Doppler analysis of the left venting line: an effective and simple technique to control heart deairing

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Air embolism is still a major risk of open-heart surgery. Different techniques of air removal have been established, even though none is completely effective. Since 1989 the authors have used a new technique to avoid air passage into the left vent line when the left heart cavities are open. A specially designed probe attached to a vascular Doppler analyser is fixed to the left vent tubing. Air passage is detected by a characteristic acoustic signal. Air removal procedures are continued until no audible signals are detected. This technique was carried out in 150 open left heart operations in which there were no clinical signs of air embolism. To validate this procedure, simultaneous assessment of air removal was made using transoesophageal echocardiography (TEE and carotid doppler CD) in six patients. When Doppler signs of air in the left vent disappeared, TEE revealed that a small amount of air was still present in two patients; carotid doppler showed only minimal passage of air bubbles in three patients after left vent removal while the heart was freely ejecting. These results demonstrate that this technique is a reliable method of assessing air removal, which is especially useful when deairing is difficult during reoperation.

Keywords: air embolism, transoesophageal echocardiography, heart deairing

Air embolism into the coronary and cerebral circulation is a serious hazard during cardiac surgery. Several studies[1] have tried to establish an effective method of eliminating entrapped air in the left side of the heart. Transoesophageal echocardiography (TEE) and transcranial Doppler have demonstrated that air embolism still occurs even though the removal technque appears perfect[2,3]. Since 1989 the authors have used a portable Doppler, which is normally employed to assess the peripheral vascular system, to document air passing though the left vent line. Air is detected because it produces a typical high frequency sound. When the noise disappears, the left vent is removed and the heart is allowed to eject freely. This technique has been performed in 150 operations in which the left heart cavities were open. There were no clinical signs of air embolism during the post-operative period.

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The aim of the present study was to assess the efficiency of the described technique using TEE and carotid Doppler (CD) in six patients.

Patients and methods

Left vent Doppler characteristics

A pocket-sized Doppler instrument (Minidop; Echomed, •••, France) is routinely used to monitor air passing through the left venting line during the air removal phase of 'left open heart' cardiac operations. The Doppler unit gives an emission signal of 6 megacycles. The Doppler shift is processed as an audible signal. The general principles of the technique have already been described[4].

A flat probe has been specially designed to allow direct contact with the 6.35-mm vent tubing. The probe and tubing are held in apposition by a metallic support. A thin layer of echographic gel is required to obtain perfect coupling. Air passage is detected as an irregular high frequency audible signal.

Study design

Intraoperative TEE and CD were performed in six patients (see clinical data in *Table 1*) who had cardiac surgery in whom the left heart cavities were open. The oesophageal echographic transducer (cardiac echograph: SSD 830, Aloka, Japan) was introduced after induction of anaesthesia and positioned in order to visualize: (1) the aortic root during institution of cardiopulmonary bypass; and (2) the left atrium and aorta during air removal procedures and after cessation of cardiopulmonary bypass. At the same time a Doppler probe (Doppler instrument: SPEAD 5; 4–8 MHz) was positioned in order to assess air passing through the left common carotid artery. This was detected by either a distinct audible signal or sudden notch in the systolic-diastolic curve on the tracings (*Figure 1*).

Air emboli were continuously monitored with particular attention being paid to the following phases of cardiopulmonary bypass: aortic cannulation; start of bypass; infusion of cardioplegia; air purging procedures; and cessation of bypass.

The duration of left vent Doppler signal presence, the duration of air removal and the presence of air in the left heart cavities at the time of left vent Doppler signal disappearance were also recorded. Air presence was arbitrarily graded by the same cardiologist into one of the following categories (*Figures 2* and *3*): 0, no air; 1, limited presence of air bubbles; 2, definite presence of air bubbles; and 3, massive presence of air bubbles.

