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ORIGINAL ARTICLE / ÖZGÜN MAKALE

The outcomes of concomitant off-pump coronary artery bypass grafting and pulmonary operations

Eş zamanlı çalışan kalpte koroner arter baypas cerrahisi ve pulmoner ameliyat sonuçları

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ABSTRACT

Background: This study aims to analyze the early- and long-term outcomes of concomitant off-pump coronary artery bypass grafting and pulmonary resection for lung cancer or a thoracic mass.

Methods: Twenty-three patients (17 females, 6 males; mean age: 69.7±6.5 years; range, 59 to 83 years) who underwent concomitant off-pump coronary artery bypass grafting and thoracic surgery procedures for lung cancer or a thoracic mass between March 2018 and February 2024 were included in the retrospective study. The surgical approach was median sternotomy for off-pump coronary artery bypass grafting, and video-assisted thoracoscopic surgery was preferred for lung tumor resections. Mortality, major adverse cardiac events, cerebrovascular events, and duration of hospital stay were evaluated.

Results: There were no postoperative deaths or perioperative myocardial infarctions. None of the patients experienced pneumothorax or atelectasis. None of the patients sustained excessive blood loss requiring reoperation. Arterial grafts were the first choice during coronary artery bypass grafting. Wedge resections, lobectomies, segmentectomies were performed in the subsequent video-assisted thoracic surgery. All patients were followed for six to 86 months. Four patients died during the postoperative one-year period, and one patient died at postoperative 29 months due to cancer relapse. The overall one-year survival rate was 86.5%, and three- and five-year survival rates were 74% and 74%, respectively.

Conclusion: The video-assisted thoracoscopic surgery approach provides a more favorable perspective for pulmonary resection and mediastinal lymph node dissection, which has importance in patients' final diagnosis, than the sternal view due to more ample, wider workspace. Combined off-pump coronary artery bypass grafting and pulmonary resection in patients with lung cancer is safe and effective and reduces possible complications of a second major surgery.

Keywords: Concomitant cardiac and pulmonary operation, lung cancer, off-pump coronary artery bypass grafting, video-assisted thoracoscopic surgery.

ÖZ

Amaç: Bu çalışmada aynı seansta yapılan çalışan kalpte koroner arter baypas greftleme ve akciğer kanseri veya torasik kitle sebebi ile akciğer rezeksiyonu yapılan hastalarımızın erken ve uzun dönem sonuçları değerlendirildi.

Çalışma planı: Mart 2018 - Şubat 2024 tarihleri arasında, aynı seansta çalışan kalpte koroner arter baypas greftleme ile akciğer kanseri veya torasik kitle nedeniyle torasik cerrahi prosedür uygulanan 23 hasta (17 kadın, 6 erkek; ort. yaş 69±6.5 yıl; dağılım, 59-83 yıl) retrospektif çalışmaya dahil edildi. Cerrahi yaklaşım, çalışan kalpte koroner arter baypas greftleme için median sternotomi iken, akciğer tümör rezeksiyonu için video yardımlı torakoskopik cerrahisi tercih edildi. Ölüm, majör advers kardiyak olaylar, serebrovasküler olaylar ve hastanede kalış süreleri değerlendirildi.

Bulgular: Ameliyat sonrasında ölüm veya perioperatif miyokart enfarktüsü görülmedi. Hastaların hiçbirinde pnömotoraks veya atelektazi tespit edilmedi. Hastaların hiçbirinde tekrar ameliyat gerektiren yoğun kanama olmadı. Koroner arter baypas greftleme sırasında ilk tercih arteriyel greftler idi. Takip eden video yardımlı göğüs cerrahisi işleminde kama rezeksiyonlar, lobektomiler, segmentektomiler uygulandı. Tüm hastalar altı ila 86 ay boyunca takip edildi. Dört hasta, ameliyat sonrası bir yıllık takipleri sırasında öldü ve bir hasta ameliyat sonrası 29. ayda kanser nüksü sebebiyle öldü. Bir yıllık sağkalım %86.5 idi ve üç ve beş yıllık sağkalımlar sırasıyla %74 ve %74 idi.

Sonuç: Video yardımlı torakoskopik cerrahisi pulmoner rezeksiyon ve hastaların kesin tanısında önemli olan mediastinal lenf nodu diseksiyonu için daha geniş çalışma alanı sağlaması nedeniyle sternal görüşe kıyasla daha iyi bir tercihtir. Akciğer kanserli hastalarda aynı seansta çalışan kalpte koroner arter baypas greftleme ve pulmoner rezeksiyon güvenli ve etkili olup, ikinci majör bir cerrahinin komplikasyonlarını azaltır.

