Precordial Doppler Probe Placement for Optimal Detection of Venous Air Embolism During Craniotomy

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Verification of appropriate precordial Doppler probe position over the anterior chest wall is crucial for early detection of venous air embolism. We studied responses to normal saline (NS) and carbon dioxide (CO_2) test injections at various probe locations during elective craniotomy. All patients received four IV injections (10 mL of NS and 1 mL of CO_2 via central and peripheral venous catheters). Doppler sounds were simultaneously recorded with two separate probes. In Group A, probes were placed in left and right parasternal positions. In Group B, the left probe was intentionally malpositioned as far laterally over the left precordium as was compatible with an audible signal. In Group A (n = 23), a left parasternal Doppler signal was easily obtainable in 23 of 23 patients, versus 18 of 23 patients for the right parasternal probe ($P < 0.05$). In Group B (n = 17), central CO_2 injection yielded a positive right parasternal response rate of 88% compared with 29% over the far left precordium ($P < 0.015$), where central NS injections yielded a 76% response rate ($P < 0.015$ versus central CO_2 injection). Left parasternal placement is at least as sensitive to clinical venous air embolism events as right parasternal placement. Peripheral saline injection represents a viable alternative (83% response rate). Vigorous central injection of 10 mL of NS however, risks false positive verification of left lateral precordial probe placement.

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Venous air embolism (VAE) is a potentially fatal complication of neurosurgical procedures (1–4). Real-time monitoring is important for early diagnosis and immediate intervention. Despite the advent of newer modalities for detection of VAE, the precordial Doppler remains an essential first-line monitor in patients at risk for VAE. Although transesophageal echocardiography (TEE) is the most sensitive method of VAE detection (5–7) and is considered the "gold standard" (8), it is costly and more invasive. When properly placed, a precordial Doppler is capable of identifying VAE at an air infusion rate as low as 0.015 mL/kg/min and consistently at a rate of 0.021 mL/kg/min (9). However, proper positioning of the precordial Doppler probe over the anterior chest wall and verification of the accurate position is crucial to receive signals from right heart structures. Recommendations for positioning a precordial Doppler probe have emphasized probe placement between the third and sixth intercostal spaces along the right parasternal border. Clinical experience and evidence in the literature suggest that successful Doppler placement can be difficult when using this approach (10). Occasionally, sounds can be obtained easily only in the left parasternal position. However, the validity of left parasternal Doppler placement for detecting VAE has been questioned (11) because it has been argued that a probe positioned on the left sternal border might fail to insonate the path of air bubbles traversing the right side of the heart.

Several techniques have been recommended for verification of accurate probe positioning, including the response to the rapid injection of small fluid or gas boluses through either a central or a peripheral venous catheter. However, trans-septally transmitted turbulence/vibration produced by a rapid fluid bolus might be detected by a probe malpositioned over the left ventricle and consequently yield false

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positive confirmation of an inadequately positioned precordial Doppler probe. To identify optimal Doppler probe verification procedures and to estimate the effects of probe malposition, we compared the Doppler responses to carbon dioxide (CO_2) and bolus normal saline (NS) administered via peripheral and central IV catheters at various Doppler probe positions over the precordium.

Methods

With IRB approval and informed patient consent, 40 patients undergoing elective craniotomy were enrolled. After induction of anesthesia and endotracheal intubation, the lungs were mechanically ventilated at tidal volumes of 10 mL/kg. A central venous catheter (Bunegin-Albin Air Aspiration Set; Cook Critical Care, Bloomington, IN) was inserted via the antecubital route, with the tip positioned using intravascular electrocardiography (12), at the superior vena cava-atrial junction (13). Doppler sounds were simultaneously monitored with two P-81 ultrasound probes attached to two separate Versatone units (Versatone®; MedaSonics, Mountain View, CA). Probes with a total acoustic power output of 3.6 mW, at a frequency of 2.4 MHz and a beam area of 16.5 cm^2, were used.

Only patients with audible right parasternal Doppler sounds were included. In Group A patients ($n = 23$), the Doppler probes were placed in the right and left parasternal locations (intercostal spaces 3–6) that yielded optimal signal intensity. In Group B patients ($n = 17$), the first probe was placed at the conventional location (i.e., the 3rd, 4th, 5th, or 6th intercostal space along the right parasternal border). To ascertain the frequency of probable false positive responses to test injections, a second probe was intentionally malpositioned as far laterally over the left precordium as was compatible with a readily audible signal. Both probes were secured with adhesive tape. Simultaneous audiotape recordings of the electrical output of each of the two Versatone units were made. The Doppler responses to test injections were later graded as either positive or negative by experienced neuroanesthesiologists blinded to the probe positions and the type of test injection.