Surgical technique

Aortic cannulation was performed just proximally to the origin of the innominate artery and in all patients a double caval cannulation was utilized. Membrane oxygenators and 40-m arterial filters were also routinely employed. A McGoon needle was used to administer anterograde cardioplegia in mitral valve replacement and left ventricular aneurysm resection while a simple 16-G needle was used in aortic valve replacement. An additional dose of retrograde cardioplegia was administered through the coronary sinus after aortic cross-clamping through a right atriotomy with direct cannulation of the coronary sinus. Left heart cavity venting was performed by two different techniques depending on the

Table 1 Clinical data of the patients

Patient no.	Sex	Type of intervention	Aortic cross-clamping time (min)	Cardiopulmonary bypass time (min)
1	M	Left vent Doppler	80	90
2	M	Aortic valve replacement	52	87
3	F	Mitral valve replacement	61	84
4	M	Mitral valve replacement	59	82
5	M	Mitral valve replacement	46	63
6	M	Aortic valve replacement	93	120

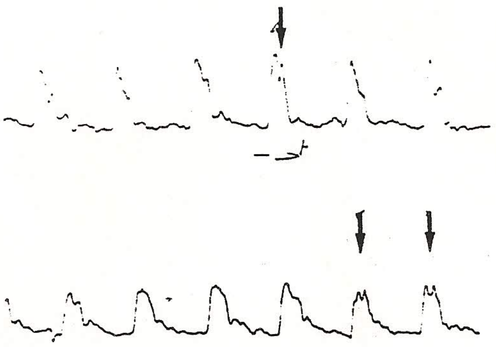

Figure 1 Intraoperative carotid doppler tracings: air bubbles are indicated by arrows

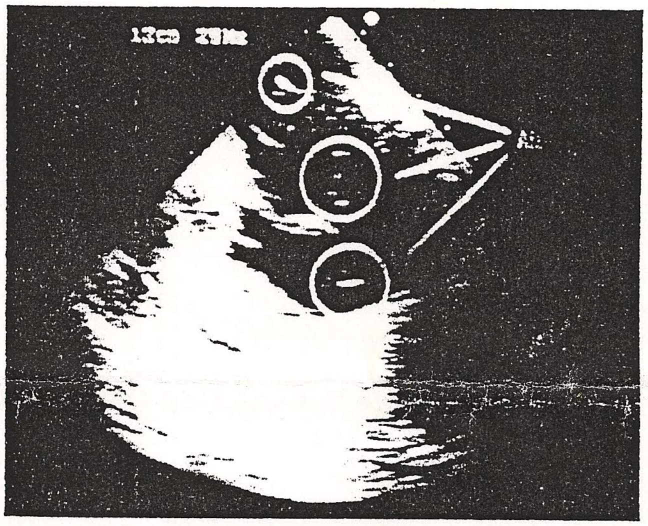

Figure 2 Transoesophageal echocardiographic image demonstrating air bubbles. This amount of air is classified as grade 3.

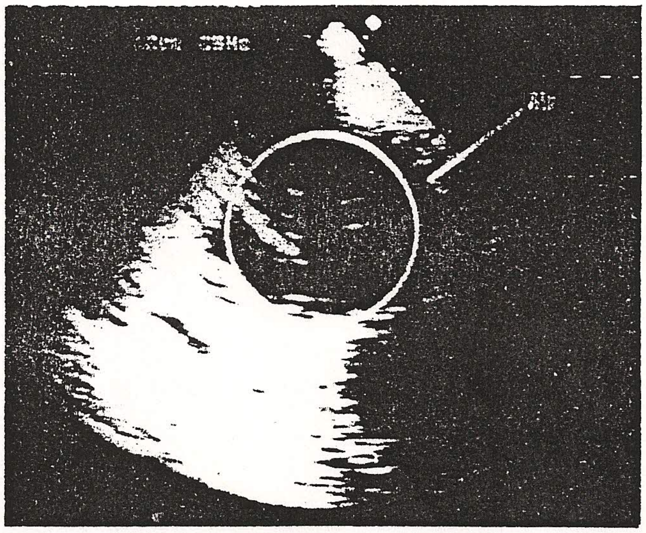

Figure 3 Transoesophageal echocardiography deairing progression to be accurately assessed. The metallic large-bore needle used to vent the left ventricle is visible