Anahtar sözcükler: Aynı seansta kalp ve akciğer cerrahisi, akciğer kanseri, çalışan kalpte koroner arter baypas, video-yardımlı torakoskopik cerrahisi.

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Lung cancer and cardiovascular diseases often simultaneously occur, and concomitant surgical diseases of the heart and lungs are uncommon. The majority of these patients present with unstable coronary heart disease and are incidentally found to have asymptomatic indeterminate pulmonary mass.[1] During the coronavirus disease 2019 pandemic, incidental pulmonary masses were reported in routine chest X-rays and chest computed tomography (CT) scans to be further evaluated for lung cancer. Less frequently, patients with pulmonary disease were found to have significant cardiac disease that would increase the risk of pulmonary resection.[2] Sporadic reports on combined cardiac and pulmonary operations have appeared in the literature.[1-15]

Traditionally, surgeons have been reluctant to perform concomitant cardiac surgery and pulmonary resection for three reasons: *(i)* heparinization and cardiopulmonary bypass (CPB) can increase the patient's risk of excessive bleeding; *(ii)* cardiac surgery requires a median sternotomy approach, which is believed to provide inadequate exposure for pulmonary resection for lung cancer; *(iii)* CPB may alter the immunologic response, increasing the patient's risk of mediastinal and pleural infection.[3,4]

Coronary artery disease carries a significant risk factor on surgical morbidity of lung cancer patients. Although the percentage of patients affected by both diseases reported by surgeons is relatively small, with 0.5%.[5,6] On the other hand, from thoracic surgery standpoint, at least 5% of patients awaiting a major lung resection require preoperative cardiologic or surgical interventions. These interventions, particularly in patients with unstable coronary artery disease, or after a recent myocardial infarction, require a good standard of care in this high-risk group to reduce surgical morbidity and mortality.[6]

It is still unclear which therapeutic option is the most beneficial. The first option is coronary angioplasty or stent placement before lung resection, which postpones the timing of the lung surgery, and the use of antiplatelet and anticoagulation medication for a certain period. The second option is coronary artery bypass grafting (CABG), followed by lung resection, which is a two-stage procedure. The potential problems with this approach include the delay in the lung resection due to postoperative recovery phase, and the additional cost of two separate operations.[7]

However, the open approach has the risk of dissemination due to manipulation of the pulmonary lobe, mechanical stress on the cardiac chambers, more difficult radical lymph node dissection, and the risk of increasing the amount of blood loss due to heparinization.[8] A minimally invasive approach for resection of early-stage lung cancers is promoted, and there is increasing interest in robotic approach.

Video-assisted thoracoscopic surgery (VATS) with concurrent lower lobectomy in combined surgical approaches involving median sternotomy was reported to be more feasible compared to anterolateral thoracotomy for lower lobectomy and complete mediastinal lymph node dissection (mLND).[9]

In the present study, we aimed to evaluate the outcomes of concomitant off-pump CABG and pulmonary operations for lung cancer patients.

PATIENTS AND METHODS

This retrospective study was conducted at Koç University, Faculty of Medicine and VKF American Hospital, Departments of Cardiovascular Surgery and Thoracic Surgery between March 2018 and February 2024. The records of all patients who underwent concomitant cardiac and pulmonary surgery were analyzed. All the patients with off-pump CABG and concomitant pulmonary operations were included in the study. Twenty-three patients (17 females, 6 males; mean age: 69.7±6.5 years; range, 59 to 83 years) were included in the study. Lung cancer or lung mass was first detected via chest radiography or CT performed during a medical check-up or due to symptoms, with cardiovascular disease subsequently discovered via preoperative examination at the cardiology department. A written informed consent was obtained from each patient. The study protocol was approved by the Koç University Ethics Committee for Clinical Studies (date: 12.10.2023, no: 2023.348.IRB1.122). Written informed consent was obtained from all participants. The study was conducted in accordance with the principles of the Declaration of Helsinki.

The records were reviewed for age, New York Heart Association (NYHA) classification, EuroSCORE, left ventricular ejection fraction (LVEF), comorbidities, smoking, previous operations, operative procedures, final pathological diagnosis, tumor, morbidity, mortality, and long-term follow-up.

All the patients underwent combined off-pump CABG and lung resection surgery in a single session. Patients had symptoms such as cough, chest pain, or chest discomfort after exercise. Clinical examination, blood serum analysis, and cardiac

echocardiography were performed for all patients. Each patient underwent coronary angiography and preoperative evaluation by positron emission tomography or CT imaging or combined positron emission tomography/CT imaging, pulmonary function tests, or bronchoscopy. Patients with lung cancer were classified and staged postoperatively in accordance with the 2015-2021 World Health Organization classification of lung tumors and using the Tumor, Node, Metastasis (TNM) staging.[11]

Surgical procedure

The decision for combined surgery was approved at a multidisciplinary meeting, including the departments of cardiology, cardiac surgery, and thoracic surgery. The best management option was separately evaluated for each patient.

