Power M-Mode Transcranial Doppler for Diagnosis of Patent Foramen Ovale and Assessing Transcatheter Closure

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ABSTRACT

Background and Purpose. Transcatheter closure of patent foramen ovale (PFO) can benefit from a less invasive diagnostic method than transesophageal echocardiography (TEE). Thirty-three gate power m-mode transcranial Doppler (pmTCD) was evaluated for its accuracy in diagnosis of PFO and utility in evaluating residual intracardiac right-to-left shunt (RLS) following transcatheter closure. *Methods*. The sensitivity of pmTCD and single-gate TCD (sgTCD) to detect contrast bubble emboli through RLS was compared during transcatheter PFO closure. During 100 preclosure diagnostic evaluations and in 81 postclosure assessments, embolic tracks on pmTCD were counted following intravenous contrast injections and were graded using a 6-level logarithmic scale. The accuracy of TEE and pmTCD was separately compared to PFO anatomical findings during transcatheter closures. *Results*. There were significantly more microemboli detectable on pmTCD (322 ± 166; 95% confidence interval [CI], 388-257) than on sgTCD (186 ± 109; 95% CI, 229-143; $P < .001$). McNemar change tests suggest that the diagnostic capabilities of pmTCD and TEE for detecting PFO are comparable and correspond to the anatomical findings determined during cardiac catheterization ($P = .69$ and .45, respectively). During 6-month postclosure evaluation (mean = 185 days), 66% of the patients demonstrated successful closure without significant RLS (ie, grades 0, I, or II), and 34% were found to have incomplete closure with significant RLS (ie, grades III, IV, or V). *Conclusions*. pmTCD provides greater sensitivity to contrast bubble emboli than does sgTCD. Among candidates for transcatheter closure, pmTCD provides an improved noninvasive method for diagnosing PFO and evaluating transcatheter closure.

Key words: Power m-mode transcranial Doppler, patent foramen ovale, transcatheter closure, transesophageal echocardiography, transthoracic echocardiography.

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Transthoracic echocardiography (TTE), transesophageal echocardiography (TEE), and single-gate transcranial Doppler (sgTCD) are ultrasound techniques that are commonly used to evaluate and diagnose patent foramen ovale (PFO). TEE is currently considered the gold standard for PFO diagnosis; however, it is poorly tolerated by patients and requires deep sedation, which limits the patient's ability to perform a Valsalva maneuver. sgTCD has proven to be a reliable technique for diagnosing PFO.[1-9] While PFO diagnosis and treatment is facilitated by TCD's less invasive technology, sgTCD and TEE are limited by a grading system that uses 3 categories to rate the degree of right-to-left shunt (RLS). In patients with ischemic or cryptogenic stroke, the need exists to further quantify RLS.[10] The ability of power m-mode TCD (pmTCD) to detect and display emboli in 33 contiguous gates[11] suggested its use for greater sensitivity to injected contrast bubbles and quantification of PFO. The purpose of this study was to describe and validate an expanded grading scale[12] for quantifying RLS of PFO using a reference standard of PFO probing during cardiac catheterization and to explore its usefulness in assessing residual RLS. Specific attention is given to differentiating minimal RLS from significant RLS that is more likely to be the source of paradoxical embolism and is amendable

