Migraine and stroke share some common risk factors, including hypertension\(^1\) and patent foramen ovale (PFO),\(^2,3\) and there is a familial basis to both.\(^4–7\) Furthermore, migraine has long been regarded as a risk factor for ischemic stroke.\(^8–11\) Migraine could confer a predisposition to stroke occurring remote from migraine events, or stroke could occur as a direct consequence of a migraine event, as in migraineous infarction.\(^12\) A spurious association between migraine and stroke could occur if cerebral ischemia with migraine, either transient or resulting in stroke, were misdiagnosed as migraine with aura.\(^13–15\) Few prior studies have addressed these different potential reasons for an association between migraine and stroke. Clarifying in more detail the clinical features of the relation between migraine and stroke may provide useful insights into the basis for the migraine-stroke association. There is some evidence that the increased risk of stroke associated with migraine may not be uniform across all migraine or stroke subgroups. For example, the association between migraine and ischemic stroke is reported to be stronger for strokes occurring among younger (ie, <50 years) than older individuals and for women than men.\(^8–10,16,17\) Recent evidence also suggests that migraine with aura may elevate the risk for stroke more than migraine without aura,\(^18–20\) and some\(^11,16,21\) but not all\(^20,22\) studies suggest that the association between migraine and stroke may be elevated among women who smoke or use oral contraceptives (OCs).

The effects of migraine frequency, lifetime duration of migraine, and time of migraine onset on stroke risk are also unclear. An association between a higher frequency (>12 per year) and a longer duration (>12 years) of migraine with ischemic stroke has been reported in at least 1 study,\(^22\) and an association between higher migraine frequency and subclinical infarcts has been reported in another.\(^17\) There is some...
evidence that migraineous infarction preferentially affects the occipital lobes and that a history of migraine with aura may increase the risk of subclinical posterior infarct. However, it is not known whether clinically recognized stroke events associated with a history of migraine have a specific anatomic predilection. The contribution of PFO to the risk of migraine-associated ischemic stroke is also uncertain. PFO is a risk factor for young-onset stroke and is more common among migraineurs compared with nonmigraineurs; however, prior epidemiologic studies of migraine and stroke have lacked information about PFO.

We sought to address many of these issues by evaluating the association between prior migraine and ischemic stroke on data from a population-based, case-control study of young white and African-American women. In our analyses, we considered traditional vascular risk factors as well as clinical and anatomic features of the association.

Methods

The Stroke Prevention in Young Women Study (SPYW) is a population-based, case-control study initiated to examine risk factors for ischemic stroke in young women. Study recruitment and data collection occurred in 2 waves: recruitment for SPYW-1 was conducted between 1992 and 1996, resulting in an enrollment of 228 case and 392 control subjects, and recruitment for SPYW-2 was conducted between 2001 and 2003, resulting in an enrollment of 263 case and 225 control subjects in addition to those enrolled during SPYW-1. In both waves, case patients were women hospitalized with a first cerebral infarction identified by discharge surveillance from 1 of 59 hospitals in the Greater Baltimore–Washington area and direct referral from regional neurologists. The methods for discharge surveillance, chart abstraction, case adjudication, and assignment of probable and possible underlying causes have been described elsewhere.

Control subjects were women with no history of stroke identified by random-digit dialing and were matched to cases by age (within 10 years) and geographic region of residence in both waves and additionally matched for race in SPYW-2. SPYW-1 included cases age 15 to 44 years recruited within 1 year of stroke and was designed with a 1:1 case-to-control ratio. SPYW-2 was conducted between 2001 and 2003, resulting in an enrollment of 263 case and 225 control subjects in addition to those enrolled during SPYW-1. In both waves, case patients were women hospitalized with a first cerebral infarction identified by discharge surveillance from 1 of 59 hospitals in the Greater Baltimore–Washington area and direct referral from regional neurologists. The methods for discharge surveillance, chart abstraction, case adjudication, and assignment of probable and possible underlying causes have been described elsewhere.

Control subjects were women with no history of stroke identified by random-digit dialing and were matched to cases by age (within 10 years) and geographic region of residence in both waves and additionally matched for race in SPYW-2. SPYW-1 included cases age 15 to 44 years recruited within 1 year of stroke and was designed with a 1:2 case-to-control ratio. SPYW-2 included cases age 15 to 49 years recruited within 3 years of stroke and was designed with a 1:1 case-to-control ratio. For both study periods, additional cases were recruited after completion of control recruitment.

