerns in PA reconstruction are bleeding, thrombosis and kinking of the reconstructed vessel. First, postoperative bleeding may be related to leakage from the suture line of PA reconstruction or the site of mediastinal lymph node dissection. Venuta and colleagues[6] reduced the systemic heparinization dose from 5000 to 1500 IU. This pharmacologic management contributed to reducing the risk of bleeding. Madariaga and colleagues[18] reported that the median blood loss and postoperative transfusion were 500 mL

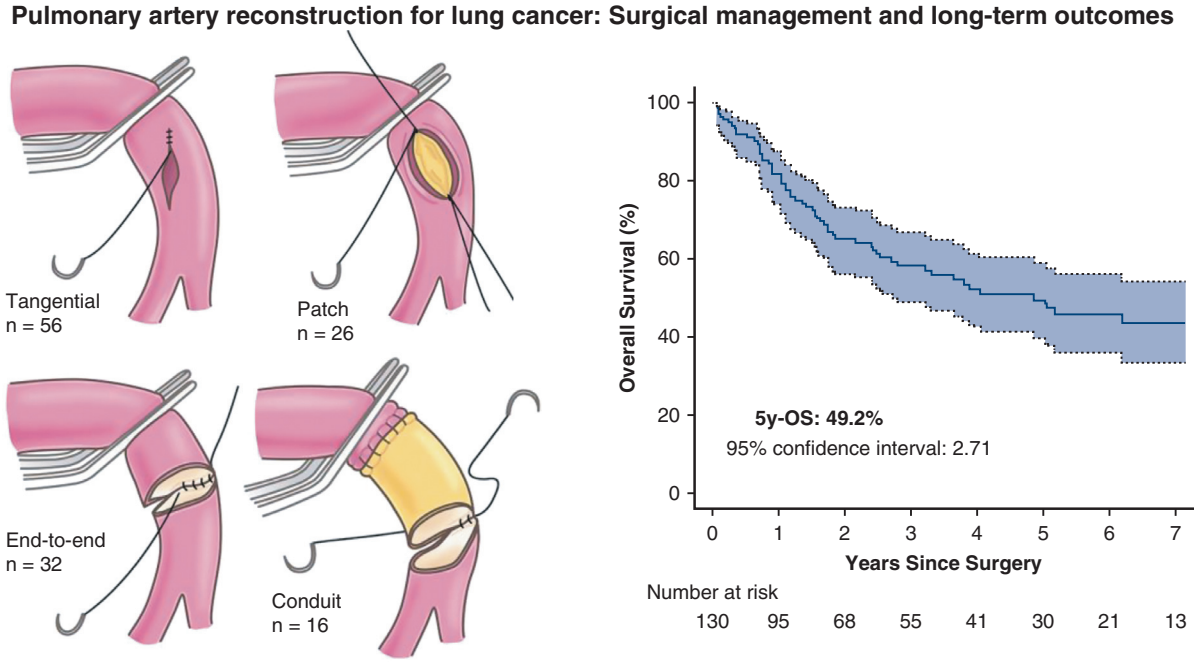


FIGURE 2. We reviewed 130 PA plasty procedures without perioperative heparinization for lung cancer. Two thromboses after pericardial conduit reconstruction required completion pneumonectomy. The 5-year overall, cancer-specific, and recurrence-free survival rates were 49.2%, 61.8%, and 37.1%, respectively. Our intraoperative strategy without heparinization is a very low risk of thrombosis as well as a very low risk for perioperative bleeding and may be a promising novel strategy for PA reconstruction in lung cancer. *OS*, Overall survival; *PA*, pulmonary artery.

and 36% of patients who received intraoperative heparin versus 300 mL and only 4.7% of patients who did not receive intraoperative heparin, respectively. Intraoperative systemic heparinization is associated with a risk of increased operative bleeding and a longer operative time. Secondarily, major lethal complications were thrombosis in the PA.[7] Early postoperative PA thrombosis after reconstruction often leads to pneumonectomy.[19] Greater rates of thrombosis have been reported after tangential resection with direct suture than after patch or anastomotic reconstruction. Compared with a report in which the incidences of pulmonary embolism and acute thrombosis were 1.9% after bronchoplastic procedures and <5% after PA reconstructions, our study observed only 2 (1.5%) cases of pulmonary embolism and acute thrombosis.[5,20] Thoracic surgeons are familiar with the symptoms and signs of bronchial stenosis or fistula. However, postoperative thrombotic complications of the pulmonary vessels are not so common.[21] Clinical diagnosis should be considered as the most important decision for completion pneumonectomy. In our study, 2 cases of PA thrombosis within 30 days required completion pneumonectomy. On reoperation, we found PA thrombosis due to bending of the reconstructed PA. The cause of the bending was an inappropriate length of the reconstructed PA with a pericardial conduit. It is difficult to adjust the length of PA conduit after lung reinflation and closing the chest.

