

## Paradoxical carbon dioxide embolism during endoscopic thyroidectomy confirmed by transesophageal echocardiography

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**Abstract** Carbon dioxide (CO<sub>2</sub>) embolism is a rare but potentially life-threatening complication of laparoscopic procedures. Although endoscopic thyroidectomy using CO<sub>2</sub> gas insufflation appears to be superior to conventional open thyroidectomy in terms of cosmetic results, it may cause venous or fatal paradoxical CO<sub>2</sub> embolism. We report a case of paradoxical CO<sub>2</sub> embolism during CO<sub>2</sub> gas insufflation in an endoscopic thyroidectomy that was confirmed by transesophageal echocardiography (TEE). Paradoxical embolization via transpulmonary right-to-left shunting of venous CO<sub>2</sub> gas emboli was revealed by TEE examination. The patient recovered without complications. In conclusion, although endoscopic thyroidectomy is a promising approach that is gaining popularity and offers excellent cosmetic results compared with conventional open thyroidectomy, this case report emphasizes the importance of anticipating and being vigilant for potential CO<sub>2</sub> embolism.

**Keywords** Embolism · Paradoxical · Endoscopy · Pulmonary embolism · Thyroidectomy

### Introduction

Although endoscopic thyroidectomy is a promising approach that is gaining popularity and offers excellent cosmetic results compared with conventional open thyroidectomy [1], the carbon dioxide (CO<sub>2</sub>) gas used to obtain surgical exposure may cause venous or paradoxical CO<sub>2</sub> embolism. Clinically apparent CO<sub>2</sub> embolism has been well described for several laparoscopic procedures, including laparoscopic cholecystectomy [2], gynecological laparoscopy [3], and laparoscopic liver resection [4]. However, to our knowledge, there is no previous report of CO<sub>2</sub> embolism during endoscopic thyroidectomy. In this case, paradoxical CO<sub>2</sub> embolism, which may be disastrous compared with venous embolism, was confirmed by transesophageal echocardiography (TEE). Thus, we present a case of paradoxical CO<sub>2</sub> embolism during CO<sub>2</sub> insufflation in endoscopic thyroidectomy that was diagnosed immediately by TEE. Transpulmonary right-to-left shunting of the venous gas embolism was found. Fortunately, the patient recovered without complications.

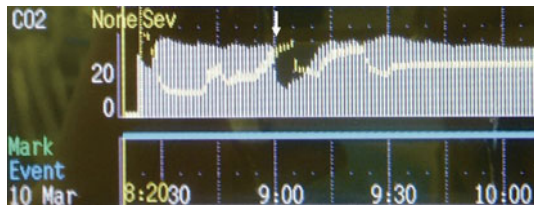
### Case description

A 59-year-old woman (150 cm, 54 kg) with Grave's disease was scheduled for endoscopic total thyroidectomy using the axillo-bilateral-breast approach (ABBA) [1]. Euthyroidism was achieved preoperatively. The clinical and laboratory preoperative assessments were unremarkable. She had a history of type 2 diabetes mellitus treated with regular medication. Anesthesia was induced with fentanyl (100 µg) and thiopental sodium (250 mg) and was maintained with sevoflurane, oxygen, and air. Monitoring included electrocardiography, pulse oximetry, noninvasive

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**Fig. 1** Changes in the end-tidal carbon dioxide concentration, documented on the anesthesia monitor (S/5 Anesthesia Monitor, GE Healthcare, Helsinki, Finland) during the carbon dioxide ( $\text{CO}_2$ ) embolism. The arrow indicates the start of the embolic event

sphygmomanometry, and capnography. Endotracheal intubation was facilitated with vecuronium, and the patient was ventilated mechanically. The end-tidal  $\text{CO}_2$  concentration ( $P_{\text{ET}}\text{CO}_2$ ) was kept within the range of 32–34 mmHg.