Surgery was performed under general anesthesia with double-lumen endotracheal tube intubation. The cardiac and lung surgical procedures were carried out simultaneously. Coronary anastomoses were performed first on the beating heart using off-pump CABG surgery, followed by VATS or thoracotomy. The off-pump CABG procedure included harvesting of an arterial or venous graft, followed by beating heart aortocoronary bypass implantation. All patients received complete coronary revascularization.

Surgical approaches included median sternotomy in 23 patients for off-pump CABG procedures. In two patients, median sternotomy was completed with thoracotomy for right upper lobectomy and left upper sleeve lobectomy. Fourteen patients had median sternotomy followed by VATS, and seven patients had their lung procedures through median sternotomy.

Video-assisted thoracoscopic surgery was performed through three incisions without rib spreading using a standardized three-port anterior approach. The first port for initial thoracoscopic exploration was placed at the seventh or eighth intercostal space (ICS) in the midaxillary line. A working window (utility incision) of about 4 cm in length was made at the fourth or fifth ICS in the midclavicular line. An additional 5-or 10-mm port was made at the fifth or sixth ICS below the scapular tip. This port location served as a prompt conversion to open thoracotomy in emergent situations by connecting the working window and the posterior port. All the lung lobes could be resected and mLND could be achieved by this three-port configuration without major modifications. Complete mLND was achieved in all cases by rotating the operating table to provide an improved visual operative field, which is crucial for achieving complete surgery.

Separate pleural and mediastinal drainage tubes were used in all patients at the end of the surgical procedure, and low-molecular-weight heparin was given to all patients until discharge. Patients received acetylsalicylic acid and clopidogrel for antiplatelet therapy.

Definitions and follow-up

Survival was estimated based on the date of surgery as the starting point and the date of the death or last follow-up as the end point. Cancer-free survival was defined as cancer relapse

Table 1. Characteristics of patients

Preoperative variables	n	%	Mean±SD
Age (year)			69.7±6.6
Sex			
Female	17	73.9	
Male	6	26.1	
NYHA class			
III	23	100	
IV	0	0	
EuroSCORE			
0-3	12	52.2	
4-6	10	43.5	
7 and over	1	4.3	
LVEF (%)			
<30	0	0	
30-50	5	21.7	
>50	18	78.3	
Comorbidities			
Hypertension	21	91.3	
Hyperlipidemia	21	91.3	
Diabetes mellitus	6	26.1	
COPD	8	34.8	
Recent MI	0	0	
Renal failure/dialysis	0	0	
Previous coronary stent	3	13	
Previous carotid stent	0	0	
Previous CABG	1	4.3	
Previous stroke/TIA	0	0	
Peripheral vascular disease	0	0	
Preoperative atrial fibrillation	1	4.3	
Smoking	15	65.2	

SD: Standard deviation; NYHA: New York Heart Association; EuroSCORE: European System for Cardiac Operative Risk Evaluation; LVEF: Left ventricular ejection fraction; COPD: Chronic obstructive pulmonary disease; MI: Myocardial infarction; CABG: Coronary artery bypass grafting; TIA: Transient ischemic attack.

and/or metastasis reoccurrence free survival at postoperative follow-up period. Operative mortality was defined as deaths occurring within 30 days of operation or during hospitalization.

All patients were followed postoperatively at the first week, first month, and third month, with scheduled follow-ups at the outpatient clinic after hospital discharge. At follow-ups, all the patients underwent physical examination, chest X-ray, and echocardiography. After a six month duration close follow-up of the patients was managed by both outpatient clinics. These patients were also followed by their cardiology and pulmonology primary attending physicians. All the patients whose final diagnosis was lung cancer were followed by the oncology department for their ongoing medical treatment. The chest CT was performed at six months postoperatively. A follow-up bronchoscopy was performed in patients with suspicion of a local recurrence.

Statistical analysis

Statistical analysis was performed using the SPSS version 27.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. Normality of the variables was checked using the Levene's test. Survival was estimated using the Kaplan-Meier method. A p value of <0.05 was considered statistically significant.

RESULTS

The clinical characteristics of patients included in the study are summarized in Table 1. All patients were NYHA class III. Twelve patients had a EuroSCORE between 0 and 3, 10 had a EuroSCORE between 4 and 6, and one patient had a EuroSCORE ≥7. The LVEF was in the range of 30 to 50% in five patients and more than 50% in 18 patients.

