Evaluation of the Vertebrobasilar–Posterior System by Transcranial Color Duplex Sonography in Adults

Martin Schöning, MD, and Jochen Walter

Background and Purpose: The transcranial color duplex sonography technique was applied to the vertebrobasilar–posterior system to provide normal data for clinical application.

Methods: The intracranial posterior circulation was studied in 49 healthy volunteers (mean±SD age, 35±12 years) by a transcranial and suboccipital approach with a 2.0-MHz sector transducer of a computed sonography system.

Results: The posterior cerebral artery and the vertebrobasilar system were depicted clearly in the color Doppler mode. Pulsed Doppler signals could be recorded in the posterior cerebral (100%), basilar (92%), and vertebral arteries (89%). The following normal values were provided for all vessels: systolic peak, end-diastolic maximum, time-averaged, and time-averaged maximum velocities; resistance and pulsatility indexes; and a spectral broadening index. Mean±SD values were 45.9±9.6, 45.5±10.8, and 39.2±10.6 cm/sec for time-averaged maximum velocity, and 28.3±6.5, 30.6±7.2, and 24.7±8.4 cm/sec for time-averaged velocity in the posterior cerebral, basilar, and vertebral arteries, respectively. In a reproducibility study, duplex measurements of the posterior cerebral arteries were repeated in 27 subjects. The correlation between the two examiners was high (r=0.56, p<0.0001 for time-averaged maximum velocity).

Conclusions: Color duplex sonography of the vertebrobasilar–posterior system is a new, noninvasive, bedside investigative technique. It permits visualization of artery flow in real time, relating these to adjacent brain and cranial structures, as well as angle-corrected duplex measurement of "true" flow velocities at defined sites of the vessels. Thus, it will open new diagnostic possibilities in disorders of the posterior circulation.

KEY WORDS • cerebral arteries • ultrasonics • vertebrobasilar circulation

Recent improvements in ultrasound technology permit application of color duplex sonography to the intracranial examination.1–5 Systematic studies of the middle cerebral artery have been reported.6–7 In this paper we describe our experience with this new method in the posterior circulation of an adult population to provide normal data for subsequent clinical application.

Subjects and Methods

Over 10 months, we studied 49 healthy volunteers (23 women and 26 men) without history or physical signs of cerebrovascular disease. Extracranial arterial disease was excluded by color duplex sonography of the carotid and vertebral arteries. Mean±SD age was 35±12 (range, 20–63) years, similarly distributed in women and men. We used a computed sonography system (Acuson 128, Mountain View, Calif.) equipped with a dual-frequency 2.0/2.5-MHz sector scan transducer of 19-mm aperture size that was used solely in the 2.0-MHz frequency mode.

Color Doppler Imaging of the PCA

Examination began after at least 10 minutes of rest in the supine position. The probe was applied to the preauricular or supra-auricular area of the temporal bone, and an optimal acoustic window was searched for in the B-mode image. Because of the high absorption rate of ultrasound energy (approximately 80%) by the skull,8 the gain level had to be augmented in B-mode scan to obtain a good demonstration of basal cerebral structures. In this way, the typical butterfly figure of the mesencephalon and the pulsating basal cerebral arteries could be detected in most cases, and the central region of the brain could be expanded to achieve a better resolution of details.

In addition to brain structures, which were shown in the customary gray scale mode, the basal cerebral arteries could be displayed directly in the color Doppler mode. With this technique, a large number of sample volumes of pulsed Doppler beams were distributed equally over a selectable portion of the B-mode image. Mean velocity measurements of any sample volume were instantaneously converted into a color code. Flow toward or away from the transducer was displayed in red and blue, respectively. Higher flow velocities were represented by a greater intensity of the color code and lower velocities by a lesser intensity. The color signal was superimposed over the B-scan image in real-time.
mode. Thus, the course of basal cerebral arteries could be recognized immediately, and mean intravascular flow velocities could be estimated simultaneously. The velocity range of the color scale could be adjusted within variable limits (from approximately 0.3 to 1.1 m/sec in both directions) to the prevailing mean flow velocities to avoid the aliasing effect with color wrapping.