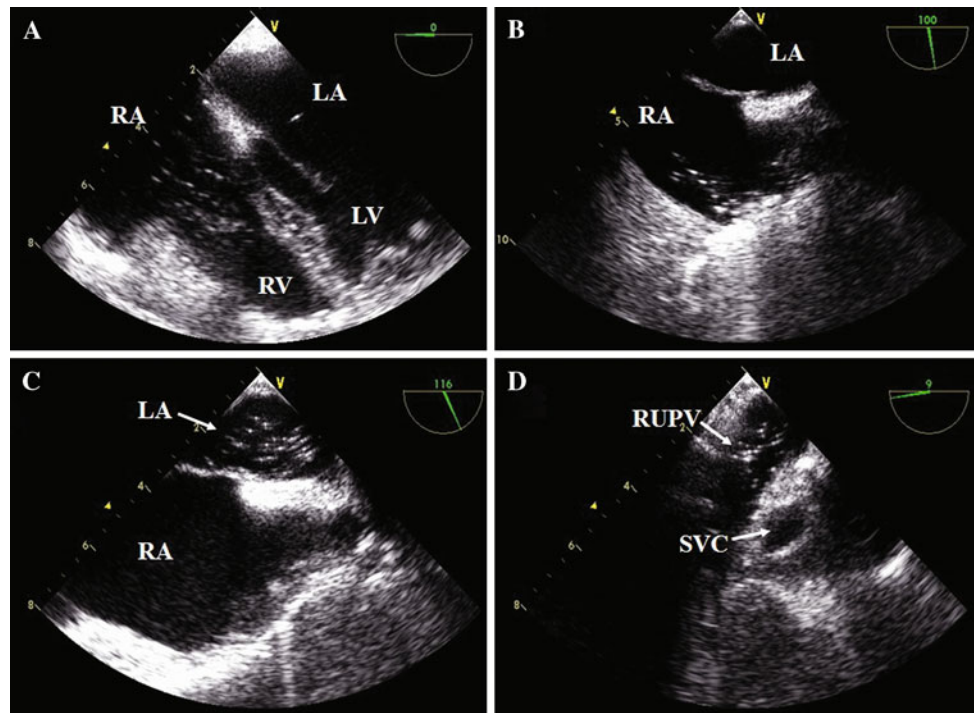
The patient was placed in the supine position with the neck extended using a shoulder pillow. Diluted (1:200,000) epinephrine solution was injected into the subcutaneous space in both breasts and the subplatysmal space in the neck to reduce bleeding during the dissection. After making incisions in both upper circumareolar areas, blunt subcutaneous and subplatysmal dissections were performed. The working space was extended to the level of the thyroid cartilage superiorly and to the medial border of each sternocleidomastoid muscle laterally. Following insertion of a 15-mm trocar through the incision, the working space was inflated with  $\text{CO}_2$  gas at a pressure of 6 mmHg. At this point, there was a sudden decrease in the  $P_{\text{ET}}\text{CO}_2$  from 34 to 13 mmHg (Fig. 1), associated with

hypotension (systolic blood pressure 70 mmHg) and a drop in the pulse oximeter oxygen saturation ( $S_{\text{pO}_2}$ ), from 99% to 88%. The electrocardiogram (ECG) showed a tall peaked T-wave change but normal sinus rhythm with a normal QRS complex.

Pulmonary embolism was suspected, and the patient was quickly placed head-down on her left side (Durant's position) [5] and given 100% oxygen immediately. At the same time, a 5-mg bolus of ephedrine was administered intravenously. To prevent any further gas entrainment, the  $\text{CO}_2$  gas insufflation was stopped immediately. An arterial blood gas measurement shortly after the event showed a partial pressure of  $\text{CO}_2$  in arterial blood ( $\text{PaCO}_2$ ) of 39.1 mmHg and a partial pressure of oxygen in arterial blood ( $\text{PaO}_2$ ) of 84.5 mmHg on 100% oxygen. Over the course of about 5 min, blood pressure,  $S_{\text{pO}_2}$ , and ECG returned to normal, but the reduced  $P_{\text{ET}}\text{CO}_2$  of 13 mmHg persisted.