Lifetime headache history was collected from case and control subjects by standardized questionnaire. Subjects were classified as having probable migraine with visual aura (PMVA) if they (1) reported ever seeing spots, lines, or flashing lights around the time of their probable migraine or (2) if they reported ever experiencing loss of vision and also reported a frequency of PMVA of at least twice per year. Subjects were identified as having probable migraine without visual aura if they reported no history of visual aura and reported nausea, vomiting, or sensitivity to light during a probable migraine and probable migraine frequency of at least 5 times per year. Our questionnaire-based definitions for probable migraine with and without visual aura are less specific than the International Headache Society (IHS) criteria for definite or probable migraine with or without aura. These definitions differ from IHS criteria in that they do not refer to phonophobia, they do not specify the untreated duration of migraine or migraine features, nor do they specify the time criteria of aura symptoms (IHS 1.6).

To evaluate the impact of lifetime duration of probable migraine on stroke risk and to assess the possibility that reported PMVA was due to an unrecognized transient ischemic attack, we classified stroke patients with probable migraine into 3 groups according to the duration of exposure for subanalyses: (1) first probable migraine occurred within 1 year of stroke onset; (2) first probable migraine occurred >1 but <12 years before stroke onset; and (3) first probable migraine occurred >12 years before stroke onset. Frequency and duration of probable migraine were collected by subject report during the interview process. Probable migraine severity was assessed by responses to the questions, “How often are you unable to work, parent, or go to school for all or part of the day due to your headaches?” and “How often do you require bedrest?” If the subject responded “more than half the time” to either question, the probable migraines were classified as severe.

Traditional stroke risk factors and other study variables, including age, ethnicity, and history of hypertension, diabetes, myocardial infarction (MI), current smoking status, and current OC use (both defined as use within 1 month of an event for cases and at the time of interview for controls), were also collected during the standardized interview and were included as covariates in our analyses.

Of 491 adjudicated cases and 617 controls, 25 subjects (23 cases and 3 controls) were excluded because they had proxy or assisted interviews, and 82 cases were excluded because they lacked definitive evidence of stroke-related abnormalities on computed tomography or magnetic resonance imaging scans, leaving 386 cases and 614 controls. A pair of neurologists determined ischemic stroke subtype and vascular distribution. Stroke subtype categories were as follows: (1) large-artery atherosclerosis, (2) cardioembolism, (3) lacunar stroke, (4) stroke of other determined cause, and (5) stroke of undetermined cause. Probable migrainous infarction was categorized as stroke of undetermined cause. Based on both clinical and neuroradiographic data, lesion location was classified into (1) anterior circulation, (2) posterior circulation, (3) both, or (4) unknown. For the subset of cases (n = 163) with an air contrast transaxial or transesophageal echocardiogram, the presence or absence of a PFO was recorded.

We compared risk factor distributions between cases and controls by t tests for continuous variables and χ² tests for categorical variables. We used multivariate logistic regression to evaluate the relation between history of PMVA and ischemic stroke; to assess a 3-way interaction between PMVA, smoking, and OC use; and to adjust for covariates. Two-tailed probability values of <0.05 were considered statistically significant. All statistical analyses were performed with SAS version 8.2 software.

This study was approved by institutional review boards at the University of Maryland, the Centers for Disease Control and Prevention, and at all participating hospitals. Each patient gave written, informed consent before enrollment.

Results

Clinical characteristics of stroke cases (n = 386) and non-stroke controls (n = 614) are shown in Table 1. Cases were significantly older on average compared with controls and were more likely to be African-American. As expected, cases were also more likely than controls to report a history of hypertension, diabetes, and MI and were more likely to be...
current smokers and current OC users. A higher proportion of cases reported a history of PMVA compared with controls; however, there was no significant difference between the proportion of cases and controls reporting a history of probable migraine without visual aura.

There were no statistically significant interactions between age, race, geographic region, and study period and the reported associations; therefore, the minimally adjusted model controlled for these factors. Women with PMVA had 1.5-fold greater odds of having a stroke compared with women with no migraine (95% CI, 1.1 to 2.0). There was no association between stroke and probable migraine without visual aura (odds ratio [OR], 1.0; 95% CI, 0.6 to 1.5). Subsequent analyses were therefore focused on assessing the clinical and anatomic characteristics of the PMVA-stroke association.

