General Thoracic and Cardiovascular Surgery (2019) 67:880–883
https://doi.org/10.1007/s11748-019-01112-8

ORIGINAL ARTICLE

Influx of air into the left atrium during lung resection

Kenta Nakahashi[1] · Hiroyuki Oizumi[1] · Jun Suzuki[1] · Akira Hamada[1] · Hikaru Watarai[1] · Satoshi Takamori[1] · Mitsuaki Sadahiro[1]

Received: 20 December 2018 / Accepted: 14 March 2019 / Published online: 2 April 2019

Abstract

Objectives In this study, we aimed to determine conditions associated with the development of air bubbles in the pulmonary veins during lung resection.

Methods A total of 28 patients who underwent lung resection at our institution between October 2016 and March 2018 were included in the study. An intraoperative transesophageal echocardiography was conducted, and the influx of air bubbles in the orifice of the pulmonary vein leading to the left atrium was observed during lung resection.

Results The median age of all patients was 75 years. The study included 13 men and 15 women. Moreover, seven, 14, and seven patients underwent wedge resection, segmentectomy, and lobectomy, respectively. The presence of air bubbles was observed in 15 patients and was detected when the lung parenchyma was cut (13 patients) or compressed (3 patients) using staplers and when an energy device was used (1 patient). No postoperative organ infarction occurred in any patients.

Conclusions Although the presence of air bubbles was noted in the pulmonary vein during lung resection via transesophageal echocardiography, the clinical condition of the patients in our study did not deteriorate. The clinical significance of air bubbles is not clear. Therefore, more data about such events must be collected in future.

Keywords Systemic air embolism · Transesophageal echocardiography · Air bubbles · Lung resection

Introduction

Cerebral infarction is a complication observed in 0.3–0.6% cases post-lung resection [1–3]. This condition is most frequently caused by a thromboembolism, and air embolism (AE) is considered a cause of cerebral infarction. AE is caused by air that enters into the artery, thereby blocking blood flow. It may cause organ ischemia and can occasionally lead to serious complications and death. Such events can be observed by computed tomography (CT)-guided pulmonary marking, CT-guided needle lung biopsy, and other methods. However, only few reports have shown the development of AE during lobectomies. Recently, the number of cases of segmentectomy that involves cutting a large portion of the lung parenchyma has increased. Thus, the incidence of AE might increase. Moreover, it may occur due to the presence of bubbles during compression or cutting of the lung parenchyma, and the incidence of AE might be reduced if the conditions and risk factors associated with the development of air bubbles are elucidated. Thus, in this study, we aimed to analyze the conditions correlating to the development of air bubbles during lung resection.

Patients and methods

We conducted an observational study of air bubbles via an intraoperative transesophageal echocardiography (TEE) and found emboli in the pulmonary vein during lung resection. A total of 28 patients who underwent lung resection at our institution between October 2016 and March 2018 were included. An intraoperative TEE was conducted, and the influx of air bubbles in the orifice of the pulmonary

Presented at the 70th Annual Scientific Meeting of the Japanese Association for Thoracic Surgery.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11748-019-01112-8) contains supplementary material, which is available to authorized users.

✉ Kenta Nakahashi
kentanakahashi@yahoo.co.jp

[1] Faculty of Medicine, Second Department of Surgery, Yamagata University, 2-2-2 Iida-Nishi, Yamagata 990-9585, Japan

vein leading to the left atrium was observed during lung resection. We selected patients who could provide informed consent for the assessment of the left atrium via TEE during lung resection. During induction of general anesthesia, an anesthesiologist inserted a probe and observed the left atrium when we sutured the vessels or treated the lung parenchyma during surgery. When the anesthesiologist or thoracic surgeon identified air bubbles during TEE, the patient was considered positive for air bubbles (Fig. 1). During surgery, we assessed for the presence of air bubbles when the lung parenchyma or pulmonary vessels and bronchus were compressed or cut and when an energy device was used. A single-center prospective analysis of data obtained from a prospective database at our institution was conducted during the study period. The following demographic, clinical, and surgical data were collected: age, gender, body mass index, presence of chronic obstructive lung disease (COPD), respiratory function, Brinkman index, type of surgical approach used, type of resection, time of surgery, number of staples, complications, and tumor location.