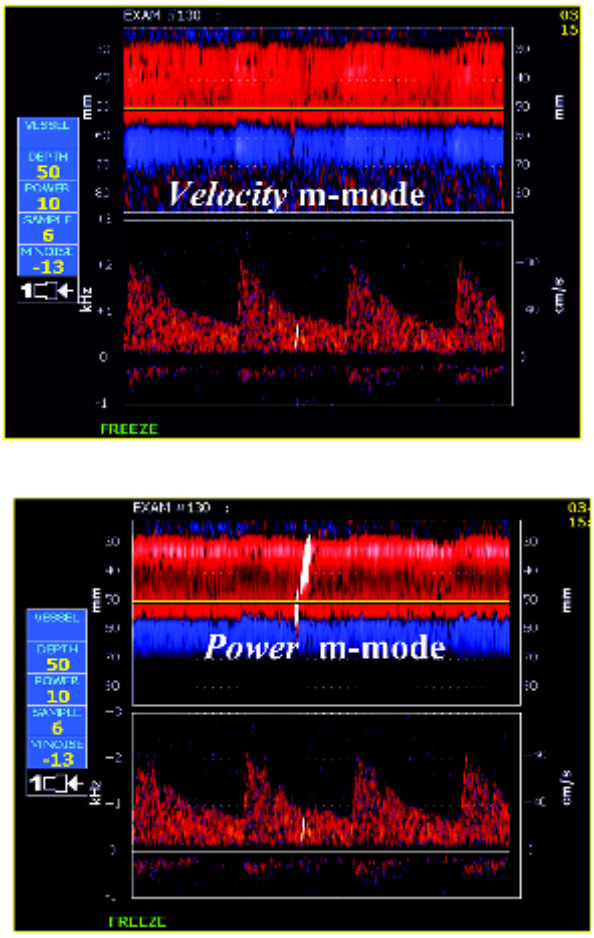

Fig 1. Simultaneous recording of the Doppler velocity m-mode and Doppler power m-mode with the corresponding single-gate transcranial Doppler spectrogram. In both the upper and lower panels, the single-gate spectrogram demonstrates a microembolic signal. The embolus is not seen in the velocity m-mode (upper panel) because it is moving with the same velocity as the blood. The embolus is clearly represented in the power m-mode (lower panel) as a sloping embolic track. Please see the text for further explanation.

to transcatheter closure using an implantable septal closure device. The opportunity to conduct a simultaneous comparison of pmTCD and echocardiography to diagnose PFO arose with the advent of transcatheter closure techniques using a new reference standard available at the time of closure.

Materials and Methods

Instrumentation

Power m-mode TCD is a new technology[11] for displaying the power in addition to the usual velocity/frequency of the Doppler signal over selectable depth ranges along the transducer beam (Fig 1). The present study used the TCD 100M digital 2-MHz Doppler platform (Spencer Technologies, Seattle, WA) with 33 gates placed at 2-mm intervals along the ultrasound beam with any gate depth selectable for spectral analysis. The insonation method for this equipment has been described.[13] The ultrasound beam included the middle cerebral artery (MCA), the anterior cerebral artery (ACA), and their immediate branches. Bilateral monitoring was performed with each probe held in place over a temporal bone by the Marc 600 head frame (Spencer Technologies, Seattle, WA). The MCA gate was selected for each spectrogram. A computer hard disk provided continuous recording that was replayed for counting bubble embolic signals.

Embolic Criteria

The standard for microembolic signals (MESs) on the sgTCD has been previously defined.[14] However, pmTCD produces unique signatures of emboli, appearing as brightly colored embolic tracks (ETs) as they pass through the insonated arteries.[11] When an embolus moves toward the transducer, a bright red upward-sloping ET is produced. In contrast, when an embolus moves away from the transducer, a bright blue downward-sloping ET is produced (Fig 2). The sloping feature of the ET is prima facie evidence of an embolus (ie, a bubble or particle) carried by the blood through a vessel within the ultrasound beam. The slope shows the embolus velocity as a change in depth over time. If the single gate is placed in any of the colored bands, ETs also appear on the spectrogram as MESs (Fig 2). All ETs were counted in the bilaterally insonated arteries from a depth of 40 mm to 75 mm. Because the beams overlap at the midline at a depth of 75 mm, ETs were not counted at depths beyond 75 mm.

To compare the sensitivities of pmTCD and sgTCD to bubble emboli, all phases of transcatheter closures were monitored in 27 consecutive patients and recorded on the hard disk. Upon replay, all ETs and MESs were counted separately throughout all phases of the procedure.