Figure 1 shows adjusted ORs for stroke among women with PMVA compared with women without migraine, stratified by hypertension, diabetes, and MI. PMVA was a significant risk factor for stroke among women without a history of hypertension (OR, 1.7; 95% CI, 1.2 to 2.4), without a history of diabetes (OR, 1.5; 95% CI, 1.1 to 2.0), and among women without a history of MI (OR, 1.6; 95% CI, 1.2 to 2.2) compared with women with no migraine. Statistical tests for effect modification were significant for a history of MI or angina ($p < 0.01$) and a history of diabetes ($p = 0.03$) but not for a history of hypertension ($p = 0.23$). Additional analyses indicated that there was no association between stroke and probable migraine without visual aura in any of these strata (data not shown).

The risk of stroke associated with PMVA, stratified by smoking and OC use, is shown in Figure 2. PMVA was a significant risk factor for stroke among smokers (OR, 1.5; 95% CI, 1.1 to 2.3). The point estimate for PMVA was similar among OC users and nonusers, but the association among nonusers attained statistical significance owing to a larger sample size (OR, 1.5; 95% CI, 1.1 to 2.1). Neither current smoking nor OC use was an independent effect.
modifier of the association between PMVA and stroke ($P=0.45$ and $P=0.87$, respectively). To evaluate the combined effect of smoking and use of OCs among women with PMVA on stroke risk, we included a 3-way interaction term for these covariates in our model. After controlling for age, race, geographic region, and study period, women with PMVA who smoked and used OCs had 7.0-fold higher odds of stroke (95% CI, 1.4 to 22.8) compared with women with PMVA who were nonsmokers and non-OC users (Figure 3). When compared with women with no migraine history who were nonsmokers and non-OC users, women with PMVA who smoked and used OCs had 10.0-fold higher odds of stroke (95% CI, 1.4 to 73.7).

ORs of probable migraine-associated stroke, stratified by stroke subtype, are shown in Table 2. Results are shown for the minimally adjusted model and for a full model additionally adjusted for vascular risk factors. In the risk factor–adjusted model, women experiencing a higher frequency of PMVA (>12 per year) had 1.7-fold higher odds of stroke (95% CI, 1.1 to 2.8), and women having severe PMVA (requiring bed rest or absence from work) had 1.3-fold higher odds of stroke (95% CI, 0.8 to 1.9) compared with women with no history of migraine, although this was not statistically significant. Compared with women who had no history of migraine, women with a lifetime duration of PMVA of >12 years had 1.2-fold higher odds of stroke (95% CI, 0.8 to 1.9), whereas women who experienced their first PMVA onset within a year of the index date (stroke date for cases, within 1 week of the interview date for controls) had 8.3 (2.6 to 25.7)-fold higher odds of stroke.

We found no evidence for a differential association between PMVA and stroke with posterior (OR 1.1; 95% CI, 0.6 to 1.8) or anterior (OR 1.4; 95% CI, 0.9 to 2.0) circulation involvement. Similarly, there was no evidence for a stronger association between PMVA and stroke in the small subgroup (n=21) with known PFO (OR 2.1; 95% CI, 0.8 to 5.3) compared with the small subgroup (n=142) whose air con-

**TABLE 2. Effect of PMVA on Stroke Risk, Stratified by Stroke Subtype (OR and 95% CI)**

<table>
<thead>
<tr>
<th>Proportion of Cases</th>
<th>Proportion of Controls</th>
<th>OR (95% CI)*</th>
<th>OR (95% CI)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>With PMVA</td>
<td>With PMVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All ischemic stroke</td>
<td>0.38</td>
<td>0.29</td>
<td>1.5 (1.1–2.0)</td>
</tr>
<tr>
<td>Large-artery atherosclerotic (n=47)</td>
<td>0.32</td>
<td>0.29</td>
<td>1.3 (0.7–2.7)</td>
</tr>
<tr>
<td>Cardioembolic (n=42)</td>
<td>0.31</td>
<td>0.29</td>
<td>1.2 (0.6–2.5)</td>
</tr>
<tr>
<td>Lacunar (n=45)</td>
<td>0.40</td>
<td>0.29</td>
<td>1.8 (0.9–3.8)</td>
</tr>
<tr>
<td>Undetermined cause (n=192)</td>
<td>0.39</td>
<td>0.29</td>
<td>1.6 (1.1–2.3)</td>
</tr>
</tbody>
</table>

