A broken heart: Right-to-left shunt in the setting of normal cardiac pressures

Natalie Gomperts MD FRCPC¹, Robert Fowler MDCM MS FRCPC², Eric Horlick MDCM FRCPC³, Peter McLaughlin MD FRCPC⁴

N Gomperts, R Fowler, E Horlick, P McLaughlin. A broken heart: Right-to-left shunt in the setting of normal cardiac pressures. *Can J Cardiol* 2008;24(3):227-229.

A patent foramen ovale (PFO) is a common structural cardiac variant occurring in approximately 30% of the general population. Patients are usually asymptomatic because the defect is flap-like and does not permit significant left-to-right shunting. However, pathological conditions that result in cardiac rotation or higher than normal right atrial pressures can reverse the normal left atrial to right atrial pressure gradient and cause a right-to-left shunt through a PFO. If the right-to-left shunt is persistent, systemic hypoxemia or paradoxical emboli may result. The present report describes a case of refractory hypoxemia in a critically ill patient with a PFO who had a right-to-left shunt with normal right-sided cardiac pressures.

Key Words: Heart diseases; Hypoxia; Shunts

A patent foramen ovale (PFO) is a common structural cardiac variant occurring in approximately 30% of the general population (1). Patients are usually asymptomatic because the defect is flap-like and does not permit significant left-to-right shunting. However, pathological conditions that result in cardiac rotation or higher than normal right atrial pressures can reverse the normal left atrial to right atrial pressure gradient and cause a right-to-left shunt through a PFO. If the right-to-left shunt is persistent, systemic hypoxemia or paradoxical emboli may result. We report on a case of refractory hypoxemia in a critically ill patient with a PFO who had a right-to-left shunt with normal right-sided cardiac pressures.

CASE PRESENTATION

A 52-year-old woman developed refractory hypoxemia after elective cholecystectomy for a porcelain gallbladder secondary to chronic cholecystitis. Her medical history was significant for a patent ductus arteriosus, diagnosed on an echocardiogram 14 years before her current presentation. Her electrocardiogram revealed normal sinus rhythm with a QRS axis of zero. A lateral view chest radiograph demonstrated an increased right ventricular silhouette, with normal lung parenchyma and vasculature. Diagnostic cardiac catheterization suggested a PFO or sinus venosus atrial septal defect. She had a left-to-right shunt with a shunt ratio of 1.4:1. There was normal left ventricular function and no evidence of pulmonary hypertension. The ductus arteriosus was closed. Because the shunt fraction was relatively low and the patient was reluctant to undergo atrial septal repair, no corrective intervention was performed. Other medical history included a seizure disorder, cognitive impairment secondary to childhood neurotrauma and chronic macrocytic anemia secondary to vitamin B₁₂ deficiency.

Un cœur brisé : Un shunt veino-artériel en présence de pressions cardiaques normales

Un foramen ovale perméable (FOP) est une variante cardiaque structurale courante qu'on observe chez environ 30 % de la population générale. D'ordinaire, les patients sont asymptomatiques parce que l'anomalie ressemble à un lambeau et ne permet pas un shunt veino-artériel significatif. Cependant, des pathologies responsables d'une rotation cardiaque ou de pressions auriculaires plus élevées que la normale peuvent inverser le gradient de pression auriculaire gauche à auriculaire droit et favoriser un shunt veino-artériel par le FOP. Si ce shunt persiste, une hypoxémie systémique ou une embolie paradoxale peut survenir. Le présent rapport décrit le cas d'une hypoxémie réfractaire chez un patient en phase critique ayant un FOP qui avait un shunt veino-artériel avec des pressions cardiaques droites normales.

Before cholecystectomy, the patient underwent pulmonary function tests that demonstrated a normal diffusion capacity and mild extrapulmonary restrictive defect, likely related to obesity. Oxygen saturation on room air was 98%. Transthoracic echocardiography showed a left ventricular ejection fraction of 55%, a slightly enlarged left atrium of 44 mm and a right ventricular systolic pressure of 39 mmHg. No intracardiac shunting was noted on colour Doppler testing, performed without concurrent agitated saline injection.

Her anesthetic administration and surgery were uneventful; however, intraoperative arterial oxygen saturations were 92% to 95%, with an inspired oxygen concentration of 50% required to maintain arterial oxygen saturation of 90%. On the seventh postoperative day, she became acutely dyspneic and hypoxic during a chest physiotherapy session. She was intubated and mechanically ventilated; arterial oxygen saturation was 90% with an oxygen tension of 66 mmHg on inspired oxygen of 100%. She was empirically treated with nitric oxide, with no response. A spiral computed tomography with intravenous contrast did not reveal pulmonary emboli.