Sample

A single-group, descriptive study was conducted to evaluate the accuracy of pmTCD for diagnosing PFO and assessing transcatheter closure residual. Between November 2001 and April 2003, 370 patients were referred to the vascular laboratory for evaluation of PFO and underwent pmTCD examination. Nonprobability consecutive sampling technique was used to enroll 100 patients who were deemed eligible for transcatheter closure based on cardiology selection and who underwent cardiac catheterization for device implantation. Written informed patient consent was obtained. All 100 patients had a positive test for RLS by 1 or more ultrasound modalities. Indications for closure included prevention of re-

current ischemic stroke or transient ischemic attack related to presumed paradoxical embolism (n = 92), active recurrent migraine as part of a prospective research study approved by the institutional review board of the participating institution (n = 7), and pulmonary embolism (n = 1). Patients were excluded if they had any cause other than PFO for the cerebrovascular event, including carotid artery atherosclerosis (> 50% stenosis by ultrasound or angiogram), atrial fibrillation, left ventricular aneurysm, hypercoagulable state, or mitral valve abnormality (by electrocardiogram, TTE, or TEE). The sample ranged in age from 18 to 86 years with a median of 52 years and a male:female ratio of 0.56. All examinations were performed in response to referrals by attending physicians, and all patients signed informed consent to use their data in scientific publications.

Intraoperatively, intracardiac echocardiography was used to assess septal morphology, and a balloon-sizing method was used to select the device size. Using a percutaneous approach, a CardioSEAL (NMT, Watertown, MA) septal occluder device was successfully implanted in 94 patients. Diagnostic examinations were performed prior to and serially following device implantation to evaluate residual RLS and completeness of closure. Bilateral temporal bone ultrasound windows were identified in all patients except for 2 women (2%) who were 70 and 79 years of age. In both patients, unilateral TCD monitoring was performed and the ET counts were doubled for grading purposes.

Testing Procedure

TCD diagnostic testing procedures were performed on all patients in the recumbent position with a pillow under their heads. A minimum of 2 contrast bolus injections consisting of 9 mL of saline, 1 mL of air, and a small amount of the patient's blood were agitated and administered into an arm vein. The first injection was performed during normal respiration; the second injection was preformed immediately prior to a calibrated Valsalva for the purpose of ensuring an adequate and reproducible strain. For the calibrated Valsalva maneuver, patients were instructed to blow into a mouthpiece that was attached to a manometer until 40 mm Hg of pressure was achieved and maintained for 10 seconds. If no ETs were detected, additional injections were made while the patient performed a noncalibrated Valsalva.

To confirm intravenous injection of the contrast bolus, the right ventricular outflow track was monitored behind the left midsternum border with a 2- or 5-MHz continuous wave Doppler surface probe. The arrival of the contrast was signaled, usually within 3 to 12 heartbeats, by a loud noise that persisted for several minutes as bubbles

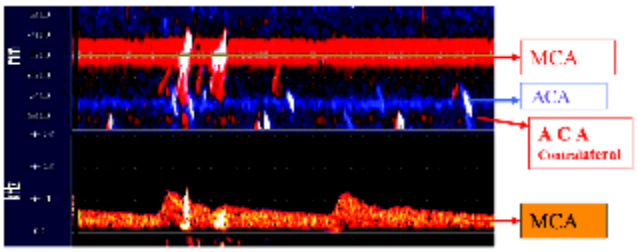

Fig 2. Embolic tracks (ETs) of bubbles on the power m-mode (upper panel) and microembolic signals (MESs) on the single-gate spectrogram of the middle cerebral artery (MCA; lower panel). The boxes to the right of the display, from the top downward, indicate 2 ETs in the MCA red band, 4 ETs in the ipsilateral anterior cerebral artery (ACA) blue band, 4 ETs in the contralateral ACA red band, and 2 MESs in the spectrogram also displayed as ETs in the MCA band. Note the single-gate Doppler detects only those bubbles passing the MCA while the power mode detects both ETs in the MCA and ETs in the ACAs. Time base = 2 seconds, stretched to accentuate the slopes of the ET.

arrived from the periphery. The arm-to-right-ventricle transit time, determined on the first injection during the resting phase of the study, was used to instruct the patient when to begin the Valsalva for subsequent injections.

To grade RLS, a 6-level logarithmic scale was used for both resting and Valsalva injections as follows: grade 0 = 0 ETs, grade I = 1-10 ETs, grade II = 11-30 ETs, grade III = 31-100 ETs, grade IV = 101-300 ETs, and grade V > 300 ETs. The numbers of ETs represented tracers of the conductance of RLS flow to the anterior circulation of the brain. The conductance takes into account many factors including the RLS flow distribution to the anterior circulation of the brain, the size of the foramen while open, and the right-to-left pressure gradient when the foramen is open. All ETs and MESs were counted visually.

