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Case Report

Air embolism during operative hysteroscopy: TEE-guided resuscitation☆,☆☆

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Abstract During hysteroscopic surgery there are concerns about potential complications such as venous air and gas embolism. The incidence of subclinical air emboli events during operative hysteroscopy is significantly underestimated. The manifestations of this complication may range from an unnoticeable decrease in $P_{ET}CO_2$ to the need for resuscitation. Three cases of air embolism with variable outcomes occurring during general anesthesia for operative hysteroscopy in otherwise healthy patients are presented.

1. Introduction

As reported by the National Survey of Ambulatory Surgery, an estimated 313,000 ambulatory surgical hysteroscopies were performed in the United States in 2006 [1].

Gas embolism is well documented during carbon dioxide (CO_2) diagnostic hysteroscopy, with a 0.51% incidence of subclinical events and 0.03% incidence of symptomatic events in a retrospective review of 3,932 cases [2]. Operative hysteroscopy carries a higher risk of gas embolism [3], with the incidence reaching 10% to 50% in one review [3]. A high incidence of asymptomatic gas embolization was found by Bloomstone et al in 2002, and recently confirmed by Leibowitz et al (2010) using transthoracic echocardiography (TTE) during operative hysteroscopy [4,5]. Air bubbles were present in the right atrium (RA) of all patients; this finding was associated with transient desaturation, which resolved without intervention in 30% of cases. While not clinically significant, an increase in pulmonary artery pressure was observed in the majority of those patients [5].

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Large uterine venous sinuses may allow entry of entrained air into the systemic venous circulation [6]. Air emboli may arterialize, resulting in paradoxical air embolism (PAE), particularly in patients with a patent foramen ovale (PFO), or through transpulmonary passage of air [3,7]. The clinical diagnosis of venous air embolism (VAE) may be difficult, as the wide range of signs and symptoms mimic other, more common cardiovascular conditions [8].

2. Case reports

All patients presented for outpatient resection of uterine fibroids and endometrial ablation. Routine ASA monitors were applied prior to induction of anesthesia, and patients were placed in the lithotomy position with 20° Trendelenburg tilt. Air bubbles were flushed out of the hysteroscope before insertion.

2.1. Case 1

A 53 year old, 76 kg, ASA physical status 1 woman was premedicated with midazolam 2.0 mg followed by induction of anesthesia with propofol 2.5 mg/kg and insertion of a size 4 Laryngeal Mask Airway (LMA). Anesthesia was maintained with sevoflurane in 100% oxygen and supplemented with fentanyl boluses ranging between 0.5 and 1.5 μg/kg/hr, as the patient was breathing spontaneously.

Approximately 30 minutes into the case, a greater than 50% decrease in partial pressure of end-tidal CO_2 ($P_{ET}CO_2$) was noted (from 48 to 22 mmHg), followed by a decline in oxygen saturation as measured by pulse oximetry (SpO_2) from 97% to 85%. Venous air embolism was suspected after other possible ventilatory and hemodynamic causes were excluded. Surgery was stopped and ventilation was assisted with 100% oxygen. An arterial blood gas (ABG) showed pH 7.27, $PaCo_2$ 57 mmHg, and PaO_2 68.7 mmHg. The patient's $P_{ET}CO_2$ and SpO_2 returned to baseline within minutes. The rest of the case was uneventful. She recovered from anesthesia and was discharged home three hours later without sequelae.

2.2. Case 2

A 46 year old, 74 kg, ASA physical status 2 woman had a history of noninsulin-dependent diabetes mellitus and hypercholesterolemia. Her physical examination was unremarkable. The patient was premedicated with midazolam 2.0 mg; anesthesia was induced with fentanyl 3.5 μg/kg and propofol 2.0 mg/kg. Tracheal intubation was facilitated with vecuronium 0.1 mg/kg. Anesthesia was maintained with sevoflurane, oxygen (O_2), and nitrous oxide (N_2O).