Twenty-one patients had both hypertension and hyperlipidemia. Six patients had diabetes mellitus type 2. Eight patients had chronic obstructive pulmonary disease, and three patients had previously underwent coronary stenting. One patient had previous history of CABG, and one patient had chronic atrial fibrillation preoperatively. Fifteen patients had a history of smoking (Table 1).

Three patients had single-vessel disease, three patients had two-vessel disease, and the rest of 17 patients had a triple-vessel coronary artery disease. Transthoracic echocardiography revealed that LVEF was 30 to 50% in five patients and >50% in 18 patients. Fifteen (65%) patients had a history of smoking.

The detailed histology/staging, cardiac procedure, lung procedure, and surgical approach are summarized in Table 2. The final pathological diagnosis of these patients was mostly squamous cell lung cancer or adenocarcinoma staging from 1A to 3B. Among the remaining four patients, two patients had thymoma, and the other two patient had final pathological diagnosis as interstitial fibrosis.

A no-touch aorta technique was performed in 19 (82.6%) patients. The mean number of anastomoses was 3.09±1.1 (range, 1 to 5). Sixteen (69.6%) patients had T-composite graft, one (4.3%) patient had Y-composite graft. Arterial revascularization was the first choice, and left internal mammary artery was used as a graft in 20 (87%) patients, right internal mammary artery in five (21.7%) patients, radial artery in 16 (69.6%) patients, and saphenous vein in one (4.3%) patient (Table 3).

All the patients had off-pump CABG with a median sternotomy approach, followed by lung operation for lung cancer or mass either via median sternotomy, thoracotomy, or VATS with mLND, including eight wedge resections, nine lobectomies, one mediastinal mass resection, two thymothymectomy, one chest wall reconstruction and forequarter amputation, and two segmentectomy was performed. Analyses of intraoperative frozen sections were used to verify the presence of tumor-free margins in all patients.

The postoperative period went uneventful for all patients. Ten patients were extubated in the operating room, and the rest of the patients were extubated in the cardiovascular intensive care unit (ICU) less than 10 h postoperatively, and one patient had CABG×4 and right pneumonectomy, who had inotropic support less than 8 h, transferred to the ward 24 h postoperatively, and discharged on the sixth postoperative day. None of the patients experienced pneumothorax or atelectasis. No patient sustained excessive blood loss requiring reoperation. The mean drainage from chest tubes was 623.3±249.4 mL during the first 24 h postoperatively. The chest and mediastinal tubes were removed if the drainage was less than 150 mL in a 24-h period.

The mean length of ICU stay was 30.8±18.7 h. One patient had postoperative atrial fibrillation, with a history of off-pump CABGx4, left lung lower lobe superior segmentectomy, and left upper lobe wedge resection with mLND. The patient's rhythm reversed

Table 2. Surgery details of patients underwent concomittant off-pump CABG and pulmonary resection

Case	Histology/staging	Cardiac procedure	Lung procedure	Incision
1	Patchy interstitial fibrosis	CABG×5	Right upper and lower WR	Median sternotomy and thoracoscopy
2	Adenocarcinoma/Stage 1A	CABG×1	LUL	Median sternotomy and thoracoscopy
3	Anaplastic carcinoma/Stage 2B	CABG×4	Right pneumonectomy	Median sternotomy
4	Thymoma/type B1	CABG×3	Mediastinal mass resection	Median sternotomy
5	Squamous cell lung ca/Stage 3B	CABG×3	RLL	Median sternotomy and thoracoscopy
6	Squamous cell lung ca/Stage 3A	CABG×1	RUL	Median sternotomy and thoracotomy
7	Adenocarcinoma/Stage 1A	CABG×4	LUL	Median sternotomy and thoracoscopy
8	Squamous cell lung ca/Stage 2B	CABG×4	RUL	Median sternotomy and thoracoscopy
9	Colonic adenocarcinoma	CABG×2	Left lower common basal segmentectomy	Median sternotomy and thoracoscopy
10	Undifferentiated pleomorphic sarcoma/Stage 3A	CABG×2	Right chest wall reconstruction, forequarter amputation	Median sternotomy
11	Adenocarcinoma/Stage 1A	CABG×3	Right upper and middle WR	Median sternotomy
12	Carcinosarcoma/Stage 1A	CABG×4	Left upper sleeve lobectomy	Median sternotomy and thoracotomy
13	Chondroid hamartoma	CABG×3	Right middle WR	Median sternotomy
14	Adenocarcinoma/Stage 1A	CABG×3	Right upper anterior segmentectomy	Median sternotomy and thoracoscopy
15	Thymoma/type AB, lymphoblastic lymphoma	CABG×2	Thymothymectomy	Median sternotomy
16	Squamous cell lung ca/Stage 1B	CABG×4	LLsS + Left upper WR	Median sternotomy and thoracoscopy
17	Adenocarcinoma/Stage 2B	CABG×1	RML	Median sternotomy and thoracoscopy
18	Adenocarcinoma/Stage 1A	CABG×3	Right upper WR + lingulectomy	Median sternotomy and thoracoscopy
19	Squamous cell lung ca/Stage 1B	CABG×4	LUL	Median sternotomy and thoracoscopy
20	Adenocarcinoma/Stage 1B	CABG×4	RLL	Median sternotomy and thoracoscopy
21	Bullous emphysema, chronic fibrosis pleuritis	CABG×4	Left upper WR	Median sternotomy
22	Thymoma/type B1	CABG×3	Left upper WR, diaphragm plication, anterior mediastinal mass excision	Median sternotomy and thoracoscopy
23	Adenocarcinoma/Stage 1A	CABG×4	Right upper WR	Median sternotomy and thoracoscopy