All subjects received a predetermined and systematically varied sequence of four IV injections consisting of two boluses of 10 mL of room temperature NS and two boluses of 1 mL of CO_2 given via the central and peripheral (16-gauge, forearm) venous catheters. All injections were made by one investigator (AS) using the same technique (rapid hand injection through a stop cock positioned 50 cm proximal to the hub of the central or the peripheral catheter). A continuous crystalloid infusion was maintained through both catheters at 200–300 mL/h. After each injection, Doppler sounds were allowed to return to normal, with at least 3 min elapsing between injections. All injections were made with the patients in the semirecumbent position and were completed before head holder placement and incision. At the conclusion of the study period, the right precordial probe was left in place for clinical monitoring during the case.

The statistical analyses we used were the χ^2 method and Fisher's exact test where appropriate.

Table 1. Patient Characteristics

	Group A ($n = 18$)[a]	Group B ($n = 17$)[b]
% Female	52	57
Age (yr)	51 ± 15	47 ± 16
Weight (kg)	74 ± 17	72 ± 18
Height (cm)	167 ± 5	168 ± 13
BMI (kg/m^2)	26 ± 5	28 ± 18

Data are expressed as mean ± SD.
BMI = body mass index.
[a] Although 23 patients were studied, right parasternal Doppler signals were only detectable in 18 of 23. Only these patients are included here.
[b] Only patients with a right parasternal Doppler signal are included.

Results

Patient characteristics are presented in Table 1. In Group A, an adequate right parasternal Doppler signal was obtained in 18 of 23 patients (78%), whereas the left parasternal Doppler signal was easily obtainable in all 23 patients ($P < 0.05$). Five patients in whom a signal could not be obtained were excluded from further analysis. Response rate data for the 18 patients in Group A are presented in Table 2. The pattern of positive responses was one of a trend (not statistically significant) toward lesser response rates at the right parasternal probe for both injectates (NS and CO_2) and from both injection sites (central and peripheral catheters). The left parasternal probe yielded a positive response whenever the right parasternal probe did. In no case was the left parasternal probe negative when the right parasternal probe showed a positive response; but in several patients, the left parasternal probe detected a response to test injections when the right parasternal probe did not. In one patient, after the study period, the conventionally placed (right parasternal) Doppler probe failed to detect a VAE during craniotomy. The occurrence of VAE in this patient was confirmed by appropriate changes in end-tidal CO_2 and nitrogen concentrations. Analysis of audio tapes for this patient revealed that the right parasternal probe had been silent to test injections, whereas the left parasternal probe had yielded a readily detectable positive response.

The results for Group B patients ($n = 17$) are presented in Table 3. The right parasternal probe showed a more frequent positive response than the extreme

Table 2. Group A Data ($n = 18$). Number of Positive Responses (%) to Central and Peripheral Normal Saline and Carbon Dioxide Injection with Doppler Probes in the Right Parasternal and Left Parasternal Locations

	Central		Peripheral	
Probe location	Normal saline	CO_2	Normal saline	CO_2
Right parasternal	17 (94%)	13 (72%)	10 (56%)	7 (39%)
Left parasternal	18 (100%)	16 (89%)	15 (83%)	9 (50%)

"Central" indicates administration via a right atrial catheter. "Peripheral" indicates administration via a 16-gauge catheter in a forearm vein. Of 23 patients studied, right parasternal Doppler signals were detected in only 18 patients.

Table 3. Number of Positive Responses (%) to Central and Peripheral Normal Saline and Carbon Dioxide Injection with Doppler Probes in the Right Parasternal and Far Left Precordial Locations (Group B, $n = 17$)

	Central		Peripheral	
Probe location	Normal saline	CO_2	Normal saline	CO_2
Right parasternal	17 (100%)	15 (88%)	14 (82%)	11 (65%)
Left lateral precordium	13 (76%)	5 (29%)*	5 (29%)	3 (18%)

* $P < 0.015$ central normal saline injection and vs. right parasternal CO_2.
"Central" indicates administration via a right atrial catheter. "Peripheral" indicates administration via a 16-gauge catheter in a forearm vein.

left lateral precordial probe. Although the trend was consistent, the differences were statistically significant for only centrally injected CO_2 (positive responses, right vs left, 88% vs 29% respectively; $P < 0.05$). For the left lateral precordial probe, the positive response rates for centrally injected NS and CO_2, 76% and 29% respectively, were statistically different ($P < 0.015$).