The posterior cerebral arteries (PCAs) appeared as semicircular colored lines surrounding the midbrain. Their precommunicating (PI) and anterior postcommunicating (P2) parts were displayed in red and the posterior P2 part beside and behind the mesencephalon in blue. The PCA was difficult to find at the color Doppler energy output level of 85 mW/cm² spatial peak time average intensity (I-SPTA) of the computed sonography system used. Therefore, the vessel was searched for at the level of 405 mW/cm² (I-SPTA) and subsequently examined also at the lower energy level. The visibility of the PCA was assessed as “clearly visible,” “barely visible,” or “not visible” in both settings. We found the P1 and P2 parts of the PCA in nearly all cases, sometimes by slightly shifting or rotating the transducer.

**Color-Coded Duplex Sonography of the PCA**

Intravascular flow velocities of the PCA were recorded by focusing one sample volume of 3-mm axial size (lateral size less than 2 mm) on its PI part. Pulsed Doppler examination of the right and left P1 was executed from the corresponding side. We always tried to place the sample volume into a part of the PI, which ran directly toward the transducer at an angle of 0–20°.

**FIGURE 1.** Top panel: Transcranial color-coded duplex sonography of the right posterior cerebral artery (PCA) in a 28-year-old woman. Above: Axial section of the brain with enlargement of the central region showing the butterfly-like figure of the midbrain and the color Doppler image of the posterior cerebral arteries. The velocity range of the color Doppler scale is set at 40 cm/sec in both directions. Sample volume (two horizontal bars) 3 mm in size is placed in PI part of right PCA at a 60-mm depth. Angle between Doppler beam (dotted line) and course of the vessel, marked by two solid lines, is adjusted (13°). Below: Doppler waveform of corresponding PCA flow pattern. Bottom panel: Schematic representation of transcranial color Doppler sonography as shown in top panel.
Vertebral and the basilar arteries, when completely measured by placing a sample volume of 3 mm size to the most distal point, where duplex sonographic correction was performed in all cases. Thereafter, the color Doppler image of the posterior P2 part and the posterior communicating artery, but pulsed Doppler measurements were not done routinely.

**Color Doppler Imaging and Duplex Measurements of the Verteobasilar System**

The intracranial part of the vertebral arteries and the basilar artery was examined by a suboccipital approach. For a better comparison of flow velocities with those of the PCA, the volunteers remained recumbent, turned on the right side, with the head midline, inclined forward, supported by the right arm or a cushion. The transducer was applied in midnuchal transverse position. When the occipital foramen was searched, a hypoechoic circle appeared, surrounded by the hyper-echoic line of the occipital bone. In this section, the vertebral and the basilar arteries, when completely displayed, made a typical Y figure (Figure 2). The distance of the vertebral artery junction to the transducer was noted.

Intravascular flow velocities of both vertebral arteries were measured by placing a sample volume of 3 mm size into a segment of at least 1.0 cm straight course. Angle correction was performed in all cases. Thereafter, the transducer was turned into the long axis. The course of the color-depicted basilar artery was followed upward to the most distal point, where duplex sonographic angle-corrected measurements of flow velocities were taken. The clivus could always be detected as an echogenic line in the B-mode scan. In some cases in which the basilar artery could not be demonstrated sufficiently in the long axis (probably because of a curved course), pulsed Doppler measurement was done in the transverse section at a proximal site of the basilar artery above the junction point of the vertebral arteries (which had to be depicted obligatorily).

**Measurements and Statistical Evaluation**

All duplex sonographic measurements were recorded only if Doppler registration was stable and reliable over a period of at least 5 seconds. Every examination was documented with a video color printer. The following measurements of each artery were noted: 1) the distance of the sample volume to the transducer; 2) the angle between the course of the vessel and the Doppler beam; 3) maximum systolic velocity (Vs); 4) maximum end-diastolic velocity (Ved); 5) time-averaged velocity (TAV) (i.e., the mean of all frequencies occurring above and below the baseline), averaged over at least three complete cardiac cycles; and 6) time-averaged maximum velocity (TAMX) (i.e., the mean of all peak frequencies), averaged over one cardiac cycle. We calculated resistance-index as RI=(Vs−Ved)/Vs according to Pourcelot and pulsatility index as PI=(Vs−Ved)/TAMX according to Gosling et al. In addition, we calculated a modified spectral broadening index with the formula SBI′=1−TAV/TAMX in analogy to a definition of Douville et al., who put the mean and maximum frequency at the systolic peak into the formula SBI=1−fmean/fmax.