type of intervention. In mitral valve replacement a left vent was inserted through the left atriotomy, while in aortic valve replacement and left ventricular aneurysm resection a large-bore metallic needle was inserted into the left ventricle using a traseptal approach. Venting lines were used for air evacuation. Air removal was performed using the authors' standard technique: just before the aorta was declamped, ventilation was reinstituted, the operating table was put in the Trendelenburg position and the heart massaged. A reduction of venous return to the heart-lung machine allows filling of the right and subsequently the left cavities. After declamping the heart is completely vented, the table is turned several times to the left and to the right and a free ejection of blood through an aorta stab incision is encouraged. The heart is vigorously ballotted by the surgeon and if necessary air removed from the apex of the heart by inserting a large-bore needle. The left vent Doppler sound signals are continuously monitored for several minutes; a few minutes after the long-lasting sound signals have disappeared the left vent line is removed, the aortic stab wound closed and the heart allowed to freely eject if the body temperature is appropriate.

Results

All six patients survived the operation, and none developed clinical signs of cerebral air embolization. The fifth patient had an episode of ventricular tachycardia after aortic declamping which was perhaps related to an air embolus in the right coronary artery. The detection of air during the different phases of the operation is summarized in *Tables 2* and *3*. In the second patient a temporary echograph failure made the first three phases of the intervention impossible to analyse and in the same patient CD was not possible during infusion of cardioplegia. A total of 26 complete assessments (TEE and CD) for the presence of air were made. In 22 of the assessments (84.6%) TEE and CD agreed while in the other four (15.4%) they disagreed.

Results were discordant at aortic cannulation in one patient, during infusion of cardioplegia in two and at cessation of bypass in one. TEE data showed that air detection occurred in three (50%) patients during infusion of cardioplegia. Air embolization occurred in the aortic root after cardiopulmonary bypass arrest in two patients. CD demonstrated air passing through the left carotid artery in two cases during aortic cannulation. Carotid air embolization was documented in half the patients after circulatory arrest.

Results during the air-purging phase according to the presence and duration of an audible left vent Doppler signal and the grading of air presence in left heart cavities when the signal disappeared are summarized in *Table 4*. The mean (s.d.) duration of air purging was 19(6) min, while the mean (s.d.) duration of left vent Doppler signal presence was 15.8(7.05) min. In four patients TEE analysis of the left heart cavities showed a complete absence of air. In the fourth patient a small amount of air was present and in the fifth a considerable amount of air was present.

Table 2 Air detected in the aortic root by transoesophageal echocardiography

Patient no.	Type of intervention	Aortic cannulation	Bypass started	Cardioplegic injection	Aortic declamping	Bypass stopped
1	Left ventricular aneurysm	Yes	No	No	No	No
2*	Aortic valve replacement	No				
3	Mitral valve replacement	No	No	Yes	No	No
4	Mitral valve replacement	No	No	Yes	No	Yes
5	Mitral valve replacement	No	No	Yes	No	Yes
6	Aortic valve replacement	No	Yes	No	No	No

*In the second patient a technical problem prevented analysis of the early phase of the operation

Table 3 Air detected in the left carotid artery by carotid Doppler

Patient no.	Type of intervention	Aortic cannulation	Bypass started	Cardioplegic injection	Aortic declamping	Bypass stopped
1	Left ventricular aneurysm	Yes	No	No	No	No
2	Aortic valve replacement	No	No	No	Yes	
3	Mitral valve replacement	Yes	No	Yes	No	No
4	Mitral valve replacement	No	No	No	No	Yes
5	Mitral valve replacement	No	No	No	No	Yes
6	Aortic valve replacement	No	Yes	No	No	No

Table 4 Deairing-phase characteristics

Patient no.	Type of intervention	Duration of air purging (min)	Duration of left vent Doppler signal (min)	Grading at left vent Doppler signal disappearance
1	Left ventricular aneurysm	21	12	0
2	Aortic valve replacement	29	28	0
3	Mitral valve replacement	16	15	0
4	Mitral valve replacement	17	10	1
5	Mitral valve replacement	20	20	2
6	Aortic valve replacement	11	10	0