Approximately 20 minutes into the case, $P_{ET}CO_2$ suddenly decreased from 34 to 10 mmHg, followed by a decrease in SpO_2 from 100% to 90%. Ventricular extrasystoles, along with T wave inversions and ST depression, were noted. Venous air embolism was suspected and surgery was interrupted. To prevent any further air entrainment, the patient was positioned supine and ventilation was continued with 100% oxygen. Partial pressure end-tidal CO_2 and SpO_2 returned to baseline within minutes. Surgery was completed, neuromuscular blockade was reversed, and her trachea was extubated. On arrival at the Postanesthesia Care Unit, a 12-lead electrocardiogram (ECG) showed normalization of the ST-segment changes, and myocardial infarction (MI) was ruled out on the basis of normal serial cardiac isoenzymes. The patient was discharged home on the same day without any sequelae.

2.3. Case 3

A 46 year old, 74 kg, ASA physical status 2 woman had a history of mild asthma. She was premedicated with midazolam 2.0 mg. Anesthesia was induced with fentanyl

Table 1 Variables of arterial blood gas analysis at different time points during resuscitation

Blood gas analysis	Sample 1 (VBG)	Sample 2 (ABG)	Sample 3 (ABG)	Sample 4 (ABG)	Reference range
pH	6.994 *	6.889 *	7.063 *	7.193 *	(7.350 – 7.450)
pCO_2 (mmHg)	83.4 *	78.0 *	54.6 *	40.2	(35.0 – 45.0)
pO_2 (mmHg)	35.1	98.6 *	255.0	233.0	(80.0 – 100.0)
Bicarbonate (mmoles/L)	19.3 *	14.1 *	14.8 *	14.9 *	(22.0 – 28.0)
Base excess (mmoles/L)	−10.6 *	−16.9 *	−13.6 *	−11.7 *	(-3.00 – 3.00)
SpO_2 (%)	42.7 *	89.6	98.7	99.0	(94.0 – 100.0)
Sodium (mEq/L)	139	140	137	137	(135 – 145)
Potassium (mEq/L)	3.8	4.1	2.6 *	3.3 *	(3.5 – 5.0)
Ca^{2+} (mg/dL)	3.69	3.73	3.40 *	3.67	(3.56 – 5.06)
Glucose (mg/dL)	156 *	214 *	280 *	285 *	(70 – 115)
Lactic acid (mmol/L)	3.6 *	5.7 *	5.0 *	3.9 *	(0.6 – 2.2)
Hematocrit (%)	31.3 *	28.0 *	32.5 *	33.5 *	(37.0 – 47.0)

VBG=venous blood gas, ABG=arterial blood gas, SpO_2 = oxygen saturation, Ca^{2+} = calcium.
* Abnormal values.

50 μg and propofol 1.5 mg/kg, followed by insertion of a size 4 LMA. Anesthesia was maintained with sevoflurane and 100% O_2 and supplemented with fentanyl boluses of 50 μg.

As the procedure was nearing completion, $P_{ET}CO_2$ abruptly decreased from 40 to 14 mmHg, followed by a decrease in SpO_2 to below 90%. Heart rate (HR) and blood pressure (BP) decreased from 79 to 62 beats per minute (bpm) and from 105/55 to 82/42 mmHg, respectively. Venous air embolism was suspected and, in the face of hemodynamic instability, intubation was performed with 100 mg of succinylcholine. The patient remained in the Trendelenburg position to avoid further right ventricular outflow tract (RVOT) occlusion with air bubbles by placing the right ventricle (RV) more superior. A venous blood gas showed pH 6.99, PaO_2 35.1 mmHg [inspired oxygen concentration (FIO_2) 1.0], and $PaCO_2$ 83.4 mmHg (Table 1); she was hyperventilated with FIO_2 1.0. Subsequently after intubation, further deterioration of vital signs (HR 30-40 bpm, SpO_2 70%-75%, and BP 60-70/30-40 mmHg from 105-115/55-75 mmHg at intubation) and sustained low $P_{ET}CO_2$ at 14-18 mmHg were observed. Cardiac massage was started followed by boluses of epinephrine, atropine (total of 2.0 mg of each), and crystalloid administration. A radial artery was cannulated and ABG showed respiratory acidosis with a worsening metabolic component: pH 6.89, $PaCO_2$ 78 mmHg, PaO_2 98.6 mmHg, HCO_3^- 14.1 mM/L, and base excess −16.9 mM/L (Table 1).

At this time transesophageal echocardiography (TEE) showed a massive air embolus filling the RA, RV, and RVOT, and causing moderate RV dysfunction. Air crossing through a PFO was noted with air bubbles in the left side of the heart, LVOT, and the aorta (Fig. 1). Left ventricular function was preserved and its regional wall motion was normal.

