Age and Sex Differences in Cerebral Hemodynamics
A Transcranial Doppler Study

Maria Matteis, MD; Elio Troisi, MD; Bruno C. Monaldo, MD; Carlo Caltagirone, MD; Mauro Silvestrini, MD

Background and Purpose—Hemodynamic factors seem to play an important role in the pathogenesis of cerebral ischemic events. The aim of this study was to evaluate whether changes in cerebrovascular reactivity occur in women after menopause.

Methods—Using transcranial Doppler ultrasonography, we studied the changes of flow velocity after hypercapnia in the middle cerebral arteries of 45 healthy premenopausal women (mean age, 32.3 years; range, 20 to 47 years) and 40 postmenopausal women (mean age, 54.4 years; range, 48 to 64 years). The same measurements were recorded in two groups of healthy male subjects age matched with premenopausal (45 subjects) and postmenopausal women (40 subjects). Moreover, a subgroup of postmenopausal women aged 48 to 53 years (15 subjects) were compared with a group of 15 premenopausal women of the same age. We obtained hypercapnia with breath holding and evaluated cerebrovascular reactivity with the breath-holding index (BHI).

Results—BHI was significantly lower in postmenopausal women (0.89 ± 0.3) than in premenopausal women (1.59 ± 0.3; P < 0.0001) and in young (1.34 ± 0.5; P < 0.0001) and old men (1.20 ± 0.4; P < 0.04). In the latter group, BHI was significantly lower than in premenopausal women (P < .0001). BHI values were also significantly lower in postmenopausal women of the same age (0.81 ± 0.1 versus 1.34 ± 0.1; P < 0.0001).

Conclusions—These findings suggest that the large reduction of cerebrovascular reactivity in postmenopausal women cannot be considered a simple factor related to aging but is probably influenced by hormonal changes. The alteration in cerebrovascular regulation could be involved in the increase of cerebrovascular disease in postmenopausal women. (Stroke. 1998;29:963-967.)

Key Words: gender □ ultrasonography, Doppler, transcranial □ vasomotor reactivity

Transcranial Doppler ultrasonography permits the noninvasive measurement of blood flow velocities in the basal brain arteries that have been found to reliably correlate with changes in cerebral blood flow.1,2 Cerebral vasomotor reactivity can easily be studied by measuring changes in flow velocity in response to vasodilatory stimuli such as CO2 inhalation, breath holding, or acetazolamide administration.3–5 The assessment of cerebral vasoreactivity can provide information regarding the reserve capacity of cerebral circulation, that is, the possibility of vessels to adapt in response to systemic modification or brain metabolic activity requiring an increase or decrease of cerebral blood flow.6,7 Reduction of this property has been found in association with situations predisposing toward cerebrovascular diseases.8–11 Epidemiological data show that there are distinctive features of cerebrovascular disease in men and women probably connected to their different patterns of sex hormones. In particular, the incidence of atherosclerotic vascular disease in premenopausal women is less than in men, but this difference disappears after menopause.12–15 Experimental studies have shown that female gerbils sustain less neuronal damage after focal ischemia than their male counterparts16 and that chronic estradiol treatment can improve regional cerebral blood flow in female rabbits during incomplete global ischemia and early reperfusion.17

Because sex hormones, in particular estrogens, have well-known vasoactive properties18,19 and their level decreases after menopause, we aimed to assess whether changes in cerebral vasomotor reactivity occur after menopause and to verify the possible existence of sexual hemodynamic differences.

Subjects and Methods
After giving informed consent, 170 right-handed healthy subjects selected from the hospital personnel (85 women and 85 men) were admitted to the study. Each female subject was matched with a male of the same age. The population was divided into four groups: 45 premenopausal women (mean age, 32.3 years; range, 20 to 47 years), 40 postmenopausal women (mean age, 54.4 years; range, 48 to 64 years), 45 men aged 47 years or younger (mean age, 36.5 years; range, 20 to 47 years), and 40 men older than 47 years (mean age, 56.5 years; range, 48 to 64). Postmenopausal status was defined as...
amenorrhea for at least 6 months, with gonadotropin and estradiol values within the postmenopausal range. The menopausal period ranged from 43 to 46 years. The interval from menopause to Doppler assessment ranged from 4 to 18 years (mean, 10.5 years).