CABG: Coronary artery bypass grafting; WR: Wedge resection; LUL: Left upper lobectomy; RLL: Right lower lobectomy; RUL: Right upper lobectomy; LLsS: Left lower lobe superior segmentectomy; RML: Right middle lobectomy.

to sinus rhythm with beta-blockers, and the final pathological diagnosis was squamous cell lung cancer (Stage 1B).

None of our patients suffered from deep sternal wound infections due to strict blood glucose during the follow-up. Cerebrovascular events were not

Table 3. Surgical outcomes

Operative variables	n	%	Mean±SD
Territory			
LDA	21	91.3	
Cx	16	69.6	
RCA	16	69.6	
Number of anastomosis			3.09±1.1
Composite graft			
T	16	69.6	
Y	1	4.3	
No-touch aorta	19	82.6	
Grafts			
Radial artery	16	69.6	
LIMA	20	87	
RIMA	5	21.7	
Saphenous	1	4.3	

SD: Standard deviation; LDA: Left anterior descending artery; Cx: Circumflex artery; RCA: Right coronary artery; LIMA: Left internal mammary artery; RIMA: Right internal mammary artery.

Table 4. Postoperative outcomes

Postoperative variables	n	%	Mean±SD
Re-exploration (bleeding)	0	0	
Atrial fibrillation	2	8.7	
Artificial ventilation >24 h	0	0	
Deep sternal wound infection	0	0	
Inotropic support	1	4.3	
Stroke/TIA	0	0	
Length of ICU stay (h)			30.8±18.7
Length of hospital stay (day)			7.9±3.0
Postoperative drainage (mL)			623.3±249.4
Blood products (pack)			
Erythrocyte suspension			0.35±0.714
Fresh frozen plasma			0.43±0.843
Mortality			
In-hospital	0	0	
30-days	0	0	

SD: Standard deviation; TIA: Transient ischemic attack; ICU: Intensive care unit.

observed during follow-up. In our institution, patient blood management policy is based on the Enhanced Recovery After Cardiac Surgery (ERAS) Society Guidelines.[13] The mean blood product usage for erythrocyte suspension was 0.35±0.714 packs, and the mean fresh frozen plasma (FFP) was 0.43±0.843 packs as summarized in Table 4.

No early postoperative patient mortality or myocardial ischemia occurred during follow-up. None of the patients had cardiovascular events, including myocardial infarction, sustained ventricular tachycardia, heart failure, or sudden cardiac death postoperatively. All the patients recovered and were discharged from the hospital. No case was lost to follow-up.

Five patients died of cancer metastasis or reoccurrence, with deaths occurring at postoperative two, three, six, 13 and 29 months. The remaining 18 patients who survived at the end of the study were followed for a mean of (31.87±21.1 months; range, 5 to 72 months).

The overall one-year survival rate was 86.5%, and three- and five-year survival rates were 74% and 74%. The one-, three-, and five-year cancer-free survival rates were 82.5%, 82.5%, and 82.5%, respectively (Figure 1).

DISCUSSION

In recent years, performing CABG and pulmonary operations in a single session has emerged as a viable strategy to optimize patient outcomes, reduce overall surgical risk, and minimize the burden of multiple procedures. Combined CABG and pulmonary operations can be successfully performed by eliminating the need for staged procedures, reducing cumulative anesthesia exposure, hospital stays, and potential complications associated with delayed lung resection. Similarly, we prefer simultaneous procedures to two-stage procedures due to certain advantages such as shorter hospital stay, lower perioperative morbidity, and potential to avoid cancer growth and dissemination. The off-pump, no-touch aorta, multi-arterial CABG, and VATS for pulmonary operations is challenging for less operative stress, pain, avoiding repeated anesthesia, a shorter hospitalization, lower cost, and no delay in lung cancer surgery. In the present study, we evaluated the outcomes of concomitant off-pump CABG and pulmonary operations for lung cancer patients. Our study results showed that VATS approach provided a more favorable perspective for pulmonary resection and mLND and was a safe method for this patient population.

