Quantification of Ultrasound Emboli Signals in Patients With Cardiac and Carotid Disease

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Background and Purpose: The use of Doppler ultrasound to detect arterial emboli has major implications for the classification and treatment of stroke. Experimental studies indicate that embolic materials produce different ultrasound signals, depending on their acoustic properties. To examine the possibility of characterizing emboli of different sources in the clinical setting, we compared the emboli signals of patients with cardiac embolic sources with those of patients with signals of carotid embolic sources.

Methods: Transcranial Doppler monitoring (30 minutes per patient) of the middle cerebral arteries was performed in 80 patients with prosthetic cardiac valves and 20 patients with internal carotid artery stenosis. The signal power of emboli was calculated in relation to the background Doppler signal.

Results: In patients who were embolizing from prosthetic heart valves, the frequency of embolus signals was greater than in patients with carotid stenosis who were embolizing (mean±SEM: 58.2±11 versus 8.2±3 signals per hour; P<.001, two-sample t test), and total signal power and duration also were higher (power, 2231±63 versus 455±109 power units; duration, 55.9±0.8 versus 29.9±1.4 milliseconds; both P<.001). The majority of emboli signals were seen during cardiac systole, especially in patients with carotid stenosis (89% in the first half of the cardiac cycle versus 72% in prosthetic valve patients). In 19 patients with prosthetic valves, embolus signals were also recorded from the anterior cerebral artery; the signal count was not significantly different from the middle cerebral artery (43.2±12.5 versus 64.3±16 per hour), but anterior cerebral artery signals were of higher power (3306±148 versus 2441±109 power units, P<.001).

Conclusions: There is promise of being able to distinguish emboli on the basis of power measurements. Emboli of different sources (eg, carotid and cardiac) appear to have different ultrasonic characteristics, which are likely to be based on composition and size. (Stroke. 1993;24:1922-1924.)

KEY WORDS • cerebrovascular disorders • embolism • ultrasonics

Doppler ultrasound detection of air emboli, initially reported in the 1960s,1,2 has received renewed attention after the development of the transcranial Doppler technique. Cardiac and carotid source emboli of gaseous and/or formed element origin have been recorded during cardiopulmonary bypass3,4 and carotid endarterectomy5 in patients with prosthetic heart valves;6 recent stroke,7 and carotid stenosis.8 Experimental observations indicate that various types of embolic material produce distinctive acoustic patterns on ultrasound testing.9,10 To determine whether different sources of emboli could be distinguished in a clinical setting, we examined the Doppler emboli signals in patients with prosthetic cardiac valves and with internal carotid artery stenosis.

Patients and Methods

Two patient groups were studied: 80 patients with prosthetic cardiac valves and 20 patients with internal carotid artery stenosis (defined by duplex ultrasound [Acuson 128, Mountain View, Calif], arteriography, or both). Carotid ultrasound was also performed in all patients with prosthetic heart valves. A ≥60% diameter reduction of the internal carotid diameter was defined as carotid stenosis. Transthoracic echocardiography was performed in 12 of the 20 patients with carotid stenosis. Anticoagulant control was measured on the day of Doppler study in all patients receiving warfarin by the prothrombin time using the international normalized ratio (INR).

A 30-minute transcranial Doppler recording was made from right and left middle cerebral arteries (MCAs) using the TC-2000 with 2-MHz probe and 128 fast Fourier transformation (EME, Uberlingen, Germany). Doppler gain was set to give a minimal background waveform signal; the screen sweep speed was 6 seconds, and this and all other machine settings were constant throughout the study. Emboli signals were recognized by their characteristic high-intensity visible and audible signal and were annotated during the recording for later off-line analysis. The position of each embolus signal in relation to the Doppler frequency spectral outline and within the cardiac cycle was noted. Embolus signal power was calculated by analysis of digital spectral information as described by Muller et al11; each Fourier spectrum is described by a series of amplitude components, A(i). As a measure of total reflected energy, the sum of the squared amplitude components is calculated and divided by the resolution to give an average power per spectral component, expressed as power units: ie, mean power = ΣA²(i)/resolution. The duration of the embolus signal was measured in spectral lines and

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converted to milliseconds; the average signal power of each embolus was defined as power units per millisecond. In a subset of 20 patients with prosthetic heart valves, a supplementary 30-minute transcranial Doppler recording was made from the anterior cerebral arteries (ACAs).

Embolus signal counts and characteristics were compared between the two patient groups by two-sample t test. Comparison of embolus power and duration during different portions of the cardiac cycle was performed by one-way analysis of variance.

**Results**

Eighty patients with mechanical prosthetic cardiac valves were studied (48 women and 32 men; median age, 60 years; range, 50 to 76 years). Of these, 35 were studied on the fifth postoperative day after prosthetic cardiac valve implantation, and 45 patients were studied 0.25 to 19 years (median, 5 years) after prosthetic valve insertion. None of these patients had hemodynamically significant internal carotid artery stenosis (>60%) on Doppler testing. All prosthetic valve patients were taking warfarin at the time of study; 6 were also taking aspirin. Anticoagulant control was at an INR of between 1.8 and 2.5 (mean, 2.2) in 22 cases, between 2.6 and 4.5 (mean, 3.4) in 45 cases, and between 4.6 and 6.2 (mean, 5.3) in 13 cases on the day of Doppler study. Heart rhythm was sinus or paced in 39 cases and atrial fibrillation with controlled ventricular response in 41 cases. Of the 80 patients, 54 had Bjork-Shiley valves; 11, Medtronic-Hall; and 17, Carpentier-Edwards (2 patients had dual valves of different types). Valves were placed in the aortic position in 32 cases, mitral in 37 cases, and dual in 11 cases.