Rigid exclusion criteria were established to avoid any bias by an unbalanced distribution of concomitant diseases or drug therapy: subjects with hypertension, diabetes mellitus, obesity, congestive heart failure (greater than New York Heart Association grade I), chronic obstructive lung disease, cerebrovascular disease (transient ischemic attack, stroke, carotid artery stenoses >30%, and intracranial stenosis evaluated by cervical Doppler sonography and TCD), hematologic disease, and cancer were excluded from the study, as well as patients being treated with hormonal substances, nitrates, \( \beta \)-blocking agents, calcium channel blockers, antiocoagulants, and vasodilatory drugs. The female group included 6 premenopausal and 4 postmenopausal smokers. Hyperlipemia (cholesterol >200 mg/dL) was present in 2 postmenopausal women. The male group comprised 12 smokers: 7 in the younger group and 5 in the older group. In a second study, to compare premenopausal and postmenopausal women of similar age, a subgroup of postmenopausal subjects aged 48 to 53 years (15 subjects) was matched with 15 premenopausal women, each coupled with a postmenopausal woman of the closest age with similar weight and height.

Informed consent was obtained according to the declaration of Helsinki. The study was approved by the local ethics committee.

The subjects were studied in the morning in a supine resting state with their eyes closed. Twenty-two premenopausal women were recorded during the follicular phase (days 3 to 8 of the menstrual cycle), that is, estrogen dominant with high concentrations of estrogen and low progesterone levels, and 23 during the luteal phase (days 18 to 23 of the menstrual cycle), that is, estrogen dominant with high concentrations of progesterone levels rise to the point at which neither hormone is dominant. The phase of the menstrual cycle was established by considering the interval between two consecutive menses. The time of this interval ranged from 25 to 31 days, with a mean of 28 days. All subjects were drug free and had abstained from smoking, alcohol, and caffeine-containing beverages for at least 12 hours before the study. A routine hemogram performed at the time of TCD evaluation showed normal hematocrit values in all the study subjects without significant differences among groups (premenopausal women, 41±3; postmenopausal women, 40±2; young men, 43±3; old men, 42±4; young postmenopausal women, 41±4; premenopausal women of similar age, 41±2).

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**TABLE 1. BHI, HR, and MBP in the Four Groups of Subjects**

<table>
<thead>
<tr>
<th></th>
<th>Premenopausal Women</th>
<th>Postmenopausal Women</th>
<th>Men ≤47 y</th>
<th>Men &gt;47 y</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BHI</strong></td>
<td>1.59 (0.3)</td>
<td>0.89 (0.3)</td>
<td>1.34 (0.5)</td>
<td>1.20 (0.4)</td>
</tr>
<tr>
<td><strong>HR, bpm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>73.3 (10.3)</td>
<td>66.5 (9.2)</td>
<td>72.2 (14.6)</td>
<td>69.7 (9.8)</td>
</tr>
<tr>
<td>After BH</td>
<td>78.2 (8.8)</td>
<td>74.5 (6.9)</td>
<td>77.3 (6.6)</td>
<td>76.4 (9.9)</td>
</tr>
<tr>
<td><strong>MBP, mm Hg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>83.2 (10.4)</td>
<td>85.7 (13.1)</td>
<td>79.6 (8.6)</td>
<td>85.9 (9.6)</td>
</tr>
<tr>
<td>After BH</td>
<td>88.7 (9.3)</td>
<td>90.2 (9.9)</td>
<td>85.2 (6.5)</td>
<td>89.3 (8.7)</td>
</tr>
</tbody>
</table>