Cardiovascular disease and lung cancer are both associated with cigarette smoking.[4] In our study group, 15 (65.2%) patients had a history of smoking. The treatment of coronary artery disease is required to minimize the perioperative risk of lung surgery for

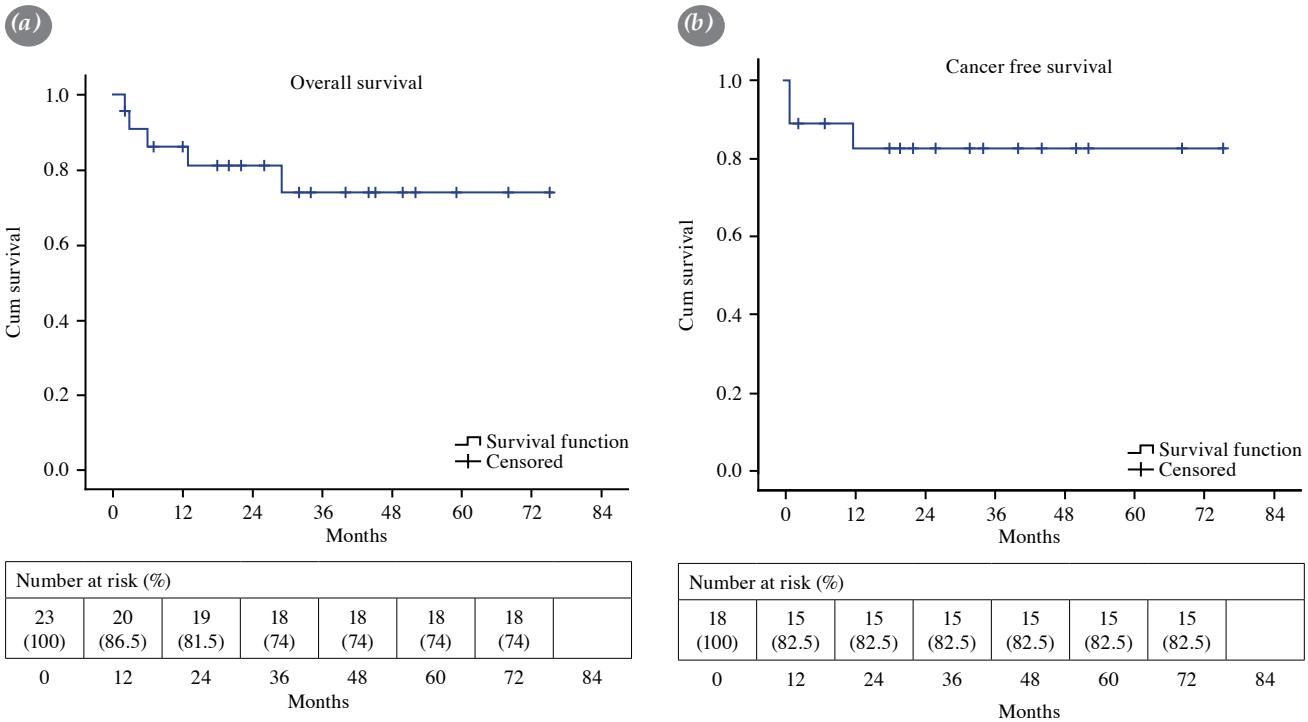

Figure 1. Kaplan-Meier survival curves for **(a)** overall survival and **(b)** cancer-free survival.

lung cancer.[14] The long-term outcomes of patients with coronary artery disease following treatment with percutaneous coronary intervention or CABG were investigated in a propensity-matched study, which showed that although percutaneous coronary intervention was associated with lower rates of periprocedural stroke, major bleeding, and acute renal injury. Coronary artery bypass grafting was associated with decreased incidence of early and late recurrent ischemia and reduced repeat revascularization procedures.[15]

