Asymptomatic Embolization Detected by Doppler Ultrasound Predicts Stroke Risk in Symptomatic Carotid Artery Stenosis

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Background and Purpose—Asymptomatic cerebral emboli can be detected using transcranial Doppler ultrasound (TCD). These embolic signals have potential as a marker of stroke risk and as a surrogate marker to evaluate antiplatelet agents. Small studies have demonstrated that they predict the combined endpoint of stroke and transient ischemic attack (TIA), but no studies have shown that they predict the more important endpoint of stroke alone.

Methods—TCD was used to record for 1 hour from the ipsilateral middle cerebral artery in 200 patients with >50% symptomatic carotid stenosis. The Doppler audio signal was recorded for later analysis blinded to clinical details. Subjects were followed-up prospectively until surgical intervention, stroke, or study end at 90 days.

Results—Embolic signals (ES) were detected in 89 (44.5%). During follow-up, 31 subjects experienced recurrent ipsilateral ischemic events: 7 strokes and 24 TIAs. The presence of ES predicted stroke alone ($P<0.001$) and the combined endpoint of stroke and TIA ($P<0.0001$). This remained significant, with an odds ratio of 4.67 (95% CI, 1.99 to 11.01; $P<0.0001$) after Cox regression to control for age, sex, smoking, hypertension, time from last symptoms, and degree of stenosis. The absence of ES identified a group at low risk for stroke alone and stroke and TIA during follow-up: 0% and 7.5%, respectively, versus 3.5% and 15.5% in all 200 subjects.

Conclusions—Asymptomatic embolization in carotid stenosis predicts short-term ipsilateral stroke risk. This supports use of the technique to identify patients at high-risk for recurrent stroke for therapeutic interventions and as a surrogate marker to evaluate antithrombotic medication. (Stroke. 2005;36:000-000.)

Key Words: carotid arteries ▪ embolism ▪ risk factors ▪ stroke ▪ ultrasonography

Improved methods of identifying patients at high risk for recurrent embolic events from large-artery atherosclerotic disease are required. This would allow more effective targeting of therapy and improve risk–benefit therapeutic ratios. One such situation is carotid stenosis. Carotid endarterectomy reduces stroke risk in recently symptomatic patients with >70% stenosis.1,2 In moderate symptomatic stenosis, the stroke risk is lower and operating has only moderate benefit, although certain high-risk subgroups may benefit more.3,4 Similarly, operating on an unselected group of patients with tight asymptomatic carotid stenosis has modest benefit.5,6

A clear implication of these results is that better methods are required to identify those patients with carotid stenosis at high risk for stroke, particularly among those with tight asymptomatic carotid stenosis and moderate symptomatic carotid stenosis.7 A number of markers of increased risk have been suggested, including degree of stenosis, plaque ulceration and morphology, brain infarction, and impaired intracerebral hemodynamics.7 Although these may allow some risk stratification, most have not been shown to be reliable independent markers of high risk. In patients with carotid stenosis, stroke is usually caused by embolism. Furthermore, transient ischemic attack (TIA), which is itself associated with markedly increased risk of subsequent stroke, is also believed to be usually caused by embolization. Therefore, an attractive potential risk marker is the detection of asymptomatic embolization using transcranial Doppler ultrasound (TCD).

Solid cerebral emboli, composed of thrombus and platelet aggregates, can be detected using TCD.8,9 Cross-sectional studies have suggested such embolic signals (ES) are clinically important, being more common in patients with symptomatic stenosis,9,10 recent symptoms,11,12 and plaque ulceration.13–15 A number of relatively small studies16–19 have shown that ES are predictors of combined TIA and stroke risk in symptomatic carotid stenosis, but the risk estimates have wide confidence intervals because of the small sample sizes. Furthermore, no studies have demonstrated prediction of the more important clinical endpoint of stroke alone. Therefore, in a single-center study, we recruited consecutive patients with recently symptomatic carotid stenosis, recorded for ES, and prospectively followed-up all patients to determine...
whether the presence of ES during a single 1-hour recording predicted subsequent short-term stroke risk.

Materials and Methods

Two hundred twenty-six consecutive patients presenting with \( \geq 50\% \) symptomatic carotid stenosis, as determined using duplex ultrasound, and no obvious cardiac embolic source were prospectively recruited. Of these, successful insonation of the ipsilateral middle cerebral artery (MCA) was possible in 200. Symptomatic status was defined as ipsilateral stroke, TIA, or amaurosis fugax within the past 3 months. The first consecutive 54 subjects have been reported previously.\(^1\)\(^6\) There were no differences in demographics between these 54 subjects and the remaining 146 subjects (mean age, 66.1 versus 68.2 \( \pm \) 10.7, \( \text{P} = 0.104 \)).

