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Paradoxical Air Embolism from a Patent Foramen Ovale

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Venous air embolism may be particularly hazardous in the patient who has a patent foramen ovale, for if right atrial pressure becomes greater than left, air can pass to the systemic circulation (paradoxical embolization). Systemic arterial embolization can result in occlusion of critical vascular beds with disastrous results. The following two cases are examples of paradoxical air embolism.

REPORT OF TWO CASES

Patient 1. A 36-year-old woman with an occipital meningioma underwent operation in the three-quarters-prone (extreme left lateral) position with her head elevated about 15–20 degrees, approximately 7–12 cm above the level of the heart. Precordial Doppler monitoring was not used. One burr hole near the confluence of the sinuses penetrated a dural sinus, causing brisk bleeding. During removal of the bone flap, three units of blood were administered, although hypotension did not occur. When the dura was lifted to clip the tear in the sinus, heart tones and blood pressure (direct) immediately disappeared, without murmurs. For approximately 2 min following cardiac "arrest" the electrocardiogram was unchanged as to rate, rhythm or ST segment. Resuscitation was unsuccessful. Postmortem radiographic examination did not demonstrate air in the great vessels or heart, but at autopsy a probe disclosed a patent foramen ovale and air in the superior vena cava, right and left atria, left ventricle, and coronary and systemic arteries. The heart and great vessels were opened under water and the released air was tested with pyrogalllic acid, which ruled out postmortem gas production due to autolysis.¹

Patient 2. A 42-year-old woman had an exploratory operation in the sitting position for an Arnold-Chiari malformation. After the dura was opened, the blood pressure abruptly decreased, and simultaneously, the Doppler monitor began to emit sounds typical of venous air embolism, although air could not be aspirated from the right atrial catheter. Blood pressure was rapidly returned to normal with a vasopressor agent. Several minutes later, the surgeon observed air bubbles in the exposed cerebellar arteries. The procedure was then terminated as rapidly as possible. Upon emergence from anesthesia, the patient was quadriparetic and comatose. Her neurologic status improved within a week to the extent that she was awake, alert, and oriented, but triplegic. She has remained essentially the same in the year since the operation.

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DISCUSSION

A patent foramen ovale directly contributed to the demise of the first patient and was a probable factor in producing disability in the second, inasmuch as significant systemic arterial air embolism developed rapidly. We are aware of only one other case report documenting paradoxical embolization of air via a patent foramen ovale,² although we have experienced a third case suggestive of this. There are, however, other case reports of paradoxical embolization through a patent foramen ovale of thrombi, tumor or other emboli.^{3,4}

The foramen ovale is at least probe-patent in 20–35 per cent of the population.^{3,5} Venous air embolism occurs in about 30–40 per cent of patients undergoing intracranial exploration in the sitting position.⁶ Thus, about one in ten patients operated in the sitting position will experience venous air embolism in the presence of a patent foramen ovale. For air to cross through a patent foramen ovale to the systemic circulation requires, at least intermittently, a right atrial pressure greater than left. Elevated right atrial pressure may occur with venous air embolism,^{7,8} intermittent positive-pressure ventilation, and the application of PEEP. The latter is recommended for treating air embolism and may increase shunting through a patent foramen ovale.⁹ By whatever means, creation of a right-to-left shunt through a patent foramen ovale permits systemic distribution of air, with possible disastrous results.

A patent foramen ovale is not detectable by routine diagnostic tests, nor is it necessarily detectable by invasive cardiac catheterization techniques. Detection requires creation of a transient increase in right atrial pressure, for example, possibly, by using Valsalva's maneuver, so as to create a transient right-to-left shunt. This might then permit recognition of the defect by abnormal passage of an injected radiopaque or densitometer-detectable dye.¹⁰

Whether or not paradoxical embolization of air can occur through the pulmonary vascular bed remains controversial. In man, anatomic studies have not demonstrated pulmonary arterial-venous shunts such those reported to exist in other species, including the dog.¹¹ However, even in experimental animals, the existence of such arterial-venous shunts remains controversial, and the weight of the evidence suggests

that it is unlikely that air in any significant volume could cross through the pulmonary vascular bed.¹¹ In a dog study using neon, the amount of gas injected in the venous system was almost completely recovered in the expired air, indicating little or no passage through the pulmonary vascular bed.¹¹ In another study,¹² in sheep, a bubble trap was interposed in the aortic outflow tract and 60 ml air were injected in the venous side. In two animals no air was captured on the systemic side, and in a third animal, only a 2-ml volume of air was trapped. In a fourth animal, 30 ml of the injected air were recovered in the bubble trap; at necropsy, this animal alone was found to have a patent foramen ovale. It would appear that paradoxical embolization of air is unlikely to occur, at least in any significant quantities, unless a cardiac defect exists.

Thus, air embolism in the presence of a patent foramen ovale could occur in about 10 per cent of patients operated on in the sitting position. When such a patient experiences prolonged or repeated episodes of air embolism, paradoxical embolization becomes increasingly likely. While its true incidence is unknown, it should be suspected in any patient who manifests an unexpected neurologic deficit following a surgical procedure known to be associated with the risk of air embolism. The intraoperative use of a Doppler monitor over the internal carotid artery is not feasible because of the likely detection of venous air in adjacent vessels.

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Racial Differences in Sacral Structure Important in Caudal Anesthesia

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Our clinical experience in 250 cases suggested that during caudal anesthesia the needle needs to be inserted more steeply in black than in white patients. We measured this angle to determine whether there is a structural difference between the pelves of black and white patients that might necessitate different angle of needle insertion. The advisability of avoiding unnecessary exposure of living persons to irradiation precluded making these measurements in ob-

stetric patients. We therefore studied 200 pelves from the Hamann-Todd collection of the Cleveland Museum of Natural History. The two anatomists after whom this collection is named prepared more than 3,000 skeletons, all of which are carefully labeled and available for study.

METHODS

We chose the first 200 skeletons that satisfied the following criteria: age at death, 20-60 years, 100 from black, 100 from white people. Half of each group was female. Altogether we examined 217 pelves, 17 of which were discarded because of anomalies such as obliteration in the sacral canal (13 of 217) or no roof on top of the canal (4 of 217).

Since the preparation of these pelves had caused dissolution of the ligaments, it was necessary to

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