*Adjusted for study period, age, race, and geographic region.
†Adjusted for study period, age, race, geographic region, smoking, diabetes, hypertension, MI, and OC use.
TABLE 3. Effect of Severity, Frequency, and Duration of PMVA on Stroke Risk (OR and 95% CI)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Cases With PMVA/Controls Without Migraine</th>
<th>Controls With PMVA/Controls Without Migraine</th>
<th>OR (95% CI)*</th>
<th>OR (95% CI)†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>65/206</td>
<td>111/360</td>
<td>1.1 (0.7–1.6)</td>
<td>0.9 (0.6–1.4)</td>
</tr>
<tr>
<td>≤12 per year</td>
<td>80/206</td>
<td>64/360</td>
<td>2.2 (1.5–3.3)</td>
<td>1.7 (1.1–2.8)</td>
</tr>
<tr>
<td>&gt;12 per year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severity‡</td>
<td>78/206</td>
<td>97/360</td>
<td>1.5 (1.0–2.2)</td>
<td>1.3 (0.8–1.9)</td>
</tr>
<tr>
<td>Nonsevere</td>
<td>64/206</td>
<td>77/360</td>
<td>1.4 (0.9–2.1)</td>
<td>1.1 (0.7–1.8)</td>
</tr>
<tr>
<td>lifetime duration§</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;12 years</td>
<td>62/206</td>
<td>68/360</td>
<td>1.5 (1.0–2.3)</td>
<td>1.2 (0.8–1.9)</td>
</tr>
<tr>
<td>1–12 years</td>
<td>52/206</td>
<td>92/360</td>
<td>1.0 (0.6–1.5)</td>
<td>0.7 (0.5–1.2)</td>
</tr>
<tr>
<td>&lt;1 year</td>
<td>17/206</td>
<td>5/360</td>
<td>6.8 (2.4–20.0)</td>
<td>8.3 (2.6–25.7)</td>
</tr>
</tbody>
</table>

*Adjusted for study period, age, race, and geographic region.
†Adjusted for study period, age, race, geographic region, smoking, diabetes, hypertension, MI, and OC use.
‡Three cases and 1 control with missing data.
§Fourteen cases and 10 controls with missing data. Index date was stroke date for cases and within 1 week of interview date for controls.

Discussion

In this population-based, case-control study of young African-American and white women, PMVA was significantly associated with increased odds of ischemic stroke, particularly stroke of undetermined origin. Risk of stroke was highest for women who reported new-onset PMVA within 1 year before stroke or study enrollment. These findings were not materially altered after exclusion of patients with probable migrainous stroke. Overall and subgroup analyses did not indicate any association between probable migrainous stroke without visual aura and stroke. Our data are consistent with existing evidence that migraine with aura is associated with an increased risk of ischemic stroke from several case-controls studies of young-onset stroke, and from 2 prospective studies carried out in middle-aged and older populations. A recent prospective study of women 45 years and older reported a significant association between migraine with aura and risk of ischemic stroke but no increased risk of stroke among women with migraine without aura, compared with women with no migraine history. Similarly, a recent nested case-control study that included African-American and white men and women between 45 and 64 years of age reported that a history of migraine or other probable migraine with aura, but not migraine or other probable migraine without aura, was associated with ischemic stroke.

Subgroup analyses of our data indicated that women without a history of hypertension, diabetes, and MI were at greatest risk for PMVA-associated stroke. This is consistent with previous findings among younger women and middle-aged and older women suggesting that PMVA may contribute to the etiology of ischemic stroke independently of atherogenic risk factors. Although smoking or OC use did not independently modify the effect of PMVA on stroke risk, these factors had a multiplicative effect on the risk of stroke. Our data support previous studies that reported an increase in stroke risk associated with smoking and the use of OCs among young women and clinical recommendations to modify these risk factors in the presence of migraine with aura.

There were 145 ischemic stroke patients among women with PMVA. When we stratified our analyses by ischemic stroke subtype, we found that PMVA was associated with strokes of undetermined origin and showed a strong trend toward an association with lacunar stroke, which is more a descriptive than an etiologic category. Associations were not present for subtypes with a clear etiology, such as atherosclerotic and cardioembolic strokes.

Our data suggest that women who reported a frequency of PMVA of >12 episodes per year have an increased risk of stroke compared to women who reported no migraine history. These findings are consistent with previous reports of increased migraine frequency as a risk factor for clinically recognized stroke and subclinical infarcts. In contrast, the Women’s Health Study recently reported that high migraine frequency within the previous year was not associated with increased ischemic stroke risk.