Twenty-seven volunteers from the original group (mean±SD age, 31 [range, 20–55] years) agreed to participate in a reproducibility study with a second transcranial examination of the PCA. This was performed some weeks after the first investigation by one of us (J.W.) who had assisted during the first examination.

Statistical evaluation was done using the SAS System 6.04 programs. All parameters and side-to-side differences are indicated as mean value and standard deviation. Age dependency of flow velocities was tested by...
Schöning and Walter  

**Color Duplex Sonography of Posterior Circulation**

FIGURE 3. Top panel: Transcranial color-coded duplex sonography of embryonal-type right posterior cerebral artery (PCA) in a 50-year-old man. Axial section of brain with enlargement of central region is analogous to Figure 1. Above: Color Doppler image of PCA emerging in a continuous way from internal carotid artery (ICA). Sample volume is placed in proximal segment of PCA that would correspond to posterior communicating artery (PCOA). P2 part of PCA is shown at lateral circumference of midbrain. Lowest velocity range of color Doppler scale is selected (30 cm/sec in both directions) for better delineation of even parts of vessel with perpendicular course to Doppler beam. Therefore, aliasing effect occurs (shown by color wrapping) in other segments with a minor angle to Doppler beam. Angle correction is applied. Below: Doppler waveform of embryonal-type PCA with flow in direction of transducer. Bottom panel: Schematic representation of top panel. M, midbrain; 1, internal carotid artery; 2, posterior cerebral artery; 3, P2 part of PCA.

Calculating the Spearman correlation coefficient. In the reproducibility study, flow velocities are correlated with the Pearson correlation coefficient.

**Results**

**Posterior Cerebral Artery**

**Color Doppler Imaging.** The semicircular course of the PCA with its P1 and P2 parts was visible in all 49 volunteers on both sides with the exception of the left PCA in a 47-year-old man. In the higher energy output setting of the Doppler device, 86 of 98 P1 segments (88%) were clearly visible and in 11 cases barely visible. Reduction of energy output to the lower level, studied in 43 subjects, impaired visibility of the vessel’s course: in 20 of 86 P1 parts (23%), the vessel could not be recognized; 42 (49%) were clearly visible; and 24 (28%) just barely visible. The posterior communicating artery was seen in 15 cases on the left side and in 23 cases on the right. In three subjects, an embryonal type of PCA was identified on one side (Figure 3).

**Color-Coded Duplex Sonography.** A pulsed Doppler signal of the PCA in its P1 or anterior P2 part was obtained in all volunteers on both sides. In the 47-year-old man mentioned above, the Doppler spectrum of the left P1 could be recorded from the right side. Of the Doppler spectra obtained in the higher energy output setting, 91 of 98 (93%) were good, and seven (7%) were sufficient for a proper evaluation. With the lower energy output, in 19 of 86 vessels (22%) no Doppler signal could be recorded, 34 (40%) could be evaluated well, and 33 (38%) could be evaluated sufficiently.

The mean±SD depths of the sample volume were 63.0±4 mm on the left side and 63.7±4 mm on the right. The mean±SD angles of the PCA to the Doppler beam were 7±13° and 8±13° on the left and right sides, respectively. Mean values, standard deviation and range
of angle-corrected flow velocities, and indexes of all vessels are shown in Table 1. There were no significant side-to-side differences of flow velocities (Table 2). Pearson correlation coefficients between right and left PCA were 0.65 and 0.53 for Vs and TAMX, respectively ($p<0.0001$) and 0.48 for TAV ($p<0.005$).

Analysis of age dependency resulted in a slight decrease of systolic peak velocity with increasing age (Spearman correlation coefficient, $-0.24$; $p<0.05$); mean velocities showed no correlation with age.

In the reproducibility study, reliable pulsed Doppler signals were recorded in 53 of 54 posterior cerebral arteries. The second examiner investigated the PCA at a slightly more lateral site of the vessel (mean difference, 1.5±4 mm), with a mean angle of 13±13° (mean angle difference of 6±17° compared with the first series). There were only small differences between the flow velocities measured (Table 3). Accordingly, the correlation of flow velocities between both series was highly significant.