Consistent with ongoing VAE, ECG showed a right bundle branch block (RBBB) and a RV strain pattern. The neurology stroke team was alerted of the possibility of PAE; hyperbaric treatment was considered.

Continued resuscitation with TEE monitoring resulted in a significant decrease in the amount of air in the RVOT and traversing via the PFO (Fig. 1); this decrease was accompanied by hemodynamic stability and improving metabolic acidosis (Table 1). The patient was transferred to the intensive care unit. A chest radiograph showed bilateral interstitial pulmonary infiltrates, which resolved by the second postoperative day. These infiltrates were thought to be related to the pulmonary effects of VAE, since TTE showed normal left ventricular (LV) function with an ejection fraction of 65%.

Although a head CT after surgery was unremarkable, the patient complained of impaired sensation of the left lower extremity. Magnetic resonance imaging showed a tiny cortical infarct in the left posterior parietal lobe. The remaining hospital course was uneventful. The patient was discharged home with resolving neurological symptoms.

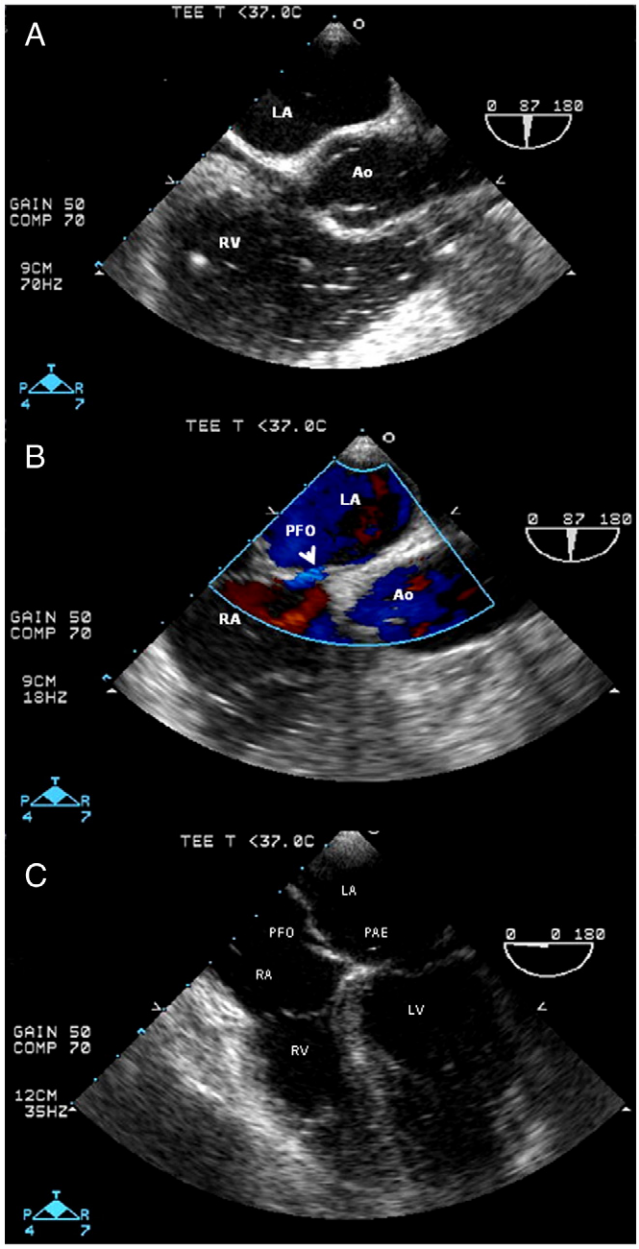

Fig. 1 **A**. Midesophageal long-axis transesophageal echocardiograph (TEE) showing right ventricle (RV), left atrium (LA), aortic valve (AV), and ascending aorta (Ao). Note the air emboli (blurred white dots) appearing within the RV, LA, and Ao, resulting in paradoxical air embolism (PAE). **B**. Color-flow Doppler of a midesophageal bicaval view showing patent foramen ovale (PFO) between RA and LA. The Ao is visible in this view because the probe is rotated slightly. **C.** Midesophageal 4-chamber view showing the LA, RA, LV, RV, and PFO. Note the single air embolus, which is clearly visible as it crosses through the PFO into the LA. Overall, the quantity of air emboli significantly lessened at this point when the images were acquired.