Positive response rates at both Doppler probe locations tended to be less for peripheral than for central injections of both NS and CO_2. However, peripherally injected NS produced a response rate of 83% at the left parasternal probe location, comparable with response rates achieved with central CO_2 injections.

Discussion

Precordial Doppler monitoring is a standard modality for the detection of VAE in neurosurgical patients at risk. Techniques that facilitate successful positioning of the precordial probe and maximize the sensitivity of this device (i.e., minimize false negative responses) should be of importance to clinicians. The present investigation provides several observations relevant to those objectives.

The data indicate that a left parasternal placement results in more frequent detectable cardiac tones than does the conventionally taught right parasternal placement. In so doing, left parasternal placement achieved a sensitivity to VAE events that is at least as good as and perhaps better than right parasternal placement. Although the differences were not statistically significant, the rate of positive responses to all test injections were more frequent at the left than at the right parasternal probe location. For instance, for central CO_2 injection, the response rates for left and right parasternal probes were 89% and 72%, respectively (Table 2). Perhaps most significant in that regard is the observation that there was never an instance in which the right parasternal probe gave a positive response and the left parasternal probe was negative, although the converse did occur. The observation that cardiac tones are more readily obtained at a left precordial location has been made before (14). However, these are the first data to confirm that left parasternal placement does not result in any loss of sensitivity to simulated VAE events relative to the traditionally taught right parasternal probe position (11,15). Our anecdotal observation in one patient further supports this view: intraoperative VAE was missed by the conventionally placed right parasternal Doppler probe, which had failed (we learned in retrospect) to respond to a test injection that had been detected by the left parasternal probe.

The far left lateral probe location was included in part B of the investigation principally to identify probable false positive responses to injection of NS. The rationale was that the ultrasound beam of probes in this location would be unlikely to traverse structures on the right side of the heart. Therefore, in the face of a negative response to CO_2 bubbles, a positive response to NS was likely to represent the response to the mechanical effects of NS injection. The Doppler ultrasound beam is reflected by the interfaces between red blood cells and plasma. Rapid NS injection might result in a change in the motion of those interfaces either directly or indirectly via motion induced in the walls of cardiac chambers (Fig. 1). The significant difference that we observed between response rates at the left lateral precordial (76% with central NS injection) and right

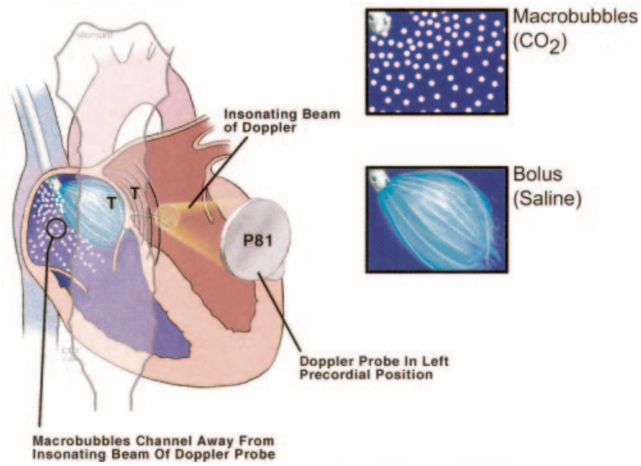

Figure 1. Schematic showing the effect of a rapid saline bolus; turbulence (T) transmitted across cardiac chambers results in a positive response at a laterally placed precordial Doppler probe (P81).

parasternal (29% with central CO_2 injection) locations ($P < 0.015$) probably points to a substantial risk of falsely confirming adequate probe positioning with vigorous central injection of a crystalloid solution, especially if the Doppler probe is placed over the far left precordium. This notion of transmitted vibration induced by vigorous central NS injection is consistent with the observation that peripherally injected NS resulted in a lesser positive response rate over the left lateral precordial probe than did central NS. The reason for this is that any turbulence associated with the forceful injection of NS is likely to dissipate in the peripheral veins en route to the right heart.

The present data also suggest an alternative for probe position verification when central venous access is unavailable or CO_2 injection is not feasible. The data therefore suggest that a rapid peripheral venous injection of 10 mL of crystalloid solution may be a reasonable alternative to central injection of 1 mL of CO_2 as a test of adequate Doppler probe placement. The positive responses to peripherally injected saline probably reflect the presence of microbubbles in suspension in the injectate. The limitation is that, although a positive response probably confirms adequate placement, the meaning of a negative response will be ambiguous.

The generally small rates of response to peripheral CO_2 injections in both groups (A and B) suggest that technique will frequently fail to confirm proper placement of the precordial Doppler probe. It is possible that this is explained by a decrease in bubble size and number en route to the pulmonary vasculature as a result of a combination of absorption and bubbles "hanging up" at vascular branchings.