No attempt was made to differentiate pulmonary shunts from cardiac shunts with pmTCD. We assumed that ET from a pulmonary capillary shunt would fall within grade I and that grades I and II may not be of sufficient conductance to justify closure. If a pulmonary arteriovenous malformation (AVM) was present, we assumed it could be identified and located at catheterization. Initially, patients with any positive grade of conductance were selected for closure. Later, it was realized that crossing the septum with the guidewire in patients with grade I or II conductance was technically difficult. Thereafter, only patients who had grades higher than grade II were selected for catheterization.

The accuracy of pmTCD, TEE, and TTE for PFO diagnosis was determined retrospectively by comparing the test results to the reference standard that was defined

as the ability of a 3-member cardiology team (W.A.G., J.V.O., and M.R.) to pass a guidewire across the atrial septum. The same team catheterized all patients.

Statistical Methods

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) for Microsoft Windows Release 9.0 (SPSS Inc, Chicago, IL). Pearson correlation coefficient and the κ coefficient were calculated for testing interrater reliability for categorizing RLS conductance using a 6-point scale. To compare the diagnostic capabilities of pmTCD to that of other ultrasound modalities used to diagnose PFO (ie, TTE, TEE), sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy were calculated according to the procedures defined by Swets.[15] McNemar change tests were used to determine if there were significant differences in the diagnosis of PFO using pmTCD, TTE, and TEE as compared to the criterion reference standard. The Kruskal-Wallis 1-way analysis of variance (ANOVA) by ranks was applied to the pmTCD grading scales to test the hypothesis that the median ETs measured on Valsalva were significantly different among the categories in the grading scale to signify genuine population differences. To compare the sensitivity of pmTCD and sgTCD, paired-sample *t* tests were performed to determine if there was a significant difference in mean contrast microemboli on simultaneous measurements. The level of significance was set at .05 for all tests.

Results

Interrater reliability was evaluated among 4 technologists who independently assessed 17 randomly selected pmTCD examinations and quantified ETs during calibrated Valsalva. Agreement among the 4 raters was measured using the Pearson correlation coefficient and ranged between .995 and 1.00 ($P < .01$, 2-tailed). Results demonstrated there was significant agreement among the technologists when quantifying ETs. After quantifying ETs, the 4 raters categorized the degree of RLS using a 0 to 5 grading scale. To assess the overall consensus among the raters, in terms of rating the RLS conductance grade, the κ coefficient of agreement *K* was computed and statistically tested. Results demonstrated that the raters exhibited significant agreement in categorizing RLS using the 6-level grading scale (.82, $P < .01$, 2-tailed).

Table 1 summarizes the frequency distribution of RLS conductance grades among 100 consecutive patients who underwent pmTCD evaluation for detection of RLS and were subsequently referred to undergo transcatheter closure of PFO. For each conductance grade, mean, standard deviation, and median are reported for ETs measured during normal respiration and during calibrated Valsalva. The findings illustrate that in comparison to normal respiration, mean ET and RLS conductance grade is significantly higher during Valsalva (116 ± 127 vs 258 ± 86, paired t test $= 11.8$, $df = 98$, $P < .001$). Kruskal-Wallis ANOVA test was performed. Results indicated that the median ET on Valsalva was significantly different among the 6 categories (grades 0-V) and supported the validity of the RLS conductance grading system used in this study ($P < .001$). Because of the small number of patients in grades I to III, additional research is needed to validate the proposed grading system.