Three consecutive groups of 54 subjects were recruited. Of these, successful insonation of the ipsilateral middle cerebral artery was possible in 175. Symptomatic status was defined as ipsilateral stroke, TIA, or amaurosis fugax within the past 3 months. The first consecutive 54 subjects have been reported previously.\(^1\)\(^6\) There were no differences in demographics between these 54 subjects and the remaining 146 subjects (mean age, 66.1 versus 68.2 \( \pm \) 10.7, \( \text{P} = 0.104 \)).

TCD recordings were made from the MCA ipsilateral to the stenosis via the transtemporal route. All recordings were made using a commercially available TCD machine (EME Pioneer 4040; EME) with a 2-MHz probe held in position with an external fixation device. Standard settings were used with a sample volume of 5 mm. Median (range) depth of insonation was 52 (46–56) mm. Each patient underwent recording for 1 hour.

The Doppler audio signal was recorded onto digital audio tape. Tapes were analyzed at a later date by an experienced investigator blinded to the patient identity, and all candidate signals were reviewed by a second observer who remained the same throughout the study. At this time, the recorded Doppler signal was replayed into the same TCD machine, at the same sweep speed of 5.1 seconds, and 128-point fast-Fourier transform spectral analysis was performed with an overlap of \( 50\% \). ES were identified by their typical visual appearance on the spectral display and their characteristic sound, according to standard consensus criteria,\(^2\) with the addition of an intensity threshold of \( \geq 7 \text{ dB} \), with intensity measured by a standard method.\(^3\)\(^4\)

All study subjects were prospectively followed-up until stroke, carotid endarterectomy or carotid angioplasty/stenting, death, or study completion at 90 days after recruitment. No patients had treatment delayed in any way for the purposes of study, and the project was approved by the Local Hospital Ethics Committee, and all patients gave signed informed consent. Recurrent stroke was confirmed by CT or MRI. All endpoints were reviewed by an experienced clinician blinded to the results of ES detection.

**Statistical Analysis**

The relationship between ES and subsequent ipsilateral events was determined using Kaplan–Meier analysis. Censor points were ipsilateral TIA or stroke, carotid endarterectomy, carotid angioplasty/stenting, and nonstroke death. Separate analysis was performed for ipsilateral stroke alone, and for the combined endpoint of ipsilateral stroke and TIA. Data were also analyzed using a Cox regression model to allow controlling for other risk factors. This is only valid when there is a sufficient number of endpoints (recurrent events) and therefore was only performed for the combined endpoint of stroke and TIA, and not for stroke alone. The number of ES per hour in subjects with ES was not normally distributed; therefore, a logarithmic transform was necessary to obtain a normal distribution for analysis of relationships between ES frequency and recurrence. Data from the more recent 146 subjects and the previously reported initial 54 subjects were initially analyzed separately. Only when similar relationships between ES and recurrent events in the 2 data sets were demonstrated were the 2 data sets combined to increase the power to examine associations with ES and their independence from other risk markers.

**Results**

ES were detected in 89 (44.5\%) subjects. In those subjects with ES present, most subjects had \( \leq 5 \) per hour (median, 4; range, 1 to 57). The distribution of ES frequencies is shown in Figure 1: Demographic details in subjects with and without ES are shown in Table 1. There were no differences in age, gender, current smoking, or hypertension. There was a negative correlation between time since last symptoms and the number of ES per hour (Spearman \( \rho = -0.164; P = 0.02 \)) and the mean (SD) time since last symptoms was shorter in patients with ES (22.5 [25.2] versus 38.2 [23.5] days; \( P = 0.002 \)). There was no relationship between antiplatelet therapy at time of recording and the presence of ES (Table 1), although there was a trend toward fewer ES in subjects on the combination of clopidogrel and aspirin versus other combinations (1 of 9 versus 88 of 191; \( \chi^2 \) with Yates correction \( P = 0.085 \)).

