Chapter 3

Success rate of transcranial color-coded duplex ultrasonography in visualizing the basal cerebral arteries in vascular patients over 60 years of age

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Abstract
Background and Purpose
Clinically important atherosclerotic cerebrovascular disease is mainly found in patients aged >60 years. Transcranial color-coded duplex ultrasonography (TCCD) is a relatively new technique for investigating the basal cerebral arteries; however, it is often hampered by impenetrable ultrasound windows. The aim of this study was to ascertain the as yet unknown success rate of TCCD regarding visualization of the basal cerebral arteries in patients >60 years, to provide reference data, and to compare any possible male/female differences.

Methods
In 112 atherosclerotic white patients >60 years of age, the anterior, middle, and posterior cerebral arteries and the vertebral and basilar arteries were insonated.

Results
In men, 99% of the temporal and 94% of the suboccipital windows could be penetrated by ultrasound compared with 77% and 95%, respectively, in women. The male versus female vessel detection rates were 91% versus 58% for the anterior cerebral artery, 97% versus 73% for the middle cerebral artery, 97% versus 68% for the posterior cerebral artery, 94% versus 93% for the vertebral artery, and 91% versus 79% for the basilar artery. In 77% of men but only 33% of women could all vascular segments be investigated. All intracranial arteries were insonated at a deeper level in men. The women showed significantly higher blood flow velocities than the men.

Conclusions
In elderly white men the vessel detection rate is >90%. In women there is a much lower detection rate, due to impenetrable temporal windows. Visualization of all major intracranial arteries is possible in only one third of female patients >60 years of age.
Transcranial color-coded duplex ultrasonography (TCCD) permits visualization of intracranial blood vessels and direction of blood flow, which can be used to detect intracranial vascular pathology and to evaluate intracranial collateral flow. An important limitation of transcranial ultrasonography is its heavy dependence on the acoustic property of the temporal bone, which worsens with ageing, notably in women.

As clinically important cerebrovascular disease is found mainly in elderly atherosclerotic patients, TCCD may well have the highest potential diagnostic benefits in these patients. However, the success rate of TCCD regarding visualization and adequate Doppler examination of the basal cerebral arteries of the circle of Willis (Figure 1) in these patients is largely unknown. Our goal was to assess the success rate of TCCD in the examination of the basal cerebral arteries in atherosclerotic vascular patients >60 years of age. A set of reference data of blood flow velocities for this particular patient group is provided, and differences between men and women are analyzed with respect to the success rate of visualization, insonation depths, and blood flow velocities.

**Figure 1.** Typical normal polygon configuration of the circle of Willis.
Subjects and Methods

Subjects
TCCD was introduced to our vascular laboratory in 1995. To become familiar with this technique, a vascular technologist with wide experience in duplex scanning of peripheral vascular arteries who was also skilled in conventional transcranial Doppler investigation techniques first examined the basal cerebral circulation in 25 volunteers. After this period of learning, the study proper began. Patients aged >60 years, all suffering from atherosclerotic vascular disease, were recruited from the vascular surgical wards or the vascular outpatient clinic. All subjects included were of Caucasian descent. Patients with a history of transient ischemic attacks or stroke were not included, because this could have influenced local functional anatomy and blood flow velocities in the basal cerebral arteries. All patients underwent routine duplex examination of the extracranial brain-supplying arteries before transcranial investigation.

Technique
TCCD was performed with a 2.0- to 2.5-MHz phased-array probe (Hewlett-Packard Sonos 2000). Examinations of the main trunk of the middle cerebral artery (M1), the precommunicating part of the anterior cerebral artery (A1), the precommunicating part of the posterior cerebral artery (P1), and the postcommunicating part of the posterior cerebral artery (P2) through the temporal window (Figure 2) and of the vertebral arteries (VAs) and basilar artery (BA) through the suboccipital window (Figure 3) were performed in a standard manner, details of which are reported elsewhere. Although in case of unilateral temporal window failure it is sometimes possible to insonate the M1, A1 and P1 through the contralateral temporal window, this was not attempted. Common carotid artery compression tests to assess the physiological presence of the anterior and posterior communicating arteries were not performed.

Blood flow velocity measurements were taken with the sample volume set as narrowly as possible and with the vector of the cursor positioned in the center of the bloodstream, parallel to the vessel axis. The angle of insonation was always <60°. An examination was considered adequate if the designated vessel could be visualized by color flow and a representative Doppler signal could be obtained on spectral analysis for the calculation of the peak-systolic velocity (PSV), mean velocity (MV), end-diastolic velocity (EDV), and the pulsatility index (PI). The mean blood flow velocity is defined as the time-averaged maximum velocity during the cardiac cycle computed from the envelope of the Doppler spectrum. The PI is defined as (PSV-EDV)/MV. To avoid the influence of stenosis of the extracranial brain-supplying arteries on intracranial blood flow velocities, velocity data of patients with stenoses
of >50% or occlusions of the internal carotid and/or vertebral arteries were not included in the analysis. The origins of the extracranial VAs were not routinely examined.

**Figure 2.** Transcranial color-coded ultrasonogram of the circle of Willis. Left temporal window, axial scanning plane at the level of the mesencephalon. Ipsilateral M1 and P1 (red) and A1 (blue) are shown. The contralateral M1 and P1 (blue) and A1 (red) are also shown.