The necessity of intraoperative systemic heparinization in patients undergoing PA resection is controversial. There is a global agreement but has been no evidence supported by phase III comparative studies. From our experience, prevention of kinking is more important than the use of intraoperative heparinization in case of PA reconstruction. The bending of the PA can occur after lung reinflation and closing the chest. Re-expansion of the residual lobe or segments may increase the risk of stenosis by bending the PA in the early postoperative period. The lengthened PA may cause kinking in the vessel, impaired blood flow, and thrombus formation. Nakajima and colleagues[7] performed left pulmonary thrombectomy and arterioplasty for acute thrombosis caused by PA kinking after left upper sleeve lobectomy. When sleeves of both the bronchus and artery were required, D'Andrilli and colleagues[22] performed PA resection and reconstruction as the first step to decrease

TABLE 3. Historical results of reconstruction of the PA in lung cancer surgery

Study	Patients	TS/P/EE/C	Intraoperative heparin, U	Postoperative heparin, U	PA thrombosis	Hemoptysis	Contrast-CT scan	Combined-bronchoplasty, n (%)	Left side, n, %	Procedure	30-d mortality (%)	5-y-OS, %
Rendina et al, 1999[16]	52	–/34/15/3	3000-5000	15,000 for 1 wk	1	1	6 m	33 (63)	40 (77)	PA→Br	0	38.3
Lausberg et al, 2005[14]	67	–/28/39/–	5000	N/A	–	–	N/A	67 (100)	38 (57)	Br→PA	1.5	42.9
Cerfolio and Bryant, 2007[3]	42	31/7/4/–	1500	–	–	–	6 wk	6 (14)	40 (95)	Br→PA	2.3	60
Venuta et al, 2009[6]	105	–/55/47/3	1500-2000	N/A	1	1	6 mo	65 (62)	74 (70)	PA→Br	0.95	44
Berthet et al, 2013[12]	32	–/2/20/10	5000 with local heparin	Low molecular for 3 wk	1	–	+	–	N/A	Br→PA	0	66
Ma et al, 2013[11]	118	36/51/22/–	1500	Aspirin High-risk only	1	–	6 mo	41 (35)	81 (69)	Br→PA	0	50.2
Galetta et al[17]	150	113/33/–/4	3000-5000	Low molecular for 2 wk	–	2	6 w	56 (37)	108 (72)	PA→Br	3.3	50.0
Shrager et al, 2000[15]	33	19/11/3/0	–	N/A	–	–	N/A	14 (42)	26 (79)	PA→Br	0	48.3 (4y)
Alifano et al, 2009[13]	93	90/-/3/-	–	Low molecular	–	–	6-8 wk	23 (25)	67 (72)	N/A	5.4	39.4
Present study, 2020	130	56/26/32/16	–	–	2	2	6 d	68 (52)	94 (72)	Br→PA	1.5	49.2

TS, Tangential suture; *P*, patch closure; *EE*, end-to-end anastomosis; *C*, conduit; *PA*, pulmonary artery; *CT*, computed tomography; *OS*, overall survival; *Br*, bronchus; *N/A*, not answered.

the artery clamp time. Conversely, after the bronchial anastomosis was made, the PA suture line, length, and position after re-expansion of the residual lung were checked. The surgical procedure of combined bronchial sleeve resection is also left to the discretion of each facility. The reconstruction procedure may lead to completion pneumonectomy in response to kinking of the PA, impaired blood flow, and ultimately, thrombus formation.

Thoracic surgeons must be capable of early detection of the slight postoperative change in patients in the clinical scenario. Our 2 cases with PA thrombosis were diagnosed with clinical symptoms and enhanced CT scan. Postoperative changes are most important, such as increased dyspnea and impaired oxygenation. Cloudiness of plain chest radiographs is the first sign of the thrombus, and a subsequent thoracic CT should be done. Enhanced CT is better, but even plain CT can detect the early phase of PA thrombosis with interstitial infiltration in the preserved lung on lung window. Abnormal result in blood gas analysis such as metabolic acidosis is often found. Fever or signs of inflammation, such as peripheral white blood cell count or C-reactive protein, are not always significant. Clinical diagnosis is so important for early surgical intervention for PA thrombosis. In the absence of clinical symptoms, CT and 3-dimensional volume rendering are useful for demonstrating PA patency.[2] Contrast-enhanced CT was recently performed to detect PA obstruction or evidence of decreased flow in our institute. PA patency evaluation was performed for 57 (44%) patients within 90 days of surgery, but no PA kinking was detected while the patients were asymptomatic. The remaining patients underwent contrast-enhanced CT at 6 months. D'Andrilli and colleagues[22] assessed PA patency at discharge and every 6 months. Other institutes also often perform the first CT scan to assess PA patency at 6 months' postoperatively. Noninvasive radiologic methods are limited because of repositioning of the heart after lung

resection, and they may be unpredictable because of a difference in the findings between the standing position and spine position. In essence, it is difficult problem to detect PA kinking in clinically asymptomatic patients. Thoracic surgeons should pay attention to lengthening of the reconstructed PA after lung reinflation during the first operation if possible.

There are several limitations to the study. First, the retrospective study design and small number of patients from a single-center may produce some selection bias. There are no controls that received heparin. Second, the operations were all done by the same surgeon, and so there is a strong "surgeon effect." This might not work as well with other surgeons. Third, the follow-up period was short; hence, further observation is necessary to assess the radiologic and oncologic effect of the procedure. Lastly, a small number of patients on preoperative antiplatelet drugs and/or anticoagulant drugs underwent the perioperative heparin bridge. However, PA reconstruction without intraoperative systemic heparinization was performed in all the patients.

In conclusion, our 10-year experience suggests that PA reconstruction without intraoperative systemic heparinization was performed with a very low risk of thrombosis as well as a very low risk for intraoperative or postoperative bleeding. Our study does not show inferior outcomes compared with previous studies concerning the postoperative complications and survival outcomes. From our experience, prevention of kinking of the PA is more important than the use of intraoperative heparinization in case of PA reconstruction.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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