Surgical technique

The surgeries were performed while the patient was in lateral position and was on general anesthesia and one lung ventilation. The pulmonary vein, pulmonary artery, and bronchus were individually divided and separated by staplers or ligated appropriately. The lung parenchyma was separated by staplers or energy devices and ligated. Data collection and analyses were approved by the institutional review board (IRB No.2016-399), and the need for a written informed consent from each patient was waived.

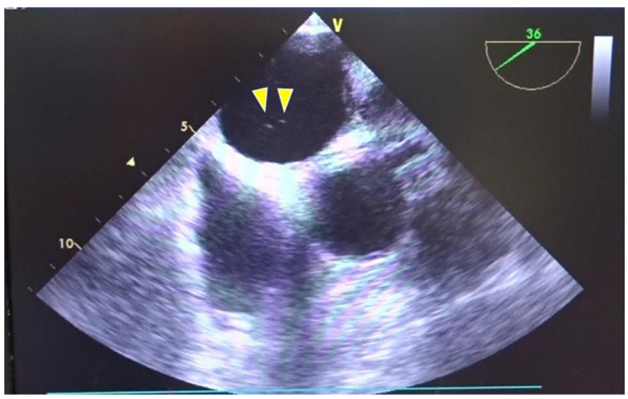

Fig. 1 Air bubbles were detected in the left atrium on transesophageal echocardiography. The patient was a 64-year-old man with multiple metastases to the lung with renal cell carcinoma, who underwent the resection of seven nodules from the right lung. We performed wedge resection via video-assisted thoracoscopic surgery. When the lung parenchyma was cut using a stapler, we identified air bubbles during transesophageal echocardiography

Results

Table 1 shows the characteristics of the patients and clinicopathological factors. The median age of all patients was 75 years. The study included 13 men and 15 women. A total of 8 (29%) patients had COPD, and the median Brinkman index of the group was 400. Regarding intraoperative factors, there were 24 (86%) video-assisted thoracoscopic surgery (VATS) and 4 (14%) open thoracotomies, and as for the type of resection, lobectomy, segmentectomy, and wedge resection were performed in seven, 14, and seven patients, respectively. The median surgery time was 170 (interquartile range, 140–210) minutes. The pathological diagnoses were primary lung cancer (18 patients), metastatic lung tumor (6 patients), and benign disease (4 patients). The average number of staples used for cutting the lung parenchyma was 4.4, and as for complications, atrial fibrillation was observed in one patient. However, postoperative organ infarction was not observed in any patients. A total of 15 patients presented with air bubbles, and the video detecting air bubbles is following (Online video 1). The patient was a 64-year-old man with multiple metastases to the lung with

Table 1 Characteristics of the patients and clinicopathological factors

	n = 28
Age, median (IQR), (years)	75 (66–80)
Gender (men/women)	13/15
BMI, mean ± SD, (L)	23 ± 3
COPD	8 (29%)
FEV1.0, mean ± SD, (L)	1.9 ± 0.6
FEV1.0%, mean ± SD, (%)	70 ± 10
Brinkman index, median (IQR)	400 (0–900)
Type of surgical approach	
Open thoracotmy/VATS	4/24
Type of resection	
Lobectomy/segmentectomy/wedge	7/14/17
Surgery time, median (IQR), (min)	170 (140–210)
Histological type	
Primary lung cancer/metastasis/benign	18/6/4
Tumor location	
RU/RM/RL/LU/LL	5/1/7/11/5
The number of staples, mean ± SD	4.4 ± 2.5
Complication	
Af	1
Organ infarction	0

Values are presented as mean ± standard deviation or median (interquartile range) or *n*

BMI body mass index, *COPD* chronic obstructive pulmonary disease, *FEV* forced epiratory volume, *VATS* video-assisted thoracoscopic surgery, *Af* atrial fibrillation, *RU* right upperlobe, *RM* right middlelobe, *LU* left upperlobe, *LL* left lowerlobe

renal cell carcinoma who underwent the resection of seven nodules from the right lung. We performed wedge resection via video-assisted thoracoscopic surgery. When the lung parenchyma was cut using a stapler, we identified air bubbles during transesophageal echocardiography.

The detailed characteristics of such patients are shown in Table 2. The type of resection, for these patients included lobectomy ($n=1$), segmentectomies ($n=7$), and wedge resections ($n=7$). The presence of air bubbles was observed in 13 patients when their lung parenchyma was cut using staplers, in three patients when their lung parenchyma was compressed, and in one patient when an energy device was used. Overlapping cases were partly observed. A total of 14 patients underwent lung resection for malignant tumors. Air bubbles were detected in 18 of 124 staplings in the lung parenchyma.