During cardiac catheterization and PFO probing, it appeared that false-positive pmTCD results were less likely to occur in patients who had a higher grade RLS during Valsalva. Two (50%) patients with Valsalva grade I to II conductance and 2 (11%) patients with grade III to IV conductance had inaccessible interatrial openings. Of the 76 patients who were categorized as having a Valsalva conductance of grade V, only 2 (3%) did not have an interatrial opening that was accessible via catheterization. To evaluate the specificity of the grading system in relation to the catheterization reference standard, binomial tests were computed using SPSS exact tests. Specifically, binomial tests were computed to determine if the proportion of patients with Valsalva conductance of grade III to IV who had an accessible interatrial opening (0.89) was different than the proportion of patients with Valsalva grade I to II who had an accessible interatrial opening (0.50). Results demonstrated that the interatrial opening was significantly more accessible during catheterization in patients with grade III to IV compared to those with grade I to II ($P = .001$, 2-tailed). Thus, the probability of probing a PFO during catheterization increases with higher Valsalva conductance grades.

The accuracy of pmTCD ($n = 100$), TTE ($n = 30$), and TEE ($n = 56$) in detecting a PFO was evaluated by comparing the results to the criterion reference standard (ie, PFO probing). Sensitivity, specificity, and overall accuracy for each ultrasound modality are summarized in Table 2. In post hoc analysis, pmTCD was considered negative when conductance grades were less than III. The 2-level categorical scale was necessary to compare pmTCD with TEE and TTE, which have a lower number of categories and had both false positives and false negatives. This strategy provided sufficient numbers of negative tests for statistical analysis. McNemar change tests were performed to determine the probability that PFO diagnosis based on pmTCD, TTE, or TEE findings would change following interatrial assessment and PFO probing during cardiac catheterization (ie, criterion reference

Table 1. Frequency Distribution of Right-to-Left Shunt Conductance Grades Among 100 Patients Who Underwent Power M-Mode Transcranial Doppler Evaluation to Detect Patent Foramen Ovale

	R-L Shunt Grade						
	0	I	II	III	IV	V	Total
Resting	14	11	20	15	14	26	100
Resting, mean ± SD		0	5.3 ± 8.4	8 ± 8.7	9.6 ± 11.9	149 ± 127	116 ± 126
Valsalva	0	1	3	6	13	76	99*
Valsalva, mean ± SD		10	22 ± 4.4	66 ± 23	169 ± 51.4	301 ± 0	258 ± 86.1

Distribution of conductance grades among 100 patients. Resting = number of patients in each conductance grade with normal respiration; resting, mean ± SD = mean and standard deviation of bubble embolic tracks in each grade with normal respiration; Valsalva = number of patients in each conductance grade with Valsalva strain; Valsalva, mean ± SD = mean and standard deviation of embolic tracks in each grade with a Valsalva strain. For grade V, embolic tracks were entered as 301 since most were uncountable.
*One patient with resting grade IV could not perform a Valsalva but a patent foramen ovale was found.

Table 2. Patent Foramen Ovale Diagnosis Contingency Tables of 3 Ultrasound Modalities

	Criterion Reference Standard						
	Positive	Negative	PPV, %	NPV, %	Sensitivity, %	Specificity, %	Accuracy, %
A*							
Positive	18	1	95	0.09	64	50	63
Negative	10	1					
B†							
Positive	48	2	96	17	91	33	88
Negative	5	1					
C‡							
Positive	92	4	96	50	98	33	94
Negative	2	2					

PPV = positive predictive value, NPV = negative predictive value. Contingency Table A represents the results of 30 transthoracic echocardiography examinations prior to closure. Table B represents the 56 transesophageal echocardiography examinations. Table C represents all 100 power m-mode transcranial Doppler examinations considering only grades > II as positive for patent foramen ovale. The McNemar change test *P* values indicate the probability of changing the diagnosis after the anatomical findings at catheterization are known.
*Transthoracic echocardiography; N = 30, $P = .012$.
†Transesophageal echocardiography; N = 56, $P = .45$.
‡Power m-mode transcranial Doppler; N = 100, Grade > II, $P = .69$.

standard). The McNemar is a nonparametric test that assesses the significance of the difference between 2 dependent samples on paired observations when the variable of interest is a dichotomy (ie, presence of PFO). For tests involving cell counts less than the minimum expected frequency, a binomial distribution was used. pmTCD results were categorized as either positive or negative according to the degree of RLS. Grades I and II were coded as negative for PFO detection, and grades III to V were coded positive. Results indicated that there was a high probability that the precardiac catheterization PFO diagnosis based on TTE findings would change following atrial septal evaluation ($P = .012$). In comparison, PFO diagnosis as determined by pmTCD or TEE was unlikely to change following atrial septal evaluation ($P = .69$ and .45, respectively).

