



# Using the capnogram to assess pulmonary perfusion during a lobectomy: case studies

Jinjun Shu<sup>1</sup> · Kexian Zhang<sup>1</sup> · Yiding Chen<sup>1</sup>  · Hongwei Zhang<sup>1</sup> · Jiang Zou<sup>1</sup> · Yumin Tang<sup>1</sup> · Jifu Dong<sup>1</sup> · Yi Du<sup>1</sup>

Received: 18 August 2018 / Accepted: 31 December 2018 / Published online: 17 January 2019  
© Springer Nature B.V. 2019

## Abstract

Capnography is an effective and non-invasive method for monitoring patients during general anesthesia and can reflect the changes in both the respiratory function as well as the circulatory function. In this paper, we present four cases of lobectomy in which we observed a “chair-like” waveform on performing capnography after the surgery. In all the cases, the appearance of this “chair-like” waveform led to the suspicion of a blockage in the pulmonary artery perfusion, which was then confirmed to be an obstruction in the pulmonary artery on further investigation. This suggests that during lobectomy, capnography can help confirm that the pulmonary circulation is unobstructed. We believe that it is very important to observe the changes of end-tidal carbon dioxide pressure and capnogram during one-lung ventilation, particularly in cases of pulmonary artery anastomosis.

**Keywords** Capnography · End-tidal carbon dioxide pressure ( $P_{et}CO_2$ ) · Lobectomy · Pulmonary artery perfusion

## 1 Introduction

Capnography has been accepted in clinical practice as a routine monitoring method for patients under anesthesia. The value and waveform of end-tidal carbon dioxide ( $ETCO_2$ ), particularly during one-lung ventilation (OLV), are important for intraoperative clinical assessment in thoracic surgery. In this paper, we present the analysis of the  $CO_2$  waveform changes that occurred due to pulmonary artery perfusion disorders in four cases of lobectomy, which were encountered over a period of 3 years. In addition, we also review the current literature available on this topic.

## 2 Case reports

### 2.1 Cases 1

A 46-year-old woman (height, 155 cm; weight, 76 kg) diagnosed with right upper lobe lung cancer was scheduled for removal of the right upper lobe and lymph node dissection. The patient was previously healthy and showed no other abnormalities during routine preoperative examination. OLV for the healthy side was efficient during the operation, and the  $ETCO_2$  pressure ( $P_{et}CO_2$ ) was maintained at 33–35 mmHg. On surgical exploration, the right upper lobe artery and bronchus were found to be infiltrated by the tumor mass. Therefore, double-sleeve resection of the right upper and middle lobes was performed; however, the surgical field view was not ideal for the creation of the right pulmonary artery anastomosis. After completing the sleeve resection and lymph node dissection, the right lower lobe was successfully reinflated. The appearance and color of the right lower lobe were normal during double-lung ventilation (DLV), with the peak airway pressure being 19 cm  $H_2O$ . The  $P_{et}CO_2$  waveforms showed a “chair-like” appearance, as shown in Fig. 1. Experimental OLV for the right (affected) side revealed that the right lower lobe inflated and deflated effectively, with the peak airway pressure being 23 cm $H_2O$ ; however, the value of

✉ Yiding Chen  
yidingch@126.com

<sup>1</sup> Department of Anesthesiology, Sichuan Cancer Hospital & Institute, Sichuan Cancer Center, School of Medicine, University of Electronic Science and Technology of China, Chengdu 610041, China

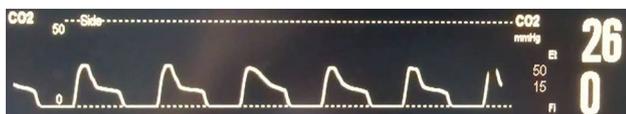


**Fig. 1** CO<sub>2</sub> waveform during double-lung ventilation after double-sleeve resection of the right upper and middle lobes

ETCO<sub>2</sub> decreased to 0 rapidly. The surgeons re-inspected the pulmonary artery, and a stenosis of the anastomosis was suspected. After re-anastomosis of the artery, P<sub>et</sub>CO<sub>2</sub> was measured to be 27 mmHg in DLV, with the normal “rectangle” waveform, and P<sub>et</sub>CO<sub>2</sub> was 20 mmHg in experimental right (affected) side OLV. After the surgery, the patient’s vital signs had stabilized, and the patient recovered well.