Values of HR and MBP are during basal conditions and after the breath-holding (BH) period. Values in parentheses are SDs.
Changes of cerebral vasomotor reactivity has shown in- 
creased vasodilatory response to the acetazolamide test in 
all the included subjects were considered without distinction 
for age, BHI was comparable in women and men (1.24 versus 
1.19). The age effect was significant (F = 38.9; P < 0.0001, df 
1 and 166). In fact, considering woman and men together, the 
BHI was significantly higher in the younger (premenopausal 
women and young men) than in the older (postmenopausal 
women and old men) subjects (1.47 versus 0.96). Finally, the 
sex×age interaction was significant (F = 16.8; P < 0.0001, df 
1 and 166). Post hoc comparison (Scheffé’s test) showed that 
BHI was significantly lower in the postmenopausal women 
with respect to premenopausal women (P < 0.0001), young 
men (P < 0.001), and old men (P < 0.04) and in old men with 
respect to premenopausal women (P < 0.001). These data are 
shown in Table 1.

HR and MBP at rest were comparable in the subgroup of 
young postmenopausal women and in the group of premeno-
pausal women of similar age (Table 2). Values of MFV at rest 
were also comparable: 60.2 ± 8.3 cm/s in postmenopausal 
women and 63.1 ± 10 cm/s in premenopausal women. Regard-
ing BHI, the group effect was significant (F = 65.2; 
P < 0.0001, df 1 and 28). This was due to the fact that the BHI 
values were lower (P < 0.0001) in postmenopausal than in 
premenopausal women (Table 2).

HR and MBP during breath holding showed a slight 
increase. These modifications, as shown in Tables 1 and 2, 
were comparable in all groups. For this reason, when the 
analysis on BHI was repeated introducing HR and MBP 
changes as covariant factors, the results remained unchanged. 
Changes of HR and MBP with respect to baseline were 
calculated considering the values of the 4-second interval 
after the breath-holding period.

**Discussion**

The results of our study suggest that changes of cerebrovas-
ular reactivity in healthy subjects may be related to aging, 
but they are probably mainly influenced by hormonal 
changes. The only previous TCD study describing sex-related 
differences in cerebral vasomotor reactivity has shown 
increased vasodilatory response to the acetazolamide test in 
female compared with male subjects.20 These data are not 
comparable with ours. In fact, the study design did not permit 
establishing the number of women in the fertile period and 
the number in the postmenopausal period at the time of the 
assessment.

Epidemiological21,22 and experimental16,23 studies suggest 
that many different aspects must be considered in the 
relationship between sex and cerebrovascular disease. 
There is evidence that cerebral ischemic events have a 
more benign natural course in women than in men15 and 
that there are sex differences in the antithrombotic effect of 
aspirin.24 Moreover, the incidence of stroke in premeno-
pausal women is lower than in age-matched men and, after 
menopause, there is a strong increase in the incidence of 
vascular diseases in women.12-15 These facts suggest that 
the relevance of several pathophysiological substrates 
involved in verifying stroke events may not be the same in 
the two sexes.

Strict exclusion criteria were used in the present inves-
tigation to eliminate any bias caused by concomitant drug 
therapy or diseases or lifestyle that might influence cere-
brovasomotor reactivity. The main finding of our study 
was the reduction of cerebrovascular reactivity in post-
menopausal with respect to premenopausal women. We 
also found that while BHI was significantly lower in the 
postmenopausal women with respect to men of the same 
age, the latter subjects did not differ from younger men but 
had a significantly lower cerebrovascular reactivity to 
hypercapnia in comparison to premenopausal women. 
These findings lead us to believe that factors other than age 
may influence the reduction of cerebrovascular reactivity 
in women at the end of the fertile period. This is also 
confirmed by the fact that we found a significantly lower 
cerebrovascular reactivity in young postmenopausal 
women with respect to premenopausal women of similar 
age. At present, the mechanisms of the decrease of 
vasomotor reactivity in women after menopause and the 
pathophysiological significance of this phenomenon cannot 
be completely defined. At menopause, levels of estradiol, 
primarily produced by the ovary, fall, and this hormone 
is replaced by estrone, a less active estrogen, produced 
mainly by conversion of androstenedione in adipose tissue. 
After menopause there is little further decrease in endogenous estrogens with advancing age.25

The low cerebrovascular reactivity in postmenopausal 
women could be connected with these changes, but further 
studies comparing changes in concentrations of specific 
sex hormones with changes in cerebral hemodynamics are 
needed before we can state this with certainty.