3. Discussion

Although gas embolism during operative hysteroscopy has been described [7,9-19], it seems that recognition of its

importance has waned in the last decade with the advent of liquid distension medium. Nevertheless, the potential lethal impact of cardiovascular and neurological complications is still substantial during hysteroscopic surgery.

Gas emboli during hysteroscopy arises from entrainment of ambient air introduced into the surgical field by repeat passes of the hysteroscope, and from the generation of electrosurgical vapors [20]. Further, air either entrains passively or is forced by irrigation solution into the open venous sinuses created by traumatic cervical dilatation [21]. Finally, air entrapment is facilitated by the venous vacuum as a result of the gravitational gradient between the right side of the heart and the uterus due to Trendelenburg positioning [21].

Case reports of accidental air emboli have described a lethal dose of air of between 200 and 300 mL, suggesting that the closer the site of entrainment to the right heart, the smaller the lethal volume [22,23]. Moore and Braselton [24] injected air or CO_2 into the pulmonary veins of dogs and cats and found that, whereas a bolus injection of as much as 3.0 mL/lb of CO_2 was well tolerated, as little as 0.6 mL/lb of air was uniformly fatal. Because of the high solubility of CO_2 in blood [25], its emboli cause a transient, partial obstruction in the pulmonary vasculature, increasing the regional CO_2 content of blood and an unchanged or even elevated $P_{ET}CO_2$ [10]. Overall, a symptomatic CO_2 embolism is rare and more easily tolerated than air; however, a massive CO_2 embolism may be symptomatic [16] or even lethal [26].

A gas embolism may impair ventilation-perfusion matching [27] by increasing physiological dead space [28], decreasing $P_{ET}CO_2$ and SpO_2, and concomitantly increasing the end-tidal to arterial CO_2 gradient. Large quantities of gas may obstruct the pulmonary circulation, lead to pulmonary vasoconstriction, and increase resistance to RV outflow, thus causing diminished effective pulmonary circulation [29]. Augmented right heart strain may force emboli to the left heart via right-to-left shunts [30], leading to arterialization of the gas and significant cardiac and neurologic complications [31]. As a result of reduced pulmonary venous return, there is decreased LV preload and cardiac output, which ultimately leads to cardiovascular collapse [29]. The clinical presentation may result in tachypnea, hypoxia, hemodynamic instability, and pulmonary hypertension, and eventually electromechanical dissociation, asystole, or cor pulmonale may follow [20].

Another pathophysiologic manifestation is governed through induction of the inflammatory response, including the intrinsic coagulation pathway [32], increased microvascular permeability [33], and endothelin-1 induced pulmonary hypertension [34]. This inflammatory cascade may escalate into a systemic inflammatory response [35] or cause isolated injury to pulmonary capillaries, leading to noncardiogenic pulmonary edema [36].

The pathophysiological pathway that predominates in clinical presentation is dependent on the rate and the volume of gas entrained [29]. If the quantity is large enough (5 mL/kg), an air-lock mechanism may lead to complete RVOT obstruction, cor pulmonale, and cardiovascular collapse [29]. Several other factors, such as gravitational gradient due to positioning, noncompressible vessels, and spontaneous ventilation, may facilitate air entrainment [29].

Gas embolism may be detected by a decrease in end-tidal CO_2 ($ETCO_2$). Unfortunately, it is neither very specific nor reliable in the event of hypotension or in a spontaneously breathing patient [29]. The diagnosis may be confirmed by the classic millwheel murmur. Precordial Doppler is the most sensitive but nonspecific noninvasive monitor, whereas TEE is the most sensitive and specific invasive monitoring for VAE, each detecting as little as 0.05 mL/kg and 0.02 mL/kg of air, respectively [37,38]. TEE-based diagnosis of PFO has been documented at a rate of 27% to 28% [39-41], which is concordant with the prevalence of 25% to 30% of autopsy detected probe-patent FO [40,42,43]. Augoustides et al showed that a TEE detection rate equivalent to the results of surgical interrogation of the inter-atrial septum is obtained by combining two multiplane TEE modalities in cardiac surgical patients [41]. The "total PFO detection" required a stepwise approach combining color-flow Doppler (midesophageal 4-chamber and bicaval views) and contrast echocardiography with concomitant release of positive airway pressure [41].

