Unexpected Air in the Left Ventricle after Aortic Cannulation in Two Patients with Severe Aortic Insufficiency: Possible Mechanisms and Clinical Implications

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Air bubbles are commonly seen in the heart on echocardiography after cardiac surgery and may lead to systemic air embolism.[1] The morbidity and mortality potential of air embolism to the coronary and cerebral circulation are described and may affect the surgical outcome.[2-5] Air embolism has been described both during initiation[6] as well as termination[7] of cardiopulmonary bypass (CPB).

However, there are no reports of air entrained into the left ventricle (LV) before the onset of CPB. The authors report 2 cases of aortic insufficiency in which air bubbles were seen unexpectedly in the LV just after aortic cannulation but before the initiation of CPB, and discuss the possible mechanisms and clinical implications.

CASE REPORT

Case 1

A 32-year-old male weighing 57 kg presented with dyspnea on exertion (New York Heart Association class II) for the last 6 months, which occasionally progressed to paroxysmal nocturnal dyspnea. Transthoracic echocardiogram (TTE) showed an aneurysmal ascending aorta measuring 45 mm associated with severe aortic insufficiency (4+). The LV was dilated (end-diastole and end-systole dimensions measuring 75 and 50 mm, respectively) with good ventricular function (ejection fraction = 60%).

A dissection flap in the ascending aorta seen on TTE was subsequently ruled out by magnetic resonance imaging. The patient was scheduled for a Bentall-De Bono repair of the ascending aortic aneurysm under CPB. After induction of anesthesia, a multiplane adult transesophageal echocardiography (TEE) probe was inserted, and images were acquired on a Philips Envisor CHD machine (Philips, Andover, MA). The fusiform dilatation of the aortic root and ascending aorta were well delineated, but no dissection flap could be seen.

After systemic heparinization, the surgeon inserted the aortic cannula into an aortotomy made in the ascending aorta above the aneurysmal segment, just proximal to the innominate artery. During this time, the last pre-CPB TEE images were being acquired to get a better profile of the aneurysm.

Suddenly, an air "shower" could be seen in the deep transgastric long-axis view (Fig 1) and coincided with the surgeon asking the perfusionist to infuse a small amount of pump prime to check the cannula resistance and flows. The air "shower" consisted of numerous fine echogenic bubbles that filled the entire LV cavity. Initially, the bubble density was high, fading subsequently over 15 to 20 seconds but never completely disappearing.

Just after the aortic cannula was inserted, snared, deaired, and connected to the arterial inflow connector, transient hypotension occurred (mean arterial pressure $<$50 mmHg). As the venous cannula was not yet in situ and hence CPB could not be established, the surgeon asked the perfusionist to infuse 50 mL of pump prime. This resulted again in a second air "shower" in the LV cavity persisting over 10 to 15 seconds (Video 1 [supplementary videos are available online]).

During both episodes of air "shower," there was no significant drop in bispectral index (BIS) values. CPB was subsequently established, and the Bentall procedure performed using a composite valve graft. The total CPB time was 146 minutes, which included 98 minutes of aortic cross-clamp. The patient was weaned from CPB with 0.05 μg/kg/min of epinephrine and 5 μg/kg/min of dopamine.

His vitals remained stable throughout the postoperative period, and the trachea was extubated on the first postoperative day after he met the institutional criteria for extubation. Although a detailed neurologic evaluation was not performed, there was an absence of any motor deficit and no gross memory loss or cognitive dysfunction.

Case 2

A 16-year-old boy weighing 30 kg presented with chief complaints of exertional dyspnea, progressing from New York Heart Association class II to class III over the last 3 to 4 years. TTE revealed a thickened, trileaflet, centrally noncoapting aortic valve with commissural calcification associated with severe aortic insufficiency (4+) and a dilated LV (end-diastolic/end-systolic dimensions = 68/48 mm). Ventricular function was reported to be good (ejection fraction = 55%). The patient was scheduled for aortic valve replacement under CPB.

After systemic heparinization, just after the aortic cannula was inserted and connected to the arterial inflow connector, an air "shower" could be seen in the LV cavity in the midesophageal aortic valve long-axis view (Fig 2). This dense air "shower" coincided similarly with the surgeon checking cannula resistance and flows.

The air bubbles tended to move toward the LV outflow tract and the aortic root. Although the intensity of the air "shower" decreased over a few beats, it never completely cleared (Video 2). The patient separated easily from CPB in the first attempt and made an uneventful recovery. There were no gross declines in cognitive, mental, or motor function.

DISCUSSION

The incidence of retained intracardiac air has been reported to be 73% after cardiac operations involving a cardiotomy to 11% after coronary artery bypass surgery.[8] The location of retained intracardiac air is a function of the chamber that is opened. After open heart procedures, intracardiac air is commonly seen in the right upper pulmonary vein, LV apex, left atrium (LA), and the right coronary sinus of Valsalva.[9] Intracardiac air may be present either as microbubbles[10] or in the pooled form.[9]

Air "bubbles" are typically described on echocardiography as highly mobile, strongly echogenic, small white dots ("fireflies"); whereas pooled air is depicted as a mobile echogenic line or area with variable area of acoustic shadowing, side lobes, and reverberation artifacts distal to the echogenic line caused by complete reflection of the ultrasound waves by the air-blood interface.[9] In both cases, air tends to collect at the highest level in the chamber because of its buoyancy.