From a clinical point of view, estrogen administration in 
postmenopausal women has been associated with a signif-
ican reduction in the development of clinical manifesta-
tions of coronary artery disease and stroke.26,27 These 
observations have been interpreted as probable evidence 
that female reproductive hormones provide vascular pro-
tection in ischemic heart disease and stroke. However, it is 
unclear whether estrogens per se are critical for modulat-
ing the risk of stroke or which mechanism provides 
protection. Although estrogens have been shown to favor-
ably alter the lipid profile12 and inhibit endothelial hyper-
plasia,28 these effects do not fully account for the degree of 
clinical benefit attributed to estrogen therapy in postmeno-

**TABLE 2. BHI, HR, and MBP in the Subgroup of Young 
Postmenopausal Women and in the Group of Premenopausal 
Women of Similar Age**

<table>
<thead>
<tr>
<th></th>
<th>Postmenopausal Women</th>
<th>Premenopausal Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHI</td>
<td>0.81 (0.1)</td>
<td>1.34 (0.1)</td>
</tr>
<tr>
<td>HR, bpm</td>
<td>68.1 (10.1)</td>
<td>68.8 (8.3)</td>
</tr>
<tr>
<td>After BH</td>
<td>73.4 (7.7)</td>
<td>73.7 (9.4)</td>
</tr>
<tr>
<td>MBP, mm Hg</td>
<td>84.5 (9.5)</td>
<td>84.8 (10.1)</td>
</tr>
<tr>
<td>After BH</td>
<td>91.6 (7.9)</td>
<td>90.7 (13.2)</td>
</tr>
</tbody>
</table>

Values of HR and MBP are during basal conditions and after the breath-
holding (BH) period. Values in parentheses are SDs.
pausal women. Another mechanism proposed for the vascular protective effect of estrogens is favorable modulation of vasoreactivity. In fact, estrogens are well known for their systemic vasoactivity. Intravenous administration of ethinyl estradiol in postmenopausal women produces an increase in coronary flow and cross-sectional area and a decrease in resistance of coronary arteries. Several studies have demonstrated that estrogens improve vascular flow and arterial pulsatility. A recent TCD study has shown an increase of flow resistance of the internal carotid artery and MCA during postmenopausal years, suggesting that this effect may be one of the mechanisms by which menopause is associated with the increased risk of vascular disease.

The mechanism for the estrogen-related arterial vasodilation and improved pulsatility is most likely mediated through increased production of prostacyclin or enhanced release and/or activity of nitric oxide. The possibility of a direct effect of estrogens on the arterial wall must also be considered, because estrogens influence artery wall metabolism, as suggested by the presence of estrogen receptors in the arterial wall.

The possible pathophysiological significance of reduced cerebral reactivity to hypercapnia in postmenopausal women does not necessarily imply that cerebrovascular disorders after menopause should be considered predominantly on a hemodynamic basis, excluding other well-known mechanisms of ischemic events. However, there is evidence that in areas of the brain where there is limited capacity for further capillary vasodilation, susceptibility to ischemic damage is increased. For this reason, altered cerebral hemodynamics can be considered a sign of increased risk of cerebrovascular events. This seems confirmed by several investigations showing an association between risk factors for stroke such as smoking or carotid lesions and the presence of a reduced cerebrovascular reserve capacity. Our finding that cerebrovascular reactivity to hypercapnia in the postmenopausal women was significantly lower than that of age-matched men is difficult to explain, but it furthermore suggests the existence of differences in the pathogenesis of stroke in the two sexes. This is also confirmed by the fact that atherosclerotic vascular lesions are more severe in men than in women of similar age. On the basis of our data we hypothesize that impaired cerebral hemodynamics, probably related to low levels of estrogen, may be particularly important in the pathophysiology of cerebrovascular disease in postmenopausal women. Further studies, also associated with measures of sex hormonal levels, are needed to confirm our data and to determine whether estrogen replacement therapy is able to bring about an improvement in cerebrovascular reactivity.

References
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