Approximately 10 min after the start of the event, a 6.0-MHz multiplane TEE probe (6T multiplane probe, GE Healthcare, USA) was inserted to confirm the diagnosis and direct further treatment. The TEE (Vivid 7<sup>TM</sup>, GE Healthcare, USA) examination showed a massive amount of gas bubbles in the right heart and a few gas bubbles in the left heart (Fig. 2a–c) but relatively good biventricular contractility, with mild right ventricular distension. Subsequent TEE, under a Valsalva maneuver (two cycles of sustained positive airway pressure at 30 cmH<sub>2</sub>O for 5 s) [6] demonstrated no intracardiac shunt (Fig. 2b). A few gas bubbles entering from the right heart to the left heart through an extracardiac transpulmonary shunt were

**Fig. 2** Transesophageal echocardiographic two-dimensional examination showing carbon dioxide gas bubbles entering from the right heart to the left heart via extracardiac transpulmonary passage. **a** Midesophageal (ME) four-chamber view, **b** ME bicaval view under a Valsalva maneuver, **c** ME bicaval view, **d** right upper pulmonary vein in the transverse view. LA left atrium, LV left ventricle, RA right atrium, RUPV right upper pulmonary vein, RV right ventricle, SVC superior vena cava



observed (Fig. 2d). The gas bubbles in both chambers delineated in the serial TEE were scattered and cleared out gradually following normalization of the  $P_{ET}CO_2$  (Fig. 1).

Given the patient's rapid hemodynamic stabilization and normalized TEE view without gas bubbles, it was decided to proceed with an open thyroidectomy. Three hours later, the surgery was completed uneventfully. The patient recovered from anesthesia uneventfully and was transferred to the intensive care unit for observation. No neurologic or cardiopulmonary sequelae were noted in the initial postoperative period. The postoperative chest radiograph and 12-lead ECG were normal. Postoperative laboratory tests were in the normal range except mild elevation of the serum level of D-dimer (0.56  $\mu\text{g/ml}$ ; normal range 0–0.4). On postoperative day 6, she was discharged with no neurologic deficit.

## Discussion

$CO_2$  embolism is a recognized risk during laparoscopic procedures [2–4]. A necessary condition for the development of gas embolism is the presence of an open vein with a lower pressure in the vein than the surrounding pressure [2]. Consequently, any kind of endoscopic procedure using  $CO_2$  insufflation is always accompanied by the possibility of  $CO_2$  embolism. In this case, the initial signs included an abrupt decrease in  $P_{ET}CO_2$ , hypotension, ECG change, and desaturation, which developed immediately after  $CO_2$  gas insufflation and strongly suggested pulmonary  $CO_2$  embolism. Subsequent TEE examination confirmed our suspicion.

To our knowledge, this is the first report of venous or paradoxical  $CO_2$  embolism during endoscopic thyroidectomy, confirmed by an immediate TEE examination. Unlike other abdominal or thoracic endoscopic surgical procedures, endoscopic thyroid surgery requires a wide working space, which is newly created between the anterior pectoral fascia and the pectoralis major muscle where there is no pre-existing cavity. This subcutaneous tunneling to the neck is performed by blunt dissection, followed by  $CO_2$  gas insufflation. When considering the rich vascularity in the neck, anterior chest, and axilla, these characteristic features of the surgical approach may increase the risk of  $CO_2$  embolism during endoscopic thyroidectomy compared with other laparoscopic procedures. Thus, when consideration is given to the possibility of complications from  $CO_2$  gas insufflation, the gasless skin-lifting method may be likely to gain greater use for endoscopic thyroidectomy [7].

Generally, endoscopic procedures for the thyroid are divided into two types of approaches, depending on the position of incisions: the neck approach and the remote approach. The remote approach, including ABBA approach

used in our case, carries better cosmetic results than the neck approach [1]. However, the remote approach tends to be more invasive than the neck approach because the former requires a wide blunt subcutaneous and submuscular dissection to create the working space. In this regard, the remote approach may carry the increased risk of  $CO_2$  embolism compared with the neck approach.