Vertebrobasilar System

Color Doppler Imaging. Both vertebral arteries and the basilar artery could be depicted as a typical Y sign in 39 subjects (80%). In eight males, a partial or complete Y figure could not be shown (seven left and four right vessels are shown in Table 1). There were no significant pulsed Doppler signal could be recorded in 42 (86%) of the right and 45 (92%) of the left vertebral arteries. They had all been depicted in the color Doppler mode before. Measurements and waveform indexes are shown in Table 1. No significant side-to-side differences could be found in the vertebral arteries (Table 2). There was no age dependency of flow velocity values in the vertebrobasilar system.

Discussion

Until now, two color Doppler studies of basal cerebral arteries existed in which the PCA was depicted in 94.6% and 54% of cases. In a recent transcranial Doppler report, Hashimoto and Hattrick indicated peak velocities of the PCA that were rather high (compare Table 4). To our knowledge, color duplex measurements of the vertebrobasilar–posterior system have not been reported to date.

Compared with transcranial Doppler sonography investigations, PCA flow velocities in our study are somewhat higher13-17 (Table 4). We attribute this to the facts that we can place a small sample volume under visual control exactly at a vessel site where the angle to the Doppler beam is small and that we can correct flow velocities recorded at higher angles. In this way, we can get as near as possible to “true” flow velocities.

The detection rate of pulsed Doppler measurements in the PCA exceeded that of transcranial Doppler studies only when the high energy output setting of our color Doppler device was selected. In clinical investigation, the time of examination could be shortened markedly, and the results were optimized when it was initiated with a high energy output and continued with the lower setting if possible. High intensities may permit transcranial Doppler investigation in a patient with poor ultrasound bone window18 and the results may make angiography unnecessary or influence important clinical decisions. Therefore, a high detection rate seems to be of great importance for us.

### TABLE 1. Normal Values for Flow Velocities and Waveform Indexes in the Vertebrobasilar–Posterior System

<table>
<thead>
<tr>
<th>Vessel</th>
<th>$n$</th>
<th>Depth (mm)</th>
<th>Vs (cm/sec)</th>
<th>Ved (cm/sec)</th>
<th>TAV (cm/sec)</th>
<th>TAMX (cm/sec)</th>
<th>RI</th>
<th>PI</th>
<th>SBI'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior cerebral artery</td>
<td>98</td>
<td>7.5±12.6</td>
<td>63.9±4.1</td>
<td>69.7±13.0</td>
<td>32.6±6.4</td>
<td>28.3±6.5</td>
<td>45.9±9.6</td>
<td>0.53±0.05</td>
<td>0.82±0.13</td>
</tr>
<tr>
<td>(0–55)</td>
<td></td>
<td>(55–72)</td>
<td>(41–101)</td>
<td>(17–48)</td>
<td>(14–50)</td>
<td>(22–73)</td>
<td>(0.41–0.65)</td>
<td>(0.53–1.12)</td>
<td>(0.18–0.63)</td>
</tr>
<tr>
<td>Basilar artery</td>
<td>45</td>
<td>11.0±17.1</td>
<td>82.5±8.0</td>
<td>67.2±15.5</td>
<td>32.6±7.7</td>
<td>30.6±7.2</td>
<td>45.5±10.8</td>
<td>0.51±0.07</td>
<td>0.77±0.17</td>
</tr>
<tr>
<td>(0–60)</td>
<td></td>
<td>(69–97)</td>
<td>(35–114)</td>
<td>(18–48)</td>
<td>(14–50)</td>
<td>(24–67)</td>
<td>(0.35–0.66)</td>
<td>(0.52–1.22)</td>
<td>(0.03–0.51)</td>
</tr>
<tr>
<td>Intracranial vertebral arteries</td>
<td>87</td>
<td>22.8±17.4</td>
<td>59.2±7.4</td>
<td>60.0±15.8</td>
<td>27.2±8.5</td>
<td>24.7±8.4</td>
<td>39.2±10.6</td>
<td>0.54±0.08</td>
<td>0.84±0.22</td>
</tr>
<tr>
<td>(0–60)</td>
<td></td>
<td>(41–78)</td>
<td>(29–95)</td>
<td>(9–50)</td>
<td>(10–43)</td>
<td>(17–64)</td>
<td>(0.35–0.79)</td>
<td>(0.48–1.70)</td>
<td>(0.17–0.68)</td>
</tr>
</tbody>
</table>