In the 22 participants whose onset of PMVA occurred within the previous year, we observed a strong association with ischemic stroke, with an adjusted OR of 8.3 (2.6 to 25.7) compared to women with no migraine. It is possible that unrecognized acute cerebral ischemia could have clinical features of PMVA and thus, could confound the association between PMVA and stroke. Prior case-control studies have not addressed this issue. The prospective Women’s Health Study, which found an association between migraine with aura and ischemic stroke in women under age 55, constructed time-varying models that updated information about migraine...
attacks in the previous year, analyzed their data with different follow-up time periods, and found no evidence for an increased association for specific follow-up periods. Furthermore, consistent with at least 1 other case-control study,22 we observed a trend toward an association between longstanding PMVA and stroke. We also considered the possibility that the strong association between recent-onset PMVA and stroke was due to migraine infarction. However, of 7 cases adjudicated as having migrainous infarction, only 1 reported onset of PMVA in the year before study enrollment, and exclusion of this case did not materially change the findings.

With regard to location of the infarct, there is some evidence of increased posterior circulation involvement for clinically recognized migrainous infarction23 and for subclinical infarcts associated with migraine, whereas other studies have reported no evidence for anatomic prediction among stroke cases with migraine compared with stroke cases without migraine.19 In our data, we found no appreciable difference in risk of stroke between the anterior and posterior regions in relation to PMVA.

PFO has been implicated as a possible mechanism for the association between migraine and stroke because it is a risk factor for young-onset stroke and is associated with migraine prevalence and frequency.35 In our study, there was no evidence for a substantially stronger association between PMVA and ischemic stroke among the small subset of women with known PFO compared with women without evidence of a PFO. However, we had limited ability to address this issue, because there were PFO data for only 163 women, some of whom might have been misclassified as having no PFO owing to the limited sensitivity of air contrast transthoracic echocardiograms as a diagnostic tool for PFO. It should be noted that the presence of a PFO does not explain the observed association found in our study. Nondifferential misclassification of probable migraine would tend to underestimate the true association between migraine and stroke. We note that our ORs were weaker than risk estimates reported from other studies of migraine and stroke and may be underestimated for this reason.

There are several strengths of our study. We used a population-based design, which is optimal for studying early-onset stroke owing to the low incidence of stroke in this age range. Cases selected by this approach are likely to be more representative of young stroke cases from the defined study area than are cases selected from tertiary care referral centers only. We included both white and African-American women; few studies have examined migraine and stroke risk among African-Americans. Our study population consisted of young women, the group that has had the greatest risk of migraine-associated stroke in previous studies. Finally, the large number of strokes allowed examination of risk stratified by ischemic stroke subtype.

Limitations of our study include self-reported migraine history, which did not include data on untreated duration of headache or headache features, phonophobia, or time and duration of aura symptoms, and therefore, was not sufficient to classify migraine status according to IHS criteria.12 Lipton and colleagues performed a validation study of migraine classification wherein subjects were considered to have migraine if they reported at least 1 severe probable migraine in the previous 12 months with unilateral or pulsatile pain and either nausea, vomiting, or phonophobia with photophobia, or visual or sensory aura before probable migraine. These criteria differed from those of IHS, which specify an attack duration of 4 to 72 hours for untreated attack and a lifetime number of attacks of at least 5. Nevertheless, the criteria used by Lipton et al were 100% specific for migraine as validated by follow-up assessment and definitive diagnosis by a physician with expertise in probable migraine. Probable migraine with aura (probable migraine that lasted at least 4 hours but did not satisfy all other IHS criteria for migraine) has also been associated with stroke in a prospective analysis. Because the only other headache disorder besides migraine that may be preceded by aura is cluster headache, which is rare, these were likely undiagnosed migraines or transient ischemic attacks.38 Similarly, the PMVAs reported by women in our study likely represent migraine with aura.

The proportion of subjects who reported PMVA was high in our study compared with the prevalence of migraine with aura in the general population. This was likely due in part to misclassification of migraine status. However, this misclassification is an unlikely explanation for the significant associations found in our study. Nondifferential misclassification of probable migraine would tend to underestimate the true association between migraine and stroke. We note that our ORs were weaker than risk estimates reported from other studies of migraine and stroke and may be underestimated for this reason.