In the new 146 patients, there were 21 recurrent ipsilateral events: 5 strokes and 16 TIs. There was a significant relationship between ES and both stroke alone (Kaplan–Meier log rank 8.87; \( P = 0.0029 \)) and TIA and stroke (log rank 13.75; \( P = 0.0002 \)). Associations with future events were consistent between the new 146 patients and the initial 54
In the first 54 subjects, 8 of 28 (28.57%) with ES had recurrent events, and in the second 146, 16 of 61 (26.23%) with ES had recurrent events ($\chi^2 P=0.817$). Therefore, to explore associations further, the full data set was explored. In the 200 subjects during follow-up, 31 subjects experienced recurrent ipsilateral ischemic events: 7 strokes and 24 TIAs. A significant association was found between ES and both stroke alone (Kaplan–Meier log rank statistic 10.85; $P=0.001$) and the combined endpoint of stroke and TIA (log rank statistic 18.52; $P=0.00001$), shown graphically in Figure 2. This remained significant after Cox regression was used to control for age, sex, current smoking, hypertension, degree of stenosis, and time since last symptoms, with an adjusted odds ratio of 4.67 (95% CI, 1.99 to 11.01; $P=0.0001$). Also, entering antiplatelet therapy during follow-up as aspirin alone ($N=138$), aspirin and dipyridamole ($N=43$), or clopidogrel with or without aspirin ($N=19$) did not alter the relationship between ES and recurrent events (odds ratio, 4.72; 95% CI, 1.99 to 11.19; $P=0.0001$). There was no significant independent association between any of the other variables and risk of stroke and TIA. (Table 2).

The predictive value of a recording negative for ES at baseline was determined. A negative recording, present in 111 subjects, was associated with an ipsilateral stroke risk during follow-up of 0% (compared with an event rate in all 200 subjects of 3.5%) and a combined ipsilateral stroke and TIA rate of 7.4% (compared with an event rate in all 200 subjects of 15.5%).

The possibility of a threshold of ES frequency above which risk was higher was explored in those 89 subjects with ES at baseline. The distribution of recurrent events related to the ES frequency is shown in Figure 1. There was a weak trend to higher ES counts per hour in subjects with stroke alone, compared with TIA, compared with no events, during follow-up, but this was not significant (log [SD] mean ES per hour: stroke alone, 0.743 [0.562]; TIA, 0.655 [0.462]; no recurrent event, 0.580 [0.504]; ANOVA $P=0.651$.) Using a threshold of an ES count above the median ($>4$ ES per hour) did not improve prediction of future stroke and TIA compared with a threshold of 1 or more ES per hour, for stroke alone (log rank

### Table 1. Details of Risk Factors and Other Potential Risk Markers in Subjects With or Without Embolic Signals

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>ES Positive (n=89)</th>
<th>ES Negative (n=111)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>67.79 (10.96)</td>
<td>68.57 (10.16)</td>
<td>0.605</td>
</tr>
<tr>
<td>Male</td>
<td>52</td>
<td>71</td>
<td>0.424</td>
</tr>
<tr>
<td>Hypertension</td>
<td>26</td>
<td>31</td>
<td>0.841</td>
</tr>
<tr>
<td>Current smoker</td>
<td>31</td>
<td>32</td>
<td>0.141</td>
</tr>
<tr>
<td>Symptomatic event</td>
<td></td>
<td></td>
<td>0.633</td>
</tr>
<tr>
<td>Stroke</td>
<td>49</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>TIA/amaurosis fugax</td>
<td>40</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Ipsilateral CT infarct</td>
<td>54</td>
<td>63</td>
<td>0.697</td>
</tr>
<tr>
<td>Antiplatelet therapy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>10</td>
<td>13</td>
<td>0.228</td>
</tr>
<tr>
<td>Aspirin</td>
<td>65</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Aspirin and dipyridamole</td>
<td>13</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Aspirin and clopidogrel</td>
<td>1</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Carotid stenosis (%)</td>
<td>85.0 (11.9)</td>
<td>82.4 (15.0)</td>
<td>0.175</td>
</tr>
<tr>
<td>Days since last event</td>
<td>22.5 (25.17)</td>
<td>38.2 (23.52)</td>
<td>0.002</td>
</tr>
</tbody>
</table>

![Figure 2](http://stroke.ahajournals.org/)

Figure 2. Kaplan–Meier survival plots showing the relationship between the presence of embolic signals and recurrent ipsilateral stroke (A); and recurrent ipsilateral TIA and stroke (B). Censored events include carotid endarterectomy, carotid angioplasty, and nonstroke death.