All parameters are mean±SD, with ranges in parentheses. $n$, Number of vessels investigated; Depth, distance of the sample volume to transducer; Vs, peak systolic velocity; Ved, maximum end-diastolic velocity; TAV, time-averaged velocity; TAMX, time-averaged maximum velocity; RI, resistance index $[(Vs/Ved) / Vs]$; PI, pulsatility index $[(Vs/Ved) / TAMX]$; SBI', modified spectral broadening index $1–TAV/TAMX$.

### TABLE 2. Side-to-Side Differences of Flow Velocities

<table>
<thead>
<tr>
<th>Vessel</th>
<th>$n$</th>
<th>Vs (cm/sec)</th>
<th>Ved (cm/sec)</th>
<th>TAV (cm/sec)</th>
<th>TAMX (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior cerebral artery</td>
<td>49</td>
<td>1.9±11.0</td>
<td>0.4±6.2</td>
<td>0.8±6.7</td>
<td>0.1±9.3</td>
</tr>
<tr>
<td>Intracranial vertebral arteries</td>
<td>42</td>
<td>0.6±20.6</td>
<td>0.5±11.1</td>
<td>0.5±10.5</td>
<td>0.3±13.4</td>
</tr>
</tbody>
</table>

All parameters are mean±SD. Vs, peak systolic velocity; Ved, maximum end-diastolic velocity; TAV, time-averaged velocity; TAMX, time-averaged maximum velocity.
The high-detail resolution of our color Doppler device allowed in three volunteers identification of an embryonal-type PCA on one side: the main stream supplying the PCA emerged in a continuous way from the internal carotid artery. There is no question that we did not confirm this by angiography. In two of these subjects, the sum of vertebral artery flow volume (evaluated according to Bendick and Glover by color duplex measurement at the intertransverse part of both vertebral arteries) was remarkably low: 92 and 133 ml/min, respectively. This may be an additional sign for a collateral supply from the anterior circulation.

Color Doppler imaging makes the examination of the vertebrobasilar system markedly easier. Because the vertebral arteries and the basilar artery can be depicted with intraluminal flow volume, provided the diameter of the vessel remains constant. At the site of a stenosis, the flow volume fluctuates and the waveform becomes irregular. A characteristic feature of a stenosis is the typical waveform with a predominant end-diastolic flow and occasionally a flow reversal. Therefore, we often could not depict the top of the basilar artery even by increasing sensitivity (i.e., by lowering the velocity range of the color Doppler scale). Therefore, color duplex recordings had to be taken mostly in the midpart of the basilar artery at a mean maximum distance of 82 mm. "Blind" Doppler registrations at deeper sites were possible but are not considered in this study. The top of the basilar artery seems to remain a blind spot in the color Doppler technique.

In eight subjects, the technique failed to depict a part of or the whole vertebrobasilar system; remarkably, they all were males. In three of them, we supposed the cause was hypoplasia of a vertebral artery by Doppler volume flow measurement at the intertransverse part of the corresponding vertebral artery. We assume that a curved or even coiled course of the basilar artery, which seems to be common, may explain the failure rate of its detection.

Table 3. Reproducibility of Flow Velocity Measurements in 53 Posterior Cerebral Arteries

<table>
<thead>
<tr>
<th>Examiner</th>
<th>Vs (cm/sec)</th>
<th>Ved (cm/sec)</th>
<th>TAV (cm/sec)</th>
<th>TAMX (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>73.7±13.0</td>
<td>34.0±6.5</td>
<td>29.0±6.2</td>
<td>48.4±9.7</td>
</tr>
<tr>
<td>2</td>
<td>69.8±10.8</td>
<td>30.4±6.0</td>
<td>29.1±6.6</td>
<td>45.7±8.5</td>
</tr>
</tbody>
</table>

Values of both measurements and their correlation coefficients are mean±SD. Vs, peak systolic velocity; Ved, maximum end-diastolic velocity; TAV, time-averaged velocity; TAMX, time-averaged maximum velocity; r, Pearson correlation coefficient.