## 2.2 Case 2

A 62-year-old woman (height, 155 cm; weight, 51 kg) with a tumor of the right upper lobe was scheduled for a video-assisted thoracoscopic surgery (VATS) for the right upper lobe. OLV was satisfactorily achieved during the operation, with P<sub>et</sub>CO<sub>2</sub> being 33–37 mmHg. VATS was performed for the resection of the right upper lobe and lymphadenectomy. After sputum suction and re-expansion of the right lung, the capnogram showed a “chair-like” appearance during DLV (Fig. 2). The anesthesiologist informed the surgeons that it was likely that gas exchange did not occur in the right (affected) lung. No ligation of the right pulmonary artery and vein was noted on thoracoscopic exploration, and no trace of vessel ligation was detected on checking the specimen (upper right lobe). Therefore, the surgeons opened the right chest and explored the operative field. The proximal ligation point of the right upper lobe artery was found to be present just at the bifurcation of the pulmonary artery, which had resulted in severe stenosis of the right pulmonary artery. The stenosed portion of the artery was removed, and right pulmonary artery anastomosis was performed. P<sub>et</sub>CO<sub>2</sub> for DLV was now 28 mmHg, with the normal “rectangle” waveform, while that for OLV of the right (affected) lung was 23 mmHg. After the operation, the vital signs of the patient had stabilized, and the patient was shifted to



**Fig. 2** CO<sub>2</sub> waveform for double-lung ventilation after resection of the right upper lobe

the intensive care unit (ICU) without any postoperative complications.

## 2.3 Case 3

A 57-year-old man (height, 170 cm; weight, 66 kg) with the diagnosis of left upper lobe cancer was scheduled for a radical resection of the left upper lobe carcinoma. During the operation, the surgeon found that the tumor had infiltrated the left main pulmonary artery and, therefore, performed sleeve resection of the left upper lobe. During the preparation for pulmonary artery anastomosis, the surgeons observed that the left lower pulmonary artery was very short, but proceeded to complete the anastomosis on that side. On re-expansion of the left lung following the anastomosis, the capnogram exhibited a “chair-like” appearance for DLV (Fig. 3). On experimental OLV for the left (affected) side, the left lower lobe was found to inflate and deflate effectively, with a peak airway pressure 23 cmH<sub>2</sub>O; however, the P<sub>et</sub>CO<sub>2</sub> decreased to 0 quickly. The anesthesiologist informed the surgeons that gas exchange did not occur on the left (affected) side. The surgeons examined the left pulmonary artery and thought that stenosis of the left pulmonary artery may have caused the post-anastomosis blood flow failure. Re-anastomosis was not performed in this case since the left lower pulmonary artery was very short, and the results of the patient’s lung function test were very good. Therefore, pneumonectomy of the left side was performed. After the operation, the vital signs of the patient stabilized, and the patient was shifted to the ICU without any postoperative complications.

## 2.4 Case 4

A 64-year-old man (height, 166 cm; weight, 57 kg) was scheduled for sleeve resection of the right upper lobe for removal of a malignant tumor. The P<sub>et</sub>CO<sub>2</sub> for OLV with the left side was 37–41 mmHg. However, during the operation, the surgeon found that the tumor had invaded the right middle lobe as well as the main stem of the right pulmonary artery. Therefore, the surgical protocol was changed to double-sleeve resection of the right middle and upper lobes. This was followed by lymph node dissection, removal of the upper and middle lobes of the right lung, and double-sleeve anastomosis of the right inferior lobar bronchi and