### Table 2. Relationship Between Risk Factors and Subsequent Risk of Stroke and TIA During Follow-up, Determined Using Cox Regression

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Odds Ratio</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>0.982</td>
<td>0.945–1.020</td>
<td>0.349</td>
</tr>
<tr>
<td>Male</td>
<td>1.836</td>
<td>0.896–3.762</td>
<td>0.097</td>
</tr>
<tr>
<td>Hypertension</td>
<td>0.719</td>
<td>0.317–1.628</td>
<td>0.428</td>
</tr>
<tr>
<td>Current smoker</td>
<td>0.813</td>
<td>0.340–1.941</td>
<td>0.641</td>
</tr>
<tr>
<td>Degree of stenosis, %</td>
<td>1.006</td>
<td>0.979–1.033</td>
<td>0.675</td>
</tr>
<tr>
<td>Ipsilateral CT/MRI infarct</td>
<td>1.540</td>
<td>0.861–2.755</td>
<td>0.146</td>
</tr>
<tr>
<td>Time since symptoms, d</td>
<td>0.983</td>
<td>0.964–1.002</td>
<td>0.072</td>
</tr>
<tr>
<td>Embolic signals detected</td>
<td>4.674</td>
<td>1.985–11.007</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Doppler ES detection is also being increasingly used as a surrogate marker to evaluate the efficacy of antiplatelet agents. Therapeutic efficacy for different agents has been demonstrated in a number of single-center studies,24–28 and more recently in the multicenter CARESS trial.22 All of these studies have been in patients with carotid artery disease. The demonstration that ES predict stroke alone, rather than the combined endpoint of TIA and stroke, strengthens their validity as a clinically relevant surrogate end point.

Our study design has a number of strengths. Investigators were blinded to the results of ES recordings reducing bias, which is particularly an issue with diagnosis of TIA. Our sample size is significantly larger than previous studies looking at the predictive value of ES. However, even with a sample size of 200, the number of strokes was small. Therefore, we were unable to perform multivariate analysis with the endpoint of stroke alone. However, Cox regression with the combined endpoint of TIA and stroke demonstrated the independent predictive value of ES. A larger sample size would require a multicenter collaboration. Furthermore, with the increasingly aggressive approach toward treating patients with symptomatic carotid stenosis such a study would be difficult to perform.

Our study recruited subjects over an 8-year period during which the use of antiplatelet agents treatment changed significantly. We examined this in 2 ways. First, we correlated the presence of ES with therapy at the baseline recording. Particularly early in the study, some patients were recruited before any agent was started. There was a trend to less ES with clopidogrel compared with other agents. Real effects of different agents can only be examined by randomized trials, but this trend was consistent with the results of the recent CARESS study. Second, we determined whether different treatments during follow-up could confound the relationship between ES and recurrent events; however, the relationship remained of similar magnitude after this was controlled for.

In this study, we classified patients according to whether any ES were present. In those subjects with ES, we found no clear relationship between the rate of ES per hour and the risk of recurrent stroke and TIA. Using a higher threshold to identify frequent embolizers did not increase the predictive power of the technique. Therefore, with current technology we would advise classifying patients according to whether any ES can be detected. However, the hour duration of recording we used is short for a dynamic process such as embolization. It is now possible to perform prolonged recordings of up to 8 hours using ambulatory transcranial Doppler systems.29 This gives a better estimate of ES load, and it may be possible to more accurately predict recurrent events using this technology and classifying patients according to the rate of embolization.

In patients with symptomatic stenosis who had ES, the early risk of recurrent stroke was ≈8%. This is consistent with recent data that suggests that the risk of recurrent stroke after TIA is much higher than previously recognized,30,31 and that this increased risk is largely accounted for by patients with large-artery disease.31 This emphasizes the need for urgent treatment of TIA and minor stroke. In cases suitable and fit for carotid endarterectomy, the benefit of rapid surgery...
has been demonstrated; however, in patients not fit for urgent operation, more aggressive antiplatelet therapy may be appropriate. Although combination antiplatelet therapy has not been proven to be of major benefit in the long-term secondary prevention of stroke, it may be of benefit in the acute phase. This is supported by the results of the CARESS trial and is being evaluated in current studies such as the FASTER study.22

In conclusion, our study provides a first evidence to our knowledge that asymptomatic ES predict stroke risk in patients with carotid artery stenosis. This technique may have use in risk stratification and also as a surrogate marker for evaluating antithrombotic therapy.

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References


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