Discussion

AE is a rare but potentially life-threatening complication. Systemic AE (SAE) is caused by the following mechanism: circulating air bubbles that obstruct blood flow, leading to organ ischemia. Moreover, it can occasionally cause serious complications. This condition is a complication of some clinical procedures, in the field of pulmonology, which includes CT-guided pulmonary marking, CT-guided needle lung biopsy, pleurodesis, and pulmonary resection. The incidence rate of SAE during CT-guided pulmonary marking is approximately 0.015–1.9% [4–7] and that during CT-guided needle lung biopsy is approximately 0.002–0.007% [4, 8, 9]. Mortality associated with CT-guided pulmonary marking or CT-guided needle lung biopsy is approximately 0.002% [10]. In addition, studies showing that SAE is caused by lung resection are extremely limited. However, there are several case reports. Yamashita et al. [10] have reported a case of cerebral AE after the administration of anticancer drug or pleural lavage liquid to the pleural cavity [10–13]. In traumatic cases, TEE is effective for the early assessment of air bubbles in the circulation and is considered a sensitive procedure [14, 15]. With reference to lung resection, only Hemmerling et al. [16] have reported regarding SAE during wedge resection of the lung. TEE was conducted because the patient had underlying dilated cardiomyopathy. When the patient underwent wedge resection using a stapler, microbubbles were suddenly visible on the TEE screen. Hemmerling et al. [16] have hypothesized that this event was caused by low pulmonary venous pressure and increased airway pressure. Kawaguchi et al. [17] have reported a case of SAE that occurred during a double-sleeve left upper lobectomy for lung adenocarcinoma. After the sealing test following bronchoplasty and pulmonary angioplasty, the cardiac function of the patient deteriorated. TEE revealed several air bubbles in the left atrium. However, in our study, the presence of air bubbles could not be detected during vascular or lung parenchymal resection via TEE during sleeve left upper lobectomy. Yuki et al. [18] have reported a case of SAE in a patient who underwent VATS bullectomy for pneumothorax. TEE led to the detection of numerous air bubbles in the left ventricle, and the presence of air bubbles caused myocardial ischemia. In our study, 6 of 14 patients who underwent VATS segmentectomy presented with air bubbles. Two mechanisms associated with SAE have been suggested: communication between the pulmonary vein and the atmosphere and communication between the bronchus or bronchiole and the pulmonary vein [7]. In our study, air bubbles were detected in various situations. Our report may be similar to the first one showing the presence of air bubbles during compression of the lung parenchyma and when energy devices are used. We assumed that former was attributed to communication between the bronchus or bronchiole and the pulmonary vein. The latter may be caused by an influx of air bubbles into the pulmonary vein generated by the energy devices. However, there is still room for consideration. Regarding the risk factors associated with the presence of air bubbles, because there was a tendency for air bubbles to be detected more frequently in segmentectomy or wedge resection than in lobectomy, we expected that stapling of the segmental plane might be associated with a higher risk of developing air bubbles because there are more veins that can be compressed by the stapler in the segmental plane than in lobar fissure. COPD or age might influence the development of air bubbles. Therefore, a detailed study must be conducted in future.

The volume of air bubbles in our study was considered low and was not enough to cause embolism in any organs. However, the presence of some bubbles in the pulmonary veins during lung resection must be identified because they may cause some serious complications via temporary

Table 2 Detailed characteristics of the 15 patients with air bubbles

Variables	
Patients presented with air bubbles	15/28 patients
Type of resection	
Lobectomy/segmentectomy/wedge	1/7/7
The situation of detecting air bubbles	
Cutting by staplers	13/15 patients
Compression parenchyma by staplers	3/15 patients
Using energy devices	1/8 patients
Fook wire marking	1/6 patients
Total number of scenes detecting air bubbles	
1 scene/2 scenes/3 scenes	13/1/1
The number of scenes detecting air bubbles using staples	18/124 staplers

ischemia of organs. This study had several limitations. First, the study was conducted at a single institution, and the sample size of the study was small. Second, this observational study of air bubbles was dependent on the anesthesiologist's skills. Third, the quantification of air bubbles was challenging, and this is a problem that must be addressed in future.