The clinical presentation of gas embolism ranges from asymptomatic to neurologic deficits, cardiopulmonary sequelae, or even death, depending on the content and diameter of the gas, total amount of gas entering the circulation, and the speed of entrainment.  $CO_2$  gas is highly soluble in the blood (solubility coefficient approximately 0.49), and the partial pressure gradient between the blood and any  $CO_2$  bubbles will be about 660 mmHg (the  $PCO_2$  of the bubbles is approximately 713 and the  $PvCO_2$  is 46 mmHg) [8]. Fortunately, our patient recovered from the embolic event without complications. This may be due primarily to these physiochemical characteristics of  $CO_2$  gas. Because the lung is an effective physiologic filter for pulmonary gas emboli, the size of the gas bubble does matter. Deformable emboli larger than 14–22  $\mu\text{m}$  will be filtered in lung capillaries with diameters of 3–15  $\mu\text{m}$  [9]. Thus, if the total volume of the  $CO_2$  emboli is not too great and the speed of entrainment is not too fast, most of the emboli will be filtered by the lungs and dissolved in the blood. In rare cases,  $CO_2$  emboli may overwhelm the capacity of the lungs to filter the emboli, resulting in a fatal “gas lock” within the right ventricle [4, 10]. An animal study demonstrated that air is approximately five times as toxic as  $CO_2$  gas as an intravenous embolic agent [11]. Although the filtering threshold of the human lung for  $CO_2$  emboli is unknown, it is clear that the severity of  $CO_2$  embolism is directly proportional to the total volume of the entrapped emboli. In our case, severe hemodynamic collapse did not occur. In this regard, the total volume of the emboli that entered the pulmonary circulation might have been small, because we stopped gas insufflation immediately after promptly diagnosing the embolism. In endoscopic thyroidectomy, the established insufflation pressure is at 5–6 mmHg, which is much lower than the insufflation pressures of 12–15 mmHg used in other laparoscopic procedures. This may also have led to the fortunate result in our case.

In this case, we observed a paradoxical  $CO_2$  embolism via transpulmonary gas passage using TEE examination in real time. A paradoxical  $CO_2$  embolism can develop during an episode of venous embolism and may result in ischemic injury to tissues distal to the arterial gas bubbles. Although it is an extremely rare complication, the result can be more devastating than a venous embolism. Generally, it occurs in patients with an intracardiac right-to-left shunt, mostly due to a patent foramen ovale (PFO), which exists in about 25%

of the general population [12]. However, the occurrence of an intracardiac gas shunt produced by a Valsalva maneuver (transiently increasing the right atrial pressure provoking the opening of a PFO) [6] was not observed in our case.

We did not employ intravenous injection of agitated saline mixed with air (bubble study), the standard procedure for detecting right-to-left shunt. Although it is generally considered a safe procedure, there is a theoretical concern for causing paradoxical air embolism [13]. Actually, several cases of neurological deficiency have been described after agitated saline contrast TEE with the Valsalva maneuver [13, 14]. Thus, we used the CO<sub>2</sub> gas bubbles, which already existed in the right heart, as contrast material for detecting right-to-left shunt. Then, we carefully increased positive airway pressure to 30 cmH<sub>2</sub>O by manual ventilation with the vigilant inspection of TEE. Previous studies suggest the usefulness and safety of intravenous CO<sub>2</sub> gas as echocardiographic contrast for detecting intracardiac shunt [15, 16]. Thus, possible transient opening of a PFO was excluded as the cause of the paradoxical gas emboli. Subsequent TEE examination confirmed the transpulmonary passage of venous CO<sub>2</sub> gas emboli into the left heart. Paradoxical embolization via transpulmonary passage through the apparently intact pulmonary vasculature has been described, as well as through pulmonary arteriovenous malformations [9]. Treatment of CO<sub>2</sub> embolism is identical to that of air embolism. It consists of supportive care and, when necessary, aspiration of the gas bubbles from the right heart through a central venous catheter. Because our patient's hemodynamic condition normalized while we were preparing for central venous catheterization and the CO<sub>2</sub> gas bubbles disappeared naturally from both heart chambers in the subsequent TEE examination, we decided to cancel the central venous catheterization.

In summary, although endoscopic thyroidectomy is a promising approach that is gaining popularity and offers excellent cosmetic results compared with conventional open thyroidectomy, this case report underscores the importance of anticipating and being vigilant for potential CO<sub>2</sub> embolism. Additionally, we demonstrated that paradoxical CO<sub>2</sub> emboli, which are potentially more dangerous than venous emboli, may develop in such a case. Thus, it is important to stop further exacerbation of the consequences by prompt diagnosis and management, because there is no definite treatment for paradoxical gas embolism.

**Conflict of interest** The authors have no conflict of interest.

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