Discussion

The risk of leaving some air in the heart chambers is a source of anxiety to all cardiac surgeons. Since the first attempts to operate inside the heart, this problem has been recognized and attempts have been made to prevent it. Experimental studies[5] performed in dogs showed that small quantities of air injected into coronary arteries caused significant myocardial depression. Simultaneous air embolism into the three main coronary arteries rapidly caused death of the animals. Carotid air embolization produced severe cerebral derangement. Microbubbles (25 l) that obstruct cerebral arterioles for less than 30 s can disrupt brain function[6]. This may be a result of the effects that gases have on blood constituents or vascular endothelial cells, or both[7]. Even though the clinical effects of a small amount of air embolization through the cerebral circulation are difficult to detect, many post-operative personality disturbances may result.

Air embolization can occur throughout an open-heart operation, though the greatest periods of risk are at aortic cannulation, the start of bypass, aortic declamping and during weaning from bypass[3]. The lowest incidence is during cardiopulmonary bypass when the aorta is clamped.

The highest incidence of microembolization occurs when the left-sided heart cavities are opened an air can completely fill the heart. The J tube shape of the pulmonary veins has an air-retaining effect[8]. Various attempts have been made to establish an effective technique of air removal for left valve replacement operations[9]. Before the aorta is declamped many surgeons fill the cardiac cavities with saline, before restoring pulmonary ventilation and pummelling the heart. After the aorta has been declamped the left-sided cavities are completely vented to prevent air ejection. An aortic needle or a freely bleeding stab wound allows any residual air to escape from the ascending aorta. Air removal procedures are generally continued until no residual air bubbles are seen coming through the venting line[10].

Nevertheless despite these procedures microembolization can occur. Every surgeon has sometimes observed air in the aortic cannula or the coronary arteries after cessation of bypass. Furthermore many episodes of unexplained reversible myocardial depression or minor postoperative neurological problems may be the result of microembolization. Highly sensitive techniques for assessing air embolization (i.e. TEE or transcranial Doppler) have clearly demonstrated an unexpectedly high incidence of this phenomenon[2,3].

Some attempts have already been made to utilize Doppler instruments in the operative field to monitor the deairing phase[11]. Despite their possible value the awkwardness of the entire procedure has discouraged their widespread use. Similar considerations and additional high cost have prevented the routine use of TEE to assess the presence of air before cessation of bypass. The frequency of air embolization in the present study is similar to that of others. Simultaneous analysis by TEE and CD confirmed air embolization during the high-risk phases of the procedure, namely at aortic cannulation, the start of cardiopulmonary bypass, aortic declamping and during weaning from cadiopulmonary bypass. A high incidence (three of six patients) of air injection during the administration of cardioplegia was also noted. This probably relates to the difficulty in purging all the from the cardioplegia circuit.

The discordance between TEE and CD in 15.3% of the assessments is of interest. Air emboli at aortic cannulation are better detected by CD as TEE can hardly visualize the aorta beyond the site of cannulation. This explains the false-negative result obtained with TEE during this phase in one patient. CD did not detect air emboli in two of the three patients in whom it occurred during the administration of cardioplegia as demonstrated by TEE. This may be because air embolization occurred in vessels other than the left carotid artery. Unfortunately the presence of central venous catheters in the right jugular veins prevented assessment of the right common carotid artery where embolization most frequently occurs[12].

Left vent Doppler analysis of air passing through the left vent line appears to be effective in determining the ideal time of air removal procedures. When the left vent Doppler audible signal disappeared, TEE documented the presence of air in two patients; yet heart deairing was considered unsatisfactory only in one of these patients. In the same two patients both TEE and CD detected air embolization after cessation of cardiopulmonary bypass. CD documented air embolization in a third patient at a similar stage: this is because of the greater sensitivity of this technqiue in demonstrating air bubbles of very small diameter. The major advantage of