**Fig. 3** CO<sub>2</sub> waveform in double-lung ventilation after sleeve resection of the left upper lobe



**Fig. 4** CO<sub>2</sub> waveform for double-lung ventilation after removal of the right upper and middle lobes

arteries, all of which were successfully performed. Then, on re-expansion of the right lung, the peak airway pressure was 19 cmH<sub>2</sub>O for DLV and the capnogram showed a “chair-like” appearance (Fig. 4). On experimental OLV with the left lung, the capnogram showed the normal “rectangle” waveform, and the P<sub>et</sub>CO<sub>2</sub> was 40 mmHg. The right (affected) side showed effective inflation and deflation of the right lower lobe, but the ET-CO<sub>2</sub> value decreased to 0 quickly and the tidal volume was 422 ml. The anesthesiologist informed the surgeons that there was no gas exchange in the right lung. Therefore, the surgeons disassembled the right pulmonary artery, checked the right pulmonary artery to ensure that it was free of any torsion, and performed the pulmonary artery anastomosis again. However, the capnogram still showed a “chair-like” appearance on DLV. After mutual discussion, the anesthesiologist and surgeon concluded that there may be a thrombus in the branch of the pulmonary artery supplying the right lung lower lobe. The pulmonary artery anastomosis was again disassembled, and the right lower pulmonary artery was washed with heparin solution and anastomosed again. This time, the capnogram for DLV returned to the normal “rectangle” appearance, and the P<sub>et</sub>CO<sub>2</sub> for OLV with the right (affected) side increased gradually. After the surgery, the patient’s vital signs had stabilized and the patient recovered well.

### 3 Discussion

Capnography is an effective, non-invasive monitoring method to guide respiratory management during general anesthesia. Monitoring of P<sub>et</sub>CO<sub>2</sub> and ET-CO<sub>2</sub> for OLV is particularly important in thoracic surgery. It had been reported that the sudden upsurge in ET-CO<sub>2</sub> had been manifested as the result of the left mainstem bronchial tear during thoroscopic tracheoesophageal fistula repair [1].

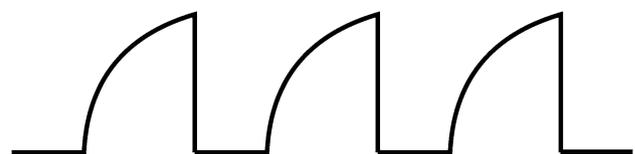
In all the four cases reported herein, the capnogram showed a “chair-like” appearance, and P<sub>et</sub>CO<sub>2</sub> for DLV had decreased significantly after lobectomy, this indicated that the concentration of CO<sub>2</sub> in the end-tidal volume had reduced when OLV was changed to DLV. Thus, the anesthesiologists could assess the changes in the capnogram and P<sub>et</sub>CO<sub>2</sub> for OLV with the affected lung and the healthy lung. In all the four cases, the P<sub>et</sub>CO<sub>2</sub> was 0 for OLV with the affected side, which indicated that there was no gas exchange

in the affected lung. The absence of gas exchange could be because of a lack of ventilation or blood flow on the affected side. In these cases, the tidal volume was normal for the affected lung during re-inflation, and therefore, ventilation-related problems could be excluded and absence of blood flow was suspected. Obstruction of the pulmonary artery perfusion on the affected side was confirmed in all the cases. In cases 1 and 3, the obstruction was caused by anastomotic stenosis after pulmonary artery anastomosis. In case 2, the obstruction was due to a mistaken occlusion of the pulmonary artery, while in case 4, it was caused by thrombosis of the distal end of pulmonary artery anastomosis.

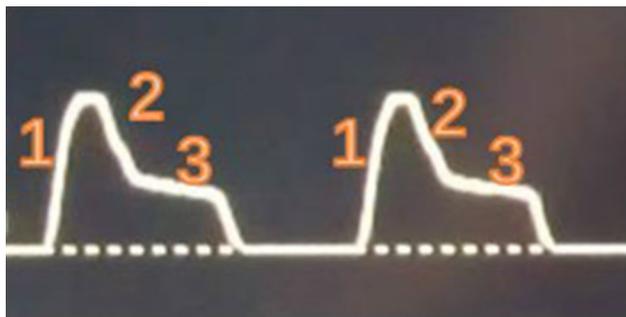
Valuable clinical information can be gained from observation of the changes in the capnogram. A “shark’s fin” (Fig. 5) appearance of the time-based capnogram occurs in the presence of bronchospasm and airway obstruction [2]. The capnogram also helps in the detection of obstruction of pulmonary artery branches after surgical correction of tetralogy of Fallot [3].