A colour Doppler transesophageal echocardiogram with agitated saline injection showed a marked right-to-left shunt through a PFO (Figure 1). The right heart pressures were normal, with a right ventricular systolic pressure of 32 mmHg. The left atrial dimension and left ventricular function were unchanged. On both transesophageal echocardiogram and computed tomography scan of the chest, the pulmonary veins could be seen entering the left atrium.

On postoperative day 19, the patient underwent cardiac catheterization with intracardiac echocardiography. Chamber saturations from catheterization demonstrated diminished left atrial saturation compatible with the right-to-left shunt (Table 1), in addition to normal atrial

¹Division of Cardiology, Department of Medicine, Faculty of Medicine, University of Western Ontario, London Health Sciences Centre University Hospital, London; ²University of Toronto, Departments of Medicine and Critical Care Medicine, Sunnybrook Health Sciences Centre; ³University of Toronto, Toronto General Hospital, Toronto; ⁴Peterborough Regional Health Centre, Peterborough, Ontario
Correspondence: Dr Robert Fowler, Departments of Medicine and Critical Care Medicine, Sunnybrook Health Sciences Centre, Room D478, 2075 Bayview Avenue, Toronto, Ontario M4N 3M5. Telephone 416-480-6100 ext 7471, fax 416-480-6191, e-mail rob.fowler@sw.ca
Received for publication May 4, 2006. Accepted October 1, 2006

Figure 1 Transesophageal echocardiogram revealing free passage of air-agitated saline from the right atrium to left atrium and early appearance of air-agitated saline in the aorta. PFO Patent foramen ovale

pressure measurements (Table 2). There was an atrial septal aneurysm associated with a PFO and a marked right-to-left shunt noted on intracardiac echocardiography (Figure 2). Right atrial, right ventricular and pulmonary pressures were normal. The relation of the inferior vena cava to the interatrial septum directed the catheter immediately across the defect. The stretched size of the defect by balloon inflation was 27 mm. When the defect was closed by balloon occlusion, systemic arterial oxygen saturation increased from 75% to 95%; when the balloon was deflated, the saturation fell again to a baseline level. Closure was performed using a 35 mm AGA PFO occluding device (AGA Medical Corporation, USA) (Figure 3). No residual leak was noted across the defect after closure. The patient was discharged one month later, with oxygen saturation of 98% on room air.

DISCUSSION

Determining the etiology of hypoxemia can be challenging. The common causes of hypoxemia are shunts (both intracardiac and extracardiac) and ventilation-perfusion mismatch within the lung (2). Less common causes include hypoventilation, low inspired oxygen concentration, impaired pulmonary oxygen diffusion and inadequate replenishment of a systemic oxygen debt, leading to low mixed venous saturation and subsequent arterial hypoxemia (2). Shunting is usually distinguished from ventilation-perfusion mismatch by the inability of supplemental oxygen to improve arterial oxygenation and lessen the alveolar-arterial oxygen gradient. Along with our patient's medical history, this was the clinical clue leading to her diagnosis. Usually, a pathological process is responsible for reversing the normal pressure gradient from the left atrium to the right atrium, predisposing patients to subsequent systemic hypoxemia (3). Such myriad conditions include severe tricuspid valve regurgitation, atresia or stenosis, right atrial myxomas or metastatic disease of the heart (4), pericardial tamponade (5), pulmonic valve stenosis, tetralogy of Fallot, recurrent pulmonary emboli, right ventricular infarction (6), pneumonectomies and other conditions leading to pulmonary hypertension (7).

Patients with shunts frequently present for medical attention when they exhibit inadequate improvement in their arterial oxygen saturation in relation to supplemental oxygen (8). Although our patient appeared to have an interatrial shunt, initial transthoracic echocardiography did not confirm a pressure gradient between the right and left atria, not an uncommon diagnostic pitfall. Several hypotheses may explain why right-to-left shunting occurs in patients with normal intracardiac pressures: transient, rather than prolonged, mean interatrial pressure differentials that occur during the normal cardiac cycle; a flow phenomenon, with preferential flow from the inferior vena cava directly through the PFO; a decrease in right ventricular

compliance, for example, one that may occur with right ventricular ischemia or infarction; and production or accentuation of interatrial gradients seen with the normal respiratory cycle or with Valsalva manoeuvres (9).