Of the 100 patients who were evaluated for PFO using pmTCD, 6 false-positive results were obtained based on a positive conductance grade. Table 3 summarizes the diagnostic data for each of the 6 patients having false-positive pmTCD results including pulmonary angiography findings. During catheterization, if the septum could not be crossed within 30 to 45 minutes' effort, the pulmonary artery was repeatedly injected with 10 mL of contrast saline, and angiography was performed if high pulmonary conductance was found. Using this technique, 2 of the 6 patients (M.L. and S.K.) were determined to have a pulmonary AVM as evidenced by more than 300 ETs on pmTCD. In both patients, the AVM was located in the left upper lobe. Subsequently, referrals were made for surgical closure. In 2 of the remaining 4 patients who had a false-positive pmTCD result (D.F. and K.M.), the minute number of embolic tracks produced from the pulmonary artery injections suggests that a small septal or pulmonary shunt may have accounted for the pmTCD findings of grade I and II conductance. Last, for the 2 patients who

Table 3. Six Power M-Mode Transcranial Doppler False Positives for the Presence of Patent Foramen Ovale

	Diagnostic ETs and Grade				
	Resting		Valsalva		Pulmonary Artery
Patient	ETs	Grade	ETs	Grade	Injection ET
D.F.	0	0	10	I	2
K.M.	0	0	17	II	1
H.C.	0	III	76	III	0
S.S.	0	0	130	IV	0
M.L.	117	IV	341	V	> 300*
S.K.	> 300	V	> 300	V	> 300*

Precatheterization power m-mode diagnostic ETs (embolic tracks) and ETs during catheterization and ETs from direct saline contrast injection of the pulmonary artery. Please see the text for comments on the other patients.
*Pulmonary angiography confirmed an arteriovenous malformation.

had false-positive pmTCD results (H.C., grade III; S.S., grade IV), an interatrial septal opening was likely, although it was either too small to probe with the guidewire or it was a fenestration that was not easily accessible.

Finally, to compare the sensitivities of pmTCD and sgTCD for detecting the presence of contrast microemboli, 27 consecutive patients were continuously monitored during the implantation procedure with simultaneous pmTCD and sgTCD. Recorded data were visually inspected to quantify ET and MES counts. Results demonstrated that there were significantly more microemboli detectable on pmTCD (322 ± 166; 95% CI, 388-251) than sgTCD (186 ± 109; 95% CI, 229-143; paired t test = 10.27, $df = 26$, $P < .001$).

Follow-up of Closures

The closure device was successfully deployed in 94 of the 100 patients who underwent cardiac catheterization. Eighty-one (86%) of these 94 patients returned for pmTCD evaluation following PFO closure. The preclosure distribution of Valsalva conductance grades were 0 with grade I, 1 with grade II, 4 with grade III, 13 with grade IV, and 63 with grade V. Median time of follow-up was 185 days and ranged from 21 days to 625 days. In follow-up, 19 (23%) patients demonstrated complete closure (grade 0). Incomplete closure was detected in 62 (77%) patients, which includes 22 (27%) with grade I, 13 (16%) with grade II, 9 (11%) with grade III, 7 (9%) with grade IV, and 11 (14%) with grade V.

Discussion

The major advantages of pmTCD over sgTCD in the diagnosis of PFO are as follows: (1) ETs are displayed objectively, providing a nonambiguous representation of bubbles that pass through the intracranial arteries[11]; and (2) by counting bubble emboli in all the arteries along the ultrasound beam, using bilateral probes, a high sensitivity is realized. In 86% of patients having positive TCD findings, ETs were appreciated in the ACA territory. Although the blue color band of the ACA did not always appear in the power m-mode display, ETs were detected in 65% of these patients. This is no doubt due to the high ultrasound reflection of bubbles, exceeding 24 dB above the background blood flow signal.