Stent placement should be avoided in patients who are being considered for soon after coronary intervention. Previously reported studies have shown preference for two-stage procedure, in which coronary intervention is performed first, followed by a lung resection with surgical treatment requiring interval of between six and twelve weeks after coronary stenting. This approach is preferred because surgeons are reluctant to perform concomitant cardiac surgery and pulmonary resection for heparinization, and CPB can increase the patient's risk of excessive bleeding. The median sternotomy approach for cardiac surgery is believed to provide inadequate exposure for pulmonary resection and mLND.[12-14] Cardiopulmonary bypass may affect the immunologic response, which might increase the patient's risk of mediastinal and pleural infection and complicate the postoperative outcome of the patient. On the other hand, if lung cancer is treated in a separate procedure, the condition that constitutes the most immediate risk to the patient (usually the cardiac disease) should be treated first, and the condition that constitutes a less immediate risk should be treated four to six weeks later.[3] Once the diagnosis of lung cancer is made, surgical resection should be performed as soon as possible. Patients also require intensive anticoagulation following coronary artery stenting, which is associated with high risk of hemorrhagic complications. In patients who have tumors with rapid doubling times, however, such a delay could affect survival. If CABG is performed, the postoperative recovery period may also postpone the lung resection, which may result in tumor progression. However, if lung tumor resection surgery is performed first, the perioperative risk of severe coronary artery impairment can reduce fatal complications. Additionally, a two-stage approach requires two rounds of general anesthesia, two separate incisions, and a longer hospital stay, whereas treating both diseases during the same procedure reduces risk, pain, and costs.[5]

In our study, a one-stage operation and concomitant off-pump CABG and pulmonary operations mainly for lung cancer were performed. None of our patients had required reoperation for excessive blood loss. All the analyses of intraoperative frozen sections were used to verify the presence of tumor-free margins in all patients. Based on the results of these analyses, pulmonary resection was complete in all our patients.

Five of our patients died between postoperative two to 29 months due metastasis or recurrence of cancer. Survival after surgical resection of lung cancer varies according to the cell type and stage of the cancer, both of which must be evaluated.[16]

In a series of 43 patients, the Mayo Clinic group reported only one death, which occurred in a patient who underwent pulmonary resection during CPB.[2] Only 11.6% of resections were performed during CPB. In their report, which compared staged and combined procedures, only three (10%) patients required reoperations for bleeding in combined cardiac and lung surgery procedure. The Texas Heart Institute reported one operative death among 21 patients who underwent cardiac and pulmonary surgery.[4] This death occurred in an 80-year-old male patient who had undergone triple-vessel CABG grafting with concomitant wedge resection of the right upper lobe for adenocarcinoma. After the operation, the patient developed an acute myocardial infarction and subsequent arrhythmias. Despite the pharmacological support and use of an intra-aortic balloon pump, the patient died on the second postoperative day. Their median follow-up duration was 4.1 years, ranging from 2 days to 7.4 years. The overall one-year survival rate was 90.5%, and the five-year survival was 52.4%.[4]

The advantage in combined CABG and lung operation was that none of our patients had extracorporeal circulation, which can increase the concentration of free oxygen radicals, leading to cell damage, inhibiting the immune system, enhancing tumor growth, and promoting tumor metastases. Off-pump full arterial revascularization CABG can reduce bleeding during tumor resection due to the decreased intraoperative heparin dose. Off-pump CABG is usually performed at first, and it can ensure that there is an adequate intraoperative coronary artery blood supply to avoid intraoperative myocardial ischemia and cardiac function.

In their study including 25 patients, Dyszkiewicz et al.[6] reported that simultaneous off-pump myocardial revascularization and lung resection was a safe and effective treatment modality, when unstable coronary artery disease and lung cancer coexisted. In their study, the median number of anastomosed coronary vessels was 1.9. Twenty of their patients had median sternotomy approach. In four patients, they preferred left lateral thoracotomy. In one patient, they used both sternotomy and a partial left thoracotomy. The three-year survival rate of their patients was 50%. The authors tended to perform combined procedure as their first-line treatment option.

In our study, simultaneous off-pump CABG and lung resection procedures require different surgical skills. The sternotomy approach, which is infrequently used by thoracic surgeons, is difficult when performing a left lower lobectomy and mLND. The combined surgery could have been reserved for patients who were clinically or surgically staged during the pre- and perioperative periods. An important aspect of this procedure is the sequence of the operative steps. It is crucial to perform the coronary anastomosis before lung resection.[17] In our patient group, mLND was performed in all patients. Pre- and perioperative judgement of the lesion was evaluated. We conclude that the sternotomy approach makes complete lymph node sampling of the posterior mediastinum difficult, and incomplete lymph node sampling could affect the long-term results of pulmonary resection for lung cancer. The survival after surgical resection of lung cancer varies according to the cell type and the stage of the cancer, both of which must be evaluated.