Throughout the cardiac cycle, left atrial pressure is generally higher than right atrial pressure. However, in early ventricular systole, right atrial pressure transiently exceeds left atrial pressure because of right atrial systole ending after left atrial systole, resulting in a transient instantaneous pressure differential during the normal cardiac cycle (10). This can also occur immediately following a Valsalva manoeuvre. The Valsalva manoeuvre has a number of phases. In phase 1 there is a rise in intrathoracic pressure and decrease in venous return to the heart. This quickly results in a decrease in systemic blood pressure and a reflex sympathetic tachycardia (termed phase 2). Phase 3 occurs with the release of the strain, which causes a further sudden transient drop in systemic blood pressure due to an almost empty pulmonary venous reservoir. However, immediately following these few beats, the blood that has been 'dammed up' in the venae cavae is released, leading to filling of the right atrium and ventricle (in contrast to the left ventricle, which still contains relatively less volume) and increased right-to-left shunting (10). In our patient, this phenomenon and desaturation occurred immediately following a bedside Valsalva manoeuvre during a chest physiotherapy session, during which she was encouraged to cough and use incentive spirometry. These exercises frequently result in respiratory pressure variations approximating a Valsalva manoeuvre. Stoddard et al (11) examined 73 patients who underwent elective contrast transthoracic echocardiography during quiet respiration, cough and the Valsalva manoeuvre. Both coughing and the Valsalva manoeuvre accentuated PFO flow, and repetitive cough was the most provocative. These authors noted that right atrial systole is completed later than left atrial systole and results in a leftward motion of the interatrial septum in early ventricular systole. Both the Valsalva manoeuvre and the coughing enhance this physiological leftward motion of the interatrial septum that occurs in early systole.

Venous blood from the inferior vena cava can be preferentially directed toward the fossa ovalis and the foramen ovale, a theory known as flow phenomenon, or streaming (8,9). Blood returning from the inferior vena cava is directed at the PFO and may therefore also account for right-to-left shunting without higher mean right atrial pressures. This phenomenon is usually associated with a persistent Eustachian valve at the junction of the inferior vena cava and the right atrium. The orientation of the atrial septum to the horizontal axis may also result in this preferential blood flow. Patients who have undergone pneumonectomies (7), abdominal surgery (8) or who have dilation of the proximal descending aorta (12,13) have also been shown to have the interatrial septum displaced toward the horizontal position, resulting in the PFO being placed in line with the inferior vena cava blood flow. In the present patient, during cardiac catheterization, the relationship of the inferior vena cava to the interatrial septum allowed the catheter to pass immediately across the defect, demonstrating this phenomenon. Such 'streaming' might have been related to the recent abdominal surgery. Inferior vena cava flow may have also been enhanced during physiotherapy and coughing, resulting in a sudden increase in systemic venous return.

Our patient was empirically treated with nitric oxide, in the belief that the hypoxemia may be due to increased pulmonary pressures and right-to-left shunting. Nitric oxide is a selective pulmonary vasodilator. It frequently improves ventilation-perfusion matching and improves oxygenation, but does not result in improved clinical outcomes for patients with hypoxemic respiratory failure (14). Its use in decreasing right-to-left shunt has been documented in patients following cardiac surgery or pulmonary embolism (15). Nitric oxide decreases right ventricular afterload, right atrial pressure, and ultimately decreases right-to-left shunting (16). It is not surprising that oxygenation did not improve in our patient, given that the interatrial shunt occurred in a setting of normal right-sided pressures.

TABLE 1
Cardiac catheterization oxygen saturation associated with right-to-left shunting

	IVC	SVC (high)	SVC (low)	RA (high)	RA (low)	RV (high)	RV (apex)	PA	PV (mid)	LA	Ao
Oxygen saturation, %	63.5	74.2	74.2	69.9	72.9	73.2	69.2	70.6	97.9	88.0	92

Ao Aorta; IVC Inferior vena cava; LA Left atrium; PA Pulmonary artery; PV Pulmonary vein; RA Right atrium; RV Right ventricle; SVC Superior vena cava

TABLE 2
Cardiac catheterization chamber pressures associated with right-to-left shunting

	RA	RVEDP	RVSP	LA	LVEDP	LVSP	AoDP	AoSP
Pressure, mmHg	11	15	36	15	16	108	60	108

AoDP Aortic end-diastolic pressure; AoSP Aortic systolic pressure; LA Left atrium; LVEDP Left ventricular end-diastolic pressure; LVSP Left ventricular systolic pressure; RA Right atrium; RVEDP Right ventricular end-diastolic pressure; RVSP Right ventricular systolic pressure

Figure 2) Intracardiac echocardiogram revealing patent foramen ovale and colour Doppler revealing flow from the right atrium to left atrium

CONCLUSIONS

Our patient had refractory hypoxemia due to a right-to-left atrial shunt in the setting of normal intracardiac pressures. The present case illustrates one of the many causes of hypoxia and highlights the mechanisms causing abnormal intracardiac flow and impaired oxygenation with intracardiac shunts. Reliance on cardiac chamber pressure measurements from a right heart catheter may not lead to a diagnosis. A review of the pathophysiology of intracardiac shunts and hypoxemia helped to lead to appropriate diagnostic testing and therapy for this patient.

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Figure 3) Intracardiac echocardiogram revealing closure device, cable and septum. Left atrial disc is below and the right atrial disc is above

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