An Ultrasonic Method for Detecting Air Embolism*

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AIR EMBOLISM is a well-recognized hazard of neurosurgical operations performed in the sitting position. Even with the most assiduous use of prophylactic measures such as frequent irrigation of the surgical field with physiological saline and the liberal application of bone wax and wet cottonoids, serious air embolism still occurs. There are several ways of treating this complication,\textsuperscript{4,6,12} but it is generally agreed that successful management demands an early recognition. Present diagnostic techniques include the use of the precordial or the esophageal stethoscope,\textsuperscript{12,13} frequent or continuous recording of the electrocardiogram,\textsuperscript{38} and continuous monitoring of the carbon dioxide and nitrogen concentrations in the expired air.\textsuperscript{2}

Recently the use of a Doppler ultrasonic flow detector has proved to be an extremely sensitive method for detecting intracardiac air emboli.\textsuperscript{10} The instrument was initially designed for determining instantaneous arterial or venous blood flow velocity through the intact skin\textsuperscript{14} and is dependent on the frequency shift of ultrasonic waves reflected from moving red blood cells. Since an air-blood interface is a much more efficient reflector of ultrasound than erythrocytes, sound waves reflected from such an interface produce audible artifacts which are easily differentiated from the signals normally produced by bloodflow alone.\textsuperscript{7} Depending on the size of the embolus and the length of time it remains within the ultrasonic field, the artifact will be heard as a fleeting “chirp” or a raucous static similar to the noise heard when a gramophone needle scrapes across a spinning record.\textsuperscript{2,10} In either case the abnormal sound is peculiarly distinctive. This preliminary communication reports early clinical experiences with this new diagnostic method.

Material and Method

The Doppler blood flow detector\textsuperscript{‡} used initially was identical to that employed in the evaluation of peripheral vascular flow.\textsuperscript{13,17} It generates a continuous 5 mHz (5 × 10\textsuperscript{6} c/s) ultrasonic beam and has an effective crossing point extending to a tissue depth of approximately 4 cm. Recently the Doppler flowmeter used for fetal cardiovascular monitoring (2.25 mHz: 10 cm crossing point)\textsuperscript{3,9} has been employed because of the greater ease with which the cardiac sounds can be detected.

To monitor right heart blood flow, a circular disc transducer, 1 cm thick and 2 cm in diameter, was applied with an acoustical gel to the skin over the lower parasternal area usually in the third or fourth right intercostal space. The cardiac Doppler signal was easily recognized by its characteristic dull snapping sound, presumably due to the heart wall or valve motion, heard coincident with the blood flow signal.\textsuperscript{4} After a satisfactory audible signal was obtained, the transducer was firmly fixed in position with suitable adhesive. A set of earphones which automatically eliminates the sound from the instrument’s loudspeaker was used to monitor the Doppler cardiac sounds and the heart rate in the same way as one would auscultate the heart with a precordial or esophageal stethoscope.

Fourteen patients were monitored in this manner. Seven were operated on in the sit-
Ultrasonic Detection of Air Embolism

Case 2 (Female, age 10, pontine glioma). Bilateral suboccipital craniectomy was performed in the sitting position.

Air was detected on two occasions. The first was during periosteal elevation and bone removal; air artifacts were heard for approximately 1 minute. A rise in heart rate from 90 to 96 bpm and unifocal ventricular ectopic beats (Lead II) occurred 30 seconds after the air embolism was first noted. These ectopics lasted for 9 minutes, but no alteration occurred in blood pressure, central venous pressure, or respiration. A transient “chirp” was heard during the muscle closure.

Case 3 (Male, age 3, aqueduct stenosis). Posterior fossa exploration was carried out in the prone position.

One transient air artifact was heard. No other changes were observed. It was thought that the embolus originated from a small air bubble in the infusion tubing.

Case 4 (Female, age 36, meningioma). Bilateral suboccipital craniectomy was carried out in the sitting position.

Air embolism occurred on three occasions. The first was heard during the incision and lasted 2 seconds. Thirty-three minutes later, during extension of the incision, another transient embolus was detected. The third and most significant embolus occurred during the removal of the very vascular tumor. The Doppler air sounds lasted intermittently for 4 minutes. Three seconds after air was first heard, the central venous pressure fell but after 1½ minutes, rose to the initial level. The blood pressure fell (145/90 to 100/70 mm Hg) as determined by an oscillogonometer. It is difficult to explain these changes since jugular compression was quickly applied and there was also considerable hemorrhage during this stage of the operation. No change in the respiratory rate or depth was noted. Blood was given, and the blood pressure returned to the previous level over the next 15 minutes. No further problems were encountered during the procedure or in the postoperative period (Fig. 1).

Case 5 (Male, age 30, aqueduct stenosis). Posterior fossa decompression was carried out in the sitting position.

Air was detected on four occasions. The