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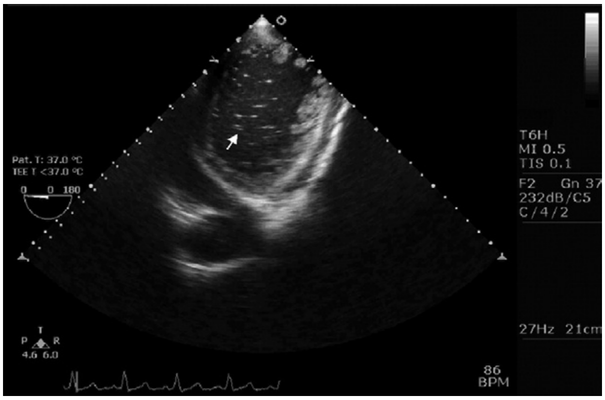

Fig 1. A deep transgastric long-axis view showing an air "shower" in the left ventricular cavity (arrow) consisting of small, mobile, echogenic dots in the first patient. The dots were too numerous to count and appeared at the time of aortic cannulation when the pump prime was infused through the arterial inflow connector to check for cannula resistance.

Air can be entrained into the LV and/or to the systemic circulation before or during initiation of CPB from various sources. Before the initiation of CPB, anesthetic causes may be an important source of air entering the systemic circulation. Air bubbles in venous cannulae and central venous catheters can enter the LV in the presence of atrial septal defect or patent foramen ovale (PFO).[11]

Paradoxic air embolism has been shown across a PFO in pigs with or without mean right atrial pressures exceeding mean LA pressures.[12] Pulmonary artery catheters (PAC) also have been described as a source of LV air.[13] Anesthetic agents and pulmonary vasodilators may further alter the pulmonary filtration capacity and allow unrestricted passage of microbubbles through the pulmonary circulation.[14]

Other causes of air entrainment into the LV before or during initiation of CPB include using a side clamp for aortic cannulation,[15] sudden unexpected respiration by the patient at the time of venous cannulation,[2] residual air in the venous circuit at the initiation of CPB,[6] insertion of left-heart vents,[16] and the extracorporeal CPB circuit.[1]

Although in both patients central venous catheters were used and presence of PFO could not be ruled out, it is unlikely that this could have been the source since air could not be demonstrated in the LV cavity in previous loops. Furthermore, depth of anesthesia was adequate, PAC were not used and air entrainment occurred before insertion of either venous cannulae or left-heart vents. The aorta also was cannulated directly in both instances without the use of any side clamp.

In both patients, the detection of air "shower' in the LV coincided with the surgeon checking for aortic cannula flows and resistance. In the first patient, air bubbles again were detected in the LV when pump prime was infused to treat the transient hypotension just before insertion of the venous cannula. This unexpected detection of air bubbles in the LV cavity before initiation of CPB raises several questions.

Flow in the ascending aorta is predominantly antegrade in early systole because of contraction of the LV.[17] However, flow reversal occurs during late systole, early diastole, and late diastole. The retrograde aortic flow is seen even in normal subjects and results in perfusion of the heart, brain, and kidneys during diastole.[17]

Such flow reversal generates small vortices in the aortic root that result in a drop of 25% of the total kinetic energy of aortic flow.[18] This phenomenon is exaggerated in patients with Marfan syndrome and aortic insufficiency and may result in a greater loss of kinetic energy.[18] The loss of kinetic energy may be translated into a transient drop in the aortic root pressure.

In patients with aortic insufficiency, ejection of a large stroke volume into the aortic root creates a transient pressure drop downstream of the aortic valve, which is mediated through a venturi effect. Rapid diastolic runoff of flow from the ascending aorta to the LV caused by exaggerated physiologic flow reversal creates a lacunae or empty space in the aortic root.

Air bubbles often are trapped within the bevel of the aortic cannula when it is pushed into the aortic root. Even though the cannula is deaired before connecting to the arterial inflow connector, it is possible that some air bubbles may remain in the aortic root. The combination of a drop in kinetic energy, venturi effect, and a rapid retrograde diastolic runoff probably exerts a suction force on the trapped air bubbles, which may result in their passive entrainment into the LV in the presence of an incompetent aortic valve (Fig 3).

The other possible source of air in the LV could have been the CPB circuit because in both instances, the air "shower" coincided with infusion of pump prime through the aortic cannula. Microbubbles are ubiquitous to cardiac surgery, and the extracorporeal circuit is an important source of such emboli despite the use of membrane oxygenators and inline arterial filters.[1,19]

Despite adequate priming of the CPB circuit, the crystalloid prime may contain microbubbles that can only be detected by ultrasound.[20] These bubbles can be pushed into the aortic root during the initiation of flow in the aortic cannula and subsequently entrained in the LV in the presence of aortic insufficiency (Fig 3).

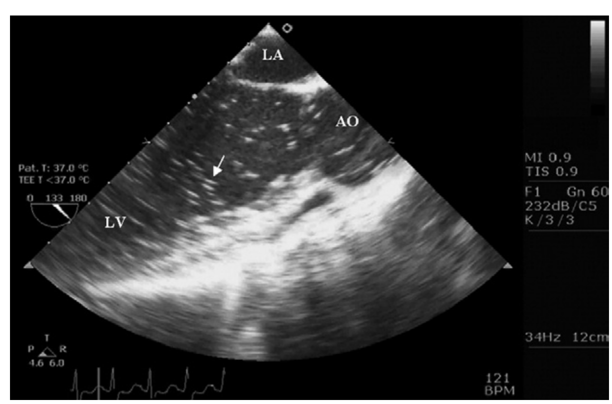

Fig 2. A midesophageal long-axis view of the aortic valve showing the air bubbles filling the entire left ventricular cavity (arrow) and moving toward the aortic root in the second patient. This air "shower" similarly appeared after aortic cannula insertion while checking for flows and resistance. LA, left atrium; LV, left ventricle; AO, aortic root.