The role of TEE as the most sensitive and specific modality in PFO diagnosis has been questioned by several studies utilizing TTE, with a second harmonic imaging (SHI), which is capable of improved visualization of echocardiographic contrasts [44,45]. Moreover, an inadequate Valsalva maneuver due to sedation and esophageal intubation may yield a false-negative TEE reading [45,46]. Thus, a comparable yield for the detection of PFO was reported with either TTE+SHI or multiplane TEE in patients referred for evaluation of stroke or transient ischemic attack [44,45], rendering TTE+SHI the modality of choice for primary evaluation of cryptogenic neurological symptomatology. However, Greim et al in 2001 documented that the positive airway pressure release maneuver in anesthetized patients was superior to the Valsalva maneuver in sedated patients during TEE examination [47]. It seems that intraoperative multiplane TEE in the anesthetized patient yields superior detection of PFO.

Interestingly, transpulmonary passage of VAE through the apparently intact pulmonary vasculature has been described in dogs [48] and reported in humans [7,30,49,50], including a study in healthy volunteers that showed exercise-induced passage of gas emboli through direct atrioventricular (AV) intrapulmonary shunts [51]. To avoid a false-positive PFO diagnosis, which may be due to transpulmonary air passage, echocontrast in the LA must be identified within three cardiac cycles [41]. However, there are other rare etiologies of false-positive PFO that may occur within three cardiac cycles. They include spontaneous gas formation caused by abrupt changes in atrial pressure following respiratory maneuver [52] and air crossing from the RA to the LA by means of Thebesian veins [53].

Given the prevalence of PFO in the adult population, it is the most common etiology for paradoxical emboli. Neurological manifestations during an episode of massive VAE in patients with PFO are most likely related to central nervous system ischemia due to cardiovascular collapse, and are less commonly a result of arterialized air migrating up to the carotid and vertebral arteries [54]. A variety of symptoms have been described, ranging from mild headache to hemiparesis, coma [55], and temporary blindness [56]; urgent hyperbaric O_2 is currently accepted therapy for cerebral gas embolism [57-59].

Hypercarbia with respiratory acidosis may contribute to the neurological effects of PAE [60]. Carbon dioxide is a potent cerebral vasodilator [60,61], known to increase cerebral blood flow and intracranial pressure, compromising cerebral autoregulation [62,63]. Because cerebrovascular reactivity to CO_2 may be diminished or lost in the areas damaged by a vascular insult [64], hypercarbia may divert blood flow to the areas with preserved reactivity, causing irreversible damage in the penumbra. Similarly, hypercarbia may lead to a decrease in perfusion to the ischemic myocardium via intramyocardial steal [60].

Patent foramen ovale is also a risk factor for coronary artery embolization with ensuing MI, ischemic heart failure [65,66], and cardiac arrest, depending on the amount of PAE [31]. Coronary artery embolization induces ECG changes indicative of ischemia and dysrhythmias. Indeed, we noticed ST changes, premature ventricular contractions, and RBBB, which might be consistent either with coronary air emboli or RVOT obstruction and RV strain, as we did not observe LV wall motion abnormalities on simultaneous TEE.

Closed cardiac massage was initiated immediately in our patient following the precipitous decrease of $P_{ET}CO_2$ accompanied by sudden hemodynamic deterioration. Pericardial thumps might break a large air bubble, opening the RVOT and prevent further devastating events [14]. Corson et al [67] reported 5 deaths from air embolism when chest compressions were not started immediately.

Given the rapid return to baseline hemodynamic status, a central venous catheter (CVC) was not placed for aspiration of entrained air bubbles in our patient. Overall, multi-lumen catheters are ineffective in aspirating air; success rates range between 6% and 16% [68,69]. In addition, there are no data supporting emergent CVC insertion for air aspiration during cardiovascular collapse caused by air embolism.

3.1. Conclusion

Three cases of VAE of varying severity during routine outpatient operative hysteroscopy are presented. Both the literature and our experience indicate that operative hysteroscopy is an intervention with an underappreciated but high risk for VAE. Based on the high prevalence of PFO in the general population, a high index of suspicion for PAE is warranted. As minimally invasive procedures utilizing pressurized fluid and or gas continue to replace open surgery, intraoperative cardiac imaging should become readily available for the diagnosis of VAE and PAE. Avoidance of the Trendelenburg position during operative hysteroscopy is suggested.

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