Why did capnogram manifest a “chair-like” waveform change in our cases? This phenomenon could be analyzed from the pathophysiological perspective. Blood flows from the right ventricle to the pulmonary artery to reach the left and right pulmonary arteries. If the pulmonary artery on the affected was obstructed, all the blood would be diverted to the healthy lung, resulting in a scenario that would be similar to one-side pneumonectomy. However, in the case of one-sided pulmonary artery obstruction, O<sub>2</sub> would still reach the affected lung. This means that there would be no gas exchange despite ventilation. As a result, the O<sub>2</sub> expired from the affected lung would mix with the CO<sub>2</sub> released from the healthy lung, thereby decreasing the concentration of P<sub>et</sub>CO<sub>2</sub>. In addition, since the diffusion rate of CO<sub>2</sub> is 20 times that of O<sub>2</sub>, the exchanged CO<sub>2</sub> from the healthy lung would diffuse faster before mixed with the O<sub>2</sub> expired from the affected lung, as the ascending branch of the capnogram (part 1) (Fig. 6). After the expired O<sub>2</sub> from the affected lung mixed with CO<sub>2</sub>, the P<sub>et</sub>CO<sub>2</sub> would reduce and would be represented as the initial portion of the descending branch of CO<sub>2</sub> (part 2) (Fig. 6). Once the CO<sub>2</sub> and O<sub>2</sub> are complete mixed, a plateau would appear on the capnogram (part 3) (Fig. 6).

All the four patients had stable vital signs, which rules out acute pulmonary embolism. Studies have shown that



**Fig. 5** A “shark’s fin” ET-CO<sub>2</sub> waveform showing severe airway obstruction



**Fig. 6** A “chair-like” ETCO<sub>2</sub> waveform

ETCO<sub>2</sub> monitoring enables the early diagnosis of acute pulmonary embolism and reduces mortality [4]. Blankush et al. included P<sub>et</sub>CO<sub>2</sub> as one of the parameters in an automated modified early warning scoring system that can be used on the general hospital floor to rapidly identify at-risk patients [5], their study has shown that the inclusion of parameters related to metabolism/gas exchange such as P<sub>et</sub>CO<sub>2</sub> can help dynamically identify at-risk patients in certain patient groups. Moreover, ETCO<sub>2</sub> monitoring in emergency medicine has been gaining importance [6, 7].

To summarize, the changes in the P<sub>et</sub>CO<sub>2</sub> and capnogram warrant closer monitoring when OLV is switched to DLV during anesthesia, especially in cases of pulmonary artery anastomosis. An analysis of these changes would be useful in determining whether there is any obstruction to the blood flow after pulmonary artery anastomosis.

## References

1. Kwok WH, Wong MK, Ho AM, Critchley LA, Karmakar MK. Left mainstem bronchial tear manifesting as sudden upsurge in end-tidal CO<sub>2</sub> during thoroscopic tracheoesophageal fistula repair. *J Cardiothorac Vasc Anesth*. 2013;27(3):539–41. <https://doi.org/10.1053/j.jvca.2012.05.013>.
2. Siobal MS. Monitoring exhaled carbon dioxide. *Respir Care*. 2016;61(10):1397–416. <https://doi.org/10.4187/respcare.04919>.
3. Garg R, Murthy K, Rao S, John C. Utility of intra- operative capnogram to detect branch pulmonary artery obstruction following totalcorrection of tetralogy of Fallot. *Ann Card Anaesth*. 2011;14(1):45–7. <https://doi.org/10.4103/0971-9784.74399>.
4. Bonderman D, Lang IM. End-tidal CO<sub>2</sub> for exclusion of suspected pulmonary embolism: a new partner for Wells? *Eur Respir J*. 2010;35 (4):723–4. <https://doi.org/10.1183/09031936.00164309>.
5. Blankush JM, Freeman R, McIlvaine J, Tran T, Nassani S, Leitman IM. Implementation of a novel postoperative monitoring system using automated Modified Early Warning Scores (MEWS) incorporating end-tidal capnography. *J Clin Monit Comput*. 2017;31(5):1081–92. <https://doi.org/10.1007/s10877-016-9943-4>.
6. Ward KR, Yealy DM. End-tidal carbon dioxide monitoring in emergency medicine, part 2: clinical applications. *Acad Emerg Med*. 1998;5(6):637–46.
7. Qvigstad E, Kramer-Johansen J, Tømte Ø, Skålhegg T, Sørensen Ø. Clinical pilot study of different hand positions during manual chest compressions monitored with capnography. *Resuscitation* 2013;84(9):1203–07. <https://doi.org/10.1016/j.resuscitation.2013.03.010>.