Conclusion

The presence of air bubbles was observed in the pulmonary vein during lung resection via TEE; however, the clinical condition of the patients in our study did not deteriorate. The clinical significance of air bubbles is not clear. Thus, more data about such events must be collected in future.

Funding This study was not supported by a sponsor or funding agency.

Compliance with ethical standards

Conflict of interest All authors have no conflict of interest to disclose.

References

1. Bateman BT, Schumacher HC, Wang S, Shaefi S, Berman MF. Perioperative acute ischemic stroke in noncardiac and nonvascular surgery: incidence, risk factors, and outcomes. Anesthesiology. 2009;110:231–8.
2. Ohtaka K, Hida Y, Kaga K, Kato T, Muto J, Nakada-Kubota R, et al. Thrombosis in the pulmonary vein stump after left upper lobectomy as a possible cause of cerebral infarction. Ann Thorac Surg. 2013;95:1924–8.
3. Yamamoto T, Suzuki H, Nagato K, Nakajima T, Iwata T, Yoshida S, et al. Is left upper lobectomy for lung cancer a risk factor for cerebral infarction? Surg Today. 2016;46:780–4.
4. Tomiyama N, Yasuhara Y, Nakajima Y, Adachi S, Arai Y, Kusumoto M, et al. CT-guided needle biopsy of lung lesions: a survey of severe complication based on 9783 biopsies in Japan. Eur J Radiol. 2006;59:60–4.
5. Nakano T, Shimizu K, Otani Y, Kakegawa S, Morishita Y, Taketoshi I. Cerebral air embolism complicating computed tomography-guided percutaneous needle biopsy of the lung: a case report with effective hyperbaric oxygen therapy. Jpn J Chest Surg. 2007;21:859–64.
6. Matsuura Y, Watari M. Two cases of air bubble in intracardiac cavity after computed tomography-guided lung puncture. Jpn J Chest Surg. 2010;24:967–71.
7. Sakiyama S, Kondo K, Matsuoka H, Yoshida M, Miyoshi T, Yoshida S, et al. Fatal air embolism during computed tomography-guided pulmonary marking with a hook-type marker. J Thorac Cardiovasc Surg. 2003;126:1207–9.
8. Sinner WN. Complications of percutaneous transthoracic needle aspiration biopsy. Acta Radiol Diagn. 1976;17:813–28. **(Stockh)**
9. Richardson CM, Pointon KS, Manhire AR, Macfarlane JT. Percutaneous lung biopsies: a survey of UK practice based on 5444 biopsies. Br J Radiol. 2002;75:731–5.
10. Yamashita Y, Mukaida H, Hirabayashi N, Takiyama W. Cerebral air embolism after intrathoracic anti-cancer drug administration. Ann Thorac Surg. 2006;82:1121–3.
11. Menendez-Gonzalez M, Oliva-Nacarino P, Alvarez-Cofino A. Cerebral gas embolism caused by pleural fibrinolytic treatment. Stroke. 2007;38:2602–4.
12. Schneider F, Lion R, Kummerlen C, Ducrocq X, Tempe JD. Neurological complications and pleural lavage with a fibrinolytic agent. A two-case report. Intensive Care Med. 2000;26:995–7.
13. Ohuchi M, Inoue S, Ozaki Y, Ueda K. Systemic air embolism during pleural lavage for empyema. Gen Thorac Cardiovasc Surg. 2017;65:602–4.
14. Saada M, Goarin JP, Riou B, Rouby JJ, Jacquens Y, Guesde R, et al. Systemic gas embolism complicating pulmonary contusion. Diagnosis and management using transesophageal echocardiography. Am J Respir Crit Care Med. 1995;152:812–5.
15. Shaikh N, Ummunisa F. Acute management of vascular air embolism. J Emerg Trauma Shock. 2009;2:180–5.
16. Hemmerling TM, Schmidt J, Bosert C, Klein P. Systemic air embolism during wedge resection of the lung. Anesth Analg. 2001;93:1135–6.
17. Kawaguchi K, Usami N, Taniguchi T, Ishikawa Y, Fukui T, Yokoi K. Systemic air embolism during double sleeve left upper lobectomy: caution regarding this fatal complication. Jpn J Chest Surg. 2013;27:472–6.
18. Yuki D, Kawano O, Fukai I. Systemic air embolism during wedge resection of the lung: Report of a case. Jpn J Chest Surg. 2015;29:798–802.