Of the 20 patients (14 men and 6 women; age range, 30 to 79 years; median age, 60 years) with internal carotid artery stenosis, 8 had previous stroke, 8 had transient ischemic attacks, and 4 had amaurosis fugax. There was bilateral stenosis in 3 cases. There was no echocardiographic evidence of valvular disease or major potential embolic source in the 12 patients who underwent this testing. Twelve patients were taking aspirin and 1 was taking warfarin at the time of Doppler study.

Embolus signals were recorded in 72 of the 80 patients with prosthetic cardiac valves (90%) and in all of the 20 patients with carotid stenosis. The embolus signal count in patients with prosthetic valves was significantly higher than in patients with carotid stenosis (58.2±11 versus 8.2±3 signals per hour; P<.001, Mann-Whitney). The proportion of emboli signals visible above or within and above the frequency envelope was similar in the two patient groups (6.5% and 5%, respectively).

A greater proportion of emboli signals was recorded during the latter half (diastolic phase) of the cardiac cycle in patients with prosthetic cardiac valves compared with patients with carotid stenosis (28% and 11%; respectively) (Figure).

In patients with prosthetic heart valves, the embolus signal count appeared higher in the MCA than in the ACA (64.3±16 versus 43.2±12.5), but the difference was not significant.

Embolus signal power was significantly higher in patients with prosthetic cardiac valves than in patients with carotid artery disease (total power, 2331±63 versus 455±109 power units; P<.001). With a power of 500 power units, the sensitivity was 85% and the specificity was 83% in distinguishing cardiac from carotid emboli.

**Top, Bar graph of position of emboli signals in the cardiac cycle. The proportion of signals recorded during systole was higher in patients with carotid stenosis than in patients with prosthetic valves. Middle, Bar graph of embolus signal duration. The duration of embolus signals was greater for diastolic than for systolic signals in patients with prosthetic valves and was greater overall in prosthetic valve cases than in patients with carotid stenosis. No significant difference was detected for carotid stenosis cases. Bottom, Bar graph of embolus signal power. Total embolus signal power was greater in patients with prosthetic valves than in those with carotid stenosis. In prosthetic valve cases, diastolic signal power was greater than systolic signal power.**
significantly higher in patients with prosthetic valves (40.7±0.9 versus 11.9±1.9 power units per millisecond, \( P<.001 \)). Signal power was also significantly higher for embolus signals that were visible above or within and above the velocity envelope than for remaining signals (total power, 4001±363 versus 2152±77 power units; \( P<.001 \)).

In patients with prosthetic heart valves, signal power and duration were greater for diastolic than for systolic signals (Figure). No significant differences in these variables were observed for patients with carotid stenosis (Figure).

Total signal power was greater in the ACA than in the MCA (3306±148 versus 2441±109 power units, \( P<.001 \)); this also was true for the average signal power (50.4±2.2 versus 48.1±1.5 power units, \( P<.001 \)) despite a longer duration of ACA signals compared with MCA signals (66.7±1.2 versus 59.0±1.4 milliseconds, \( P=.001 \)).

**Discussion**

The technique of detecting emboli using Doppler ultrasound has major potential for improving the clinical management of patients with cardiac and stroke disease. Intraoperative detection of gas emboli has been used to improve filtration devices for cardiopulmonary bypass, leading to improved neuropsychological outcome.3,12 The clinical significance of embolic signals in other settings remains to be established. Our results suggest that cardiac and carotid source emboli can be differentiated on the basis of ultrasound signal characteristics and that emboli of cardiac origin are larger and/or have different constituents than carotid emboli.9,10 The increased distance of the embolic source from the brain and the greater potential for blood admixture may explain the higher proportion of diastolic signals in cardiac than in carotid stenosis cases. The finding of higher signal power in diastole and in ACA recordings may be due to a lower background signal at these points. Alternatively, the transit time of a diastolic embolus may be longer than a systolic embolus due to the lower velocity, and the sample volume for the ACA may have been greater than that for the MCA, resulting in increased sensitivity. Experimental pulsatile flow studies may be useful to further evaluate these observations.

The presence in individual patients of more than one potential source of embolism has been a major limitation in the clinical diagnosis of embolic stroke,13 although simultaneous MCA and common carotid or peripheral artery Doppler studies may be useful.14 Patients with heart valve disease of predominantly rheumatic origin are useful in this regard as they have less atherosclerosis than other groups, as confirmed by the absence of significant carotid disease in our study population. However, it remains to be determined whether emboli of prosthetic valve origin have characteristics similar to those of emboli from other cardiac sources. Furthermore, in our study, we have not excluded alternative cardiac or aortic sources of emboli because echocardiography was not routinely performed and the transesophageal approach was not used. Even if the distinction of cardiac and carotid emboli holds true for other groups, the high prevalence of subclinical embolization8-10 will make identification of the source of a recent clinical event difficult, especially in patients with widespread atherosclerotic disease.

Our calculation of signal power allowed easier distinction between emboli signals and the background waveform signal than visual or computer-assisted analysis of the intensity amplitude of the spectral waveform, as used previously.8-10 We deliberately avoided defining criteria of emboli signals on the basis of duration or signal intensity because this could bias the characterization of emboli of different sources. For example, applying a maximum signal duration of 70 milliseconds would have excluded 28% of signals in our patients with prosthetic cardiac valves but only 3% of signals in patients with carotid stenosis.

The differences that we have observed in embolus signal characteristics arising from different embolic sources and the experimental observations that indicate that this is due to different constituents and/or sizes of embolic material9,10 suggest that quantitation studies should be extended to other patient groups.

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