For the purposes of this investigation, the "gold standard" for determining the ability of a Doppler probe to identify the air bubbles associated with clinical VAE events was the ability of the probe to identify centrally delivered bubbles of CO_2. There are two limitations inherent to this approach. The first is that it entails the assumption that the CO_2 bubbles actually traversed the right side of the heart. However, the response rates at the left and right parasternal locations to centrally injected CO_2 were <100% (right 72%, left 89%, Table 2). It is possible that the limited amount of CO_2 (1 mL) was able to bypass the sound beam of the Doppler probe. A second possibility is suggested by an investigation performed by Bunegin et al. (13). Those authors, using a latex model of the right side of the heart, demonstrated the occurrence of a vortex in which air bubbles were "held up" in the superior vena cava. This may have occurred and resulted in negative responses from well-positioned probes. In the ideal, TEE should have been used to confirm that bubble passage across the right side of the heart actually occurred. The absence of TEE information makes definitive interpretation of the 100% response rate of left and right parasternal probes to centrally injected NS difficult.

An additional limitation is that, in the present investigation, only one "dose" of test material was studied: either 10 mL of NS or 1 of mL CO_2. It is conceivable that our results might have been different with different injectate volumes.

In summary, our data confirm that a Doppler signal can be obtained more reliably at the left parasternal than at the right parasternal border. Furthermore, as judged by the ability to detect the intravascular injection of CO_2 bubbles, left parasternal placement is likely to be at least as sensitive to clinical VAE events as right parasternal placement. Left lateral precordial probe locations frequently fail to detect intravascular bubbles that are detected by parasternally located probes; i.e., they have a frequent false negative response rate. The data further indicate that vigorous injection of 10 mL of saline via a central catheter entails a significant risk of false positive verification of adequate probe placement, in particular for probes at far left precordial positions.

References

1. Smith DS, Osborn I. Posterior fossa: anesthetic considerations. In: Cottrell JE, Smith DS, eds. Anesthesia and neurosurgery. St. Louis: Mosby, 2001:335–51.
2. Black S, Ockert DB, Oliver WC Jr, Cucchiara RF. Outcome following posterior fossa craniectomy in patients in the sitting or horizontal positions. Anesthesiology 1988;69:49–56.
3. Buckland RW, Manners JM. Venous air embolism during neurosurgery. A comparison of various methods of detection in man. Anaesthesia 1976;31:633–43.
4. Slbin MS, Babinski M, Maroon JC, Jannetta PJ. Anesthetic management of posterior fossa surgery in the sitting position. Acta Anaesthesiol Scand 1976;20:117–28.

5. Cucchiara RF, Nugent M, Seward JB, Messick JM. Air embolism in upright neurosurgical patients: detection and localization by two-dimensional transesophageal echocardiography. Anesthesiology 1984;60:353–5.
6. Schwarz G, Fuchs G, Weihs W, et al. Sitting position for neurosurgery: experience with preoperative contrast echocardiography in 301 patients. J Neurosurg Anesthesiol 1994;6:83–8.
7. Souders JE. Pulmonary air embolism. J Clin Monit Comput 2000;16:375–83.
8. Domaingue CM. Anaesthesia for neurosurgery in the sitting position: a practical approach. Anaesth Intensive Care 2005;33: 323–31.
9. Gildenberg PL, O'Brien RP, Britt WJ, Frost EA. The efficacy of Doppler monitoring for the detection of venous air embolism. J Neurosurg 1981;54:75–8.
10. Michenfelder JD, Miller RH, Gronert GA. Evaluation of an ultrasonic device (Doppler) for the diagnosis of venous air embolism. Anesthesiology 1972;36:164–7.
11. Tinker JH, Gronert GA, Messick JM, Michenfelder JD. Detection of air embolism, a test for positioning of right atrial catheter and Doppler probe. Anesthesiology 1975;43:104–6.
12. Martin JT. Neuroanesthetic adjuncts for patients in the sitting position. Anesth Analg 1970;49:793–808.
13. Bunegin L, Albin MS, Helsel PE, et al. Positioning the right atrial catheter: a model for reappraisal. Anesthesiology 1981;55:343–8.
14. Craft RM, Weglinski MR, Perkins WJ, and Losasso TJ. Precordial Doppler probe placement for detecting venous air embolism reassessed [abstract]. Anesthesiology 1994;81[3A].
15. Maroon JC, Albin MS. Air embolism diagnosed by Doppler ultrasound. Anesth Analg 1974;53:399–402.