The potential for recall bias between case and control subjects is also a study limitation. It is possible that case patients more frequently recalled migraine history due to the experience of their stroke event. Finally, we did not control for factors such as medication use, cholesterol, alcohol consumption, and physical activity in our model, which may have resulted in unmeasured or residual confounding of our risk estimates.

In summary, we found an association between PMVA and ischemic stroke of undetermined cause. The association of smoking, OC use, and PMVA with ischemic stroke indicates a high-risk population for which appropriate management strategies are warranted.

Acknowledgments

We are indebted to the following members of the SPYW research team for their dedication: Esther Berrent, Julia Clark, Mohammed Huq, Nasrin Huq, Ann Maher, Tamar Pair, Mary Jane Seipp, Mary Simmons, Mark Waring, Latasha Williams, Mary J. Sparks, and Nancy Zappala.

The authors appreciate the following individuals who sponsored the SPYW at their institutions: Clifford Andrew, MD, PhD; Brian Avin, MD; Merrill Ansher, MD; Harjit Bajaj, MD; Robert Baumann, MD; Christopher Beaver, MD; David Buchholz, MD; Nicholas Buendia, MD; Young Ja Cho, MD; James Christensen, MD; Kevin Crutchfield, MD; Renzi Demir, MD; Terry Detrich, MD; Mohammed Dughly, MD; Boyd Dwyer, MD; Christopher Earley, MD; John Eckholdt, MD (deceased); Nirmala Fernback, MD (deceased); Jerold Fleishman, MD; Benjamin Frishberg, MD; Stuart Goodman, MD, PhD; Adrian Goldszmidt, MD; Kalpana Hari Hall, MD; Norman Hershkowitz, MD, PhD; Aleem Iqbal, MD; Constance Johnson, MD; Luke Kao, MD, PhD; Walid Kamshel, MD; John Kelly, MD; Andrew Keenan, MD; Harry Kerasidis, MD; Mehruliah Khan, MD; Ramesh Khurana, MD; Ruediger Kratz, MD; John Kurtzke, MD; Somchai Laos Wattana, MD; William Leahy, MD; Alan Levitt, MD; William Lightfoote II, MD; Bruce Lobar, MD; Paul Melnick, MD; Michael Miller, MD, PhD; Harshad Mody, MBBS; Marvin Mordes, MD; Seth
Sources of Funding

This material is based on work supported in part by the Office of Research and Development, Medical Research Service, and the Research Enhancement Award Program in Stroke, the Geriatrics Research, Education, and Clinical Center, Department of Veterans Affairs; a cooperative agreement with the Cardiovascular Health Branch, Division of Education and Clinical Center, Department of Veterans Affairs Medical Center in Baltimore, Doctors Community Hospital, Dorchester Hospital, Franklin Square Hospital Center, Freight Memorial Hospital, Good Samaritan Hospital, Greater Baltimore Medical Center, Harbor Hospital Center, Hartford Memorial Hospital, Holy Cross Hospital, Johns Hopkins Bayview, Johns Hopkins Hospital, Howard County General Hospital, Kerman Hospital, Laurel Regional Hospital, Maryland General Hospital, McCrady Memorial Hospital, Memorial Hospital at Easton, Mercy Medical Center, Montgomery General Hospital, North Arundel Hospital, Northwest Hospital Center, Peninsula Regional Medical Center, Prince George's Hospital Center, Saint Agnes Hospital, Saint Joseph Medical Center, Saint Mary's Hospital, Shady Grove Adventist Hospital, Sinai Hospital of Baltimore, Southern Maryland Hospital Center, Suburban Hospital, The Union Memorial Hospital, Union Hospital Cecil County, University of Maryland Medical System, Upper Chesapeake Medical Center, Washington Adventist Hospital and Washington County Hospital; in Washington, DC: George Washington University Medical Center, Georgetown University Hospital, Hadley Memorial Hospital, Howard University Hospital, National Rehabilitation Hospital, Providence Hospital, Sibley Memorial Hospital, Veteran's Affairs Medical Center; and the Washington Hospital Center; in Pennsylvania: Gettysburg Hospital.

Disclosures

None.

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Probable Migraine With Visual Aura and Risk of Ischemic Stroke: The Stroke Prevention in Young Women Study
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Stroke. 2007;38:2438-2445; originally published online August 9, 2007;
doi: 10.1161/STROKEAHA.107.488395

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