Fourteen of 23 our patients with concomitant cardiac and lung surgery were planned with VATS. Thoracoscopic equipment was used to minimize the incision size and minimize the postoperative pain. Thoracoscopic lobectomy has been shown to be superior in terms of length of stay, postoperative pain, pulmonary function, and postoperative complications compared to open lobectomy.[18] Lung cancer resection with a median sternotomy may be associated with technical problems, as left lower lobectomy is difficult to perform through a median sternotomy, and the use of two incision approach can lead to significant postoperative discomfort, pain, delayed mobilization, and increased incidence of early postoperative complications. Furthermore, VATS is safe in combined procedures, the operated heart and anastomosed new grafts would not be retracted, and there would be less incidence of arrhythmia and myocardial ischemia.

Liu et al.[14] reported their experience with combined off-pump CABG and lung resection in 23 patients over 50 years of age. Their mean length of hospital stay was 19.2±12.3 days, with a mean duration of stay in

the ICU of 40.4±32.4 h. In our study of 23 patients, the mean length of hospital stay was 7.9±3.0 days, with a mean ICU stay of 30.8±18.7 h. Liu et al.[14] reported a five-year survival rate of 47.9% for the remaining 15 patients. The five-year survival rate of the remaining 18 patients was 74%.

Shaff et al.[2] showed that at the time of pulmonary resection, a thorough evaluation of paratracheal, subcarinal and inferior pulmonary ligament lymph nodes was mandatory. Limited sampling of these areas has the potential for underestimating the stage of disease and may be the reason of reduced long-term survival in previous studies with a combined technique.

Karagoz et al.[19] and Vural et al.[20] reported a total arterial revascularization experience on beating heart CABG in patients with low ejection fraction for more than 30 years. The patients with an ejection fraction between 30 and 50% tolerated the following lung surgery well. None of the patients had extracorporeal circulation during CABG and high doses of heparinization, whereas our patients did not require an extensive amount of blood products due to combined surgery. The mean postoperative blood drainage from chest and mediastinal tubes was 623.3±249.4 mL. In our study, we observed no atelectasis, pneumothorax, or any pleural infection due to combined surgery.

Kanzaki et al.[21] reported their combined and two-stage approach and concluded that the surgical risk related to the simultaneous lung cancer procedure and off-pump CABG was lower than that of cardiac surgery with extracorporeal circulation (on-pump).

Zhang et al.[22] reported that simultaneous procedure had advantages such as shorter hospital stay, lower perioperative morbidity, and the potential to avoid cancer growth and dissemination, particularly in on-pump cardiac surgery. They observed a much lower five-year survival rate of 43.6%. Older age was the major factor associated with worse outcomes in patients with malignant incidental solitary pulmonary nodules. Accurate surgical nodal staging is mandatory to identify patients who may need adjuvant therapy.

Al-Attar et al.[23] reported combined left pneumonectomy and off-pump CABG through left thoracotomy in early 2000s as a single-stage approach. Omeroglu et al.[24] summarized their three patients with combined off-pump CABG and lung surgery. They reported that myocardial revascularization on beating heart CABG, when feasible, was preferred over the use of CPB to avoid side effects, particularly hemorrhage, making the following lung surgery safer.

Furthermore, Zhang et al.[25] reported that during simultaneous off-pump revascularization and pulmonary operations, the pulmonary resection surgery should be performed after reversal of anticoagulation and recommended videoscopy to evaluate suspected bleeding. Tourmousoglou et al.[26] also showed that off-pump CABG and lung resection could be safe and effective treatment, when unstable coronary artery heart disease and lung cancer coexisted. In their systematic review, Cheng et al.[27] showed that off-pump CABG might reduce the complication rate compared to on-pump CABG. Considering median sternotomy approach compared to a lateral thoracotomy, mLND is technically more difficult and time-consuming, the subcarinal and posterior mediastinal lymph nodes are particularly difficult to sample.

In another study, Choong et al.[28] highlighted the importance of a skilled anesthetist in ensuring the proper placement of a double-lumen endotracheal tube and careful intraoperative management of the patient. Our patients had multi-arterial revascularization off-pump CABG following lung resection for lung cancer. All patients tolerated the perioperative period of lung surgery well. The utility of VATS assistance in performing lobectomy, lingulectomy, segmentectomy, and mediastinal lymph node resection in combined cardiac surgery is significant.

The limitations to this study include its retrospective design, the inclusion of patients from two centers, and the allocation of the patients to concomitant off-pump CABG and pulmonary operations based on the surgeons' discretion regarding the surgical technique.

In conclusion, combined off-pump coronary artery bypass grafting and pulmonary resection for lung surgery can be safe and effective, preferably with video-assisted thoracoscopic surgery assistance. Complete mediastinal lymph node sampling is crucial for achieving long-term survival. Combined techniques should be performed at reference hospitals with skilled anesthesiologist teams.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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