Table 4. Normal Values of Flow Velocities in Posterior Cerebral Arteries Reported in Different Studies

<table>
<thead>
<tr>
<th>References</th>
<th>n</th>
<th>Detection rate (%)</th>
<th>Vs (cm/sec)</th>
<th>Ved (cm/sec)</th>
<th>TAMX (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aaslid et al (1982)</td>
<td>50</td>
<td>60</td>
<td>54±12 L</td>
<td>27±7 L</td>
<td>39±9 L</td>
</tr>
<tr>
<td>Harders and Gilsbach (1985)*</td>
<td>50</td>
<td>94</td>
<td>57±12 R</td>
<td>28±8 R</td>
<td>41±9 R</td>
</tr>
<tr>
<td>Arnolds and Reutern (1986)*</td>
<td>51</td>
<td>80</td>
<td>59±11</td>
<td>29±7</td>
<td>37±10</td>
</tr>
<tr>
<td>Grolimund and Seiler (1988)</td>
<td>535</td>
<td>65</td>
<td>53±11†</td>
<td>26±7†</td>
<td>34±8†</td>
</tr>
<tr>
<td>Hennerici et al (1987)</td>
<td>50</td>
<td>88</td>
<td>60±21‡</td>
<td>29±8‡</td>
<td>37±10‡</td>
</tr>
<tr>
<td>Ringelstein et al (1990)</td>
<td>106</td>
<td>97</td>
<td>192±180 L</td>
<td>152±68 R</td>
<td>39±10</td>
</tr>
<tr>
<td>Hashimoto and Hattrick (1991)</td>
<td>13</td>
<td>92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schonning and Walter (1992)</td>
<td>49</td>
<td>100</td>
<td>70±13</td>
<td>33±6</td>
<td>46±10</td>
</tr>
</tbody>
</table>

Flow velocities are mean±SD. n, number of subjects investigated; Vs, peak systolic velocity; Ved, maximum end-diastolic velocity; TAMX, time-averaged maximum velocity; L, left posterior cerebral artery (PCA); R, right PCA.

*Flow velocities indicated in kilohertz were converted by the factor 39 in centimeters per second.
†Age of subjects, <40 years.
‡Age of subjects, 40–60 years.
time-averaged maximum velocity generally increases markedly, whereas time-averaged velocity may remain constant or even decrease. Typically, the Doppler spectrum broadens. Douvoule et al. expressed the degree of broadening of the Doppler spectrum in the formula $SBI = 1 - \frac{I_{\text{mean}}}{I_{\text{max}}}$ and attributed high sensitivity to this index for assessing minor or moderate stenoses of the carotid artery. As we were able to measure both time-averaged flow velocities and time-averaged maximum flow velocities, we propose a modified spectral broadening index as $SBI = 1 - \frac{\text{TAV}}{\text{TAMX}}$. This index is remarkably constant throughout the extracranial and intracranial vessels that supply the brain, and it increases in stenoses of the basal cerebral arteries (M. Schöning, unpublished data). Its diagnostic significance remains to be established by further investigations.

An important objective of our study was to have our results verified by a second examiner. In the reproducibility study, flow velocity measurements of both investigators correlated well. The high side-to-side and interobserver correlations show that flow velocities of the PCA, which has been considered difficult to examine, can be measured in a fairly precise manner.

In conclusion, we think that color duplex sonography of the vertebrobasilar–posterior system is a reliable method in the evaluation of the posterior circulation; color depiction of basal cerebral arteries facilitates an exact placement of a sample volume at any site of a vessel's course. Angle-corrected measurement of true flow velocities is possible. As a noninvasive, real-time examination technique, color duplex sonography can be performed at bedside and repeated as often as desired for follow-up control. In conjunction with color Doppler imaging of the extracranial vertebral arteries, the technique permits investigation of the posterior circulation through an integrated approach.

Acknowledgment

The authors are indebted to Mr. C. Meisner for his support in the statistical evaluation of data.

References

Evaluation of the vertebrobasilar-posterior system by transcranial color duplex sonography in adults.

M Schöning and J Walter

*Stroke*. 1992;23:1280-1286
doi: 10.1161/01.STR.23.9.1280

*Stroke* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1992 American Heart Association, Inc. All rights reserved.
Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/23/9/1280