A new criterion reference standard for PFO diagnosis was used in the present study to compare diagnostic modalities. The findings suggest that pmTCD is a sensitive and accurate test to detect PFO and that it compares favorably with the anatomical findings on catheterization. However, the findings of this study cannot be generalized beyond the population referred for PFO closure. Because the sample consisted only of patients who had a positive result on diagnostic evaluation and were therefore referred for PFO closure, the measures of sensitivity for all 3 modalities may be erroneously high. For the same reason, the specificity and negative predictive values may be undervalued. A future study should consider testing patients undergoing cardiac catheterization for reasons other than PFO closure. It is clear that all 3 ultrasound modalities have a high positive predictive value so that patients taken to closure on the basis of a positive ultrasound report for a PFO is reasonable.

Several findings in this study suggest pmTCD is a valid alternative to TEE in diagnosing PFO. These include its high sensitivity and the high significance of conductance grades greater than II in predicting whether a PFO is present and can be found by catheterization. A low conductance grade of I or II is probably not clinically important. The pulmonary artery injection studies in patients with false-positive pmTCD results suggest that some patients may have an interatrial communication that is too small or inaccessible to close with existing percutaneous techniques.

Patients with the highest conductance grades may be more likely to benefit from PFO transcatheter closure, but further experience and validation is necessary to determine the prognostic value of the expanded conductance grading scale. Patients who have clinical indications for PFO closure and have a positive pmTCD result of grade III or higher may be sent directly to the catheterization laboratory, where TEE or intracardiac echocardiography can be performed prior to closure. If a pulmonary AVM is suspected, diagnosis can be confirmed with pulmonary artery contrast and localized with angiography.

The use of a 1-minute counting period after each injection may increase the sensitivity of pmTCD and may lead to some false-positive results; however, the logarithmic grading scale confines pulmonary transcapillary bubbles to grade I conductance. The 1-minute counting strategy was chosen because all bolus injections in an arm vein inevitably spread out in the venous return, producing many late-arriving bubbles in the heart. This delay of bubbles occurred regardless of speed of injection, and the delay of bubbles could clearly be heard with the precordial Doppler probe for more than 5 minutes following injections.

The use of a Doppler probe over the left sternum border is an innovation for TCD protocols to prove contrast injections are intravenous and not in the tissues and to compensate for the variable arm-to-heart time of the bubble bolus. This technique emulates that of echocardiography, when the first arrival of the bubbles in the right atrium signals the time to begin the Valsalva strain. Both techniques ensure the presence of a large number of bubbles in the right atrium during the Valsalva strain and take into account patient-to-patient differences in arm-to-heart circulation time.

It is noteworthy that all 5 TEE false-negative patients were graded positive at IV or V with a calibrated pmTCD Valsalva test. TEE false negatives may be due to the difficulty patients have under sedation in performing an adequate Valsalva maneuver. Because more than 10% of the cardiac output is distributed to the internal carotid arteries, at least 10 times more bubbles should be seen passing through the left side of the heart. Echocardiography may not be suitable for an expanded grading scale because far fewer bubbles can be counted accurately because of recirculation within the heart chambers. TEE is indicated for detecting left ventricular aneurysm and thrombus, but these conditions can usually be diagnosed from the patient's history and TTE. The presence of atrial fibrillation can be diagnosed by palpation or by electrocardiogram. If these cardiac conditions are present, cerebral symptoms cannot be considered cryptogenic, and there may be no need for a PFO test in such patients. In case of recurrent strokes at follow-up, a TEE may be necessary to ensure that dislocation of the device or a thrombus is not the cause for the recurrent stroke. The presence of a coexisting atrial septal aneurysm with a PFO, although highly associated with cryptogenic ischemic stroke and its recurrence,[16] has not yet been shown to be a necessary determinate in the decision for closure of a PFO.

Following transcatheter closure of PFO residual RLS serial evaluations using pmTCD has revealed that closure of PFO is often incomplete, and improvements in device deployment and device refinement are warranted. The use of TEE for follow-up not only is difficult for patient compliance but also may underestimate the completeness of closure. Power m-mode TCD is a more reasonable instrument than TEE to determine if recurrent strokes are associated with incomplete closure.

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