**Figure 3.** Transcranial color-coded ultrasonogram of the vertebrobasilar arteries using the suboccipital window. Typical Y sign, with both VAs in the upper part and the basilar artery in the lower part. The foramen magnum is circled. Vert indicates vertebral artery; Bas, basilar artery.

**Statistical analysis**

*Statistical Package for the Social Sciences* (SPSS 8.0; SPSS Inc) for Windows was used to analyze the results of the study. Comparison of the differing rates of arterial segment detection between the male and female groups was carried out using the $\chi^2$ test. Blood flow velocity in the cerebral arteries was found to be normally distributed and is therefore expressed as mean ±2SD. Mean insonation depths and their ranges were also calculated. Comparison of velocity data and insonation depth was performed using nonpaired $t$ tests. Significance was assumed at the 5% level.
Results

TCCD was performed on 112 patients, 70 men and 42 women. The mean age of the male patients was 70 years (range, 61 to 89 years) and of the female patients 71 years (range, 61 to 93 years). A striking difference was found in temporal window failure between male and female patients (Table 1). In the female patient group, 23% of the temporal windows were impenetrable (no signal from any of the intracranial arteries could be picked up), whereas only 1% of the temporal windows in men could not be penetrated by ultrasound. Suboccipital window failure was more equally distributed among men and women (6% versus 5%, respectively). Only 40% of female subjects as opposed to 83% of male subjects had adequate bilateral temporal windows through which both the anterior (A1 and M1) and the posterior circulation (P1 and P2) could be entirely visualized.

Table 1. Window Insonation.

<table>
<thead>
<tr>
<th></th>
<th>Male Patients (n=70)</th>
<th>Female Patients (n=42)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal windows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adequate</td>
<td>90%</td>
<td>51%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bilateral adequate</td>
<td>83%</td>
<td>40%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Impenetrable</td>
<td>1%</td>
<td>23%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Suboccipital windows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adequate</td>
<td>91%</td>
<td>79%</td>
<td>NS</td>
</tr>
<tr>
<td>Impenetrable</td>
<td>6%</td>
<td>5%</td>
<td>NS</td>
</tr>
<tr>
<td>All</td>
<td>77%</td>
<td>33%</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

"Adequate" indicates successful insonation of all arterial segments; "impenetrable" indicates complete absence of arterial Doppler signals. "All" indicates the total of 11 intracranial vascular segments that could be insonated in each patient.

In addition, even in the female subjects with echoluent temporal windows, vessel detection was sometimes difficult and Doppler signals were often weak. When individual patients are considered, successful insonation of all major intracranial vascular segments was possible in 77% of men but in only 33% of women. In women, the ability to penetrate the temporal window worsened with increasing age. Window failure in the 60- to 75-year age group was 13%, whereas window failure in the >75-year age group was 46% (P=0.001). Examination of the A1 and P2 was notably unsuccessful in the female group (Table 2). Examination of the VA was equally successful in both men and women. Insonation of the BA, however, was less successful in women, although the difference was not statistically significant (P=0.053).

All intracranial arteries were insonated at a deeper level in the cranium in men than in
TCCD in older patients

women (Table 2). The vertebrobasilar arteries in particular were insonated at a deeper level in men, which is presumably a reflection of the larger size of the male neck. As a consequence of impenetrable bone windows and because of the exclusion of patients with significant carotid and/or vertebrobasilar stenosis, the velocity data of 72 patients (46 men and 26 women) remained to be analyzed. Overall arterial blood flow velocity was not found to be significantly higher in either the left or the right cerebral hemisphere. Therefore, to investigate

<table>
<thead>
<tr>
<th>Artery</th>
<th>Insonation Depth, cm</th>
<th>Velocity, cm/s</th>
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<tbody>
<tr>
<td></td>
<td>[Success of Insonation, %]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>A1</td>
<td>6.6 (4.6-8.0)</td>
<td>6.4 (4.7-7.5)</td>
</tr>
<tr>
<td></td>
<td>[91%]</td>
<td>[58%]</td>
</tr>
<tr>
<td>M1</td>
<td>5.2 (4.2-6.5)</td>
<td>5.0 (4.1-5.8)</td>
</tr>
<tr>
<td></td>
<td>[97%]</td>
<td>[73%]</td>
</tr>
<tr>
<td>P1</td>
<td>6.6 (5.7-7.5)</td>
<td>6.3 (5.3-7.3)</td>
</tr>
<tr>
<td></td>
<td>[97%]</td>
<td>[68%]</td>
</tr>
<tr>
<td>P2</td>
<td>6.1 (5.3-7.3)</td>
<td>5.7 (4.2-6.6)</td>
</tr>
<tr>
<td></td>
<td>[96%]</td>
<td>[63%]</td>
</tr>
<tr>
<td>VA</td>
<td>6.3 (4.5-9.2)</td>
<td>5.8 (4.4-7.2)</td>
</tr>
<tr>
<td></td>
<td>[94%]</td>
<td>[93%]</td>
</tr>
<tr>
<td>BA</td>
<td>8.3 (6.9-10.0)</td>
<td>7.8 (6.6-10.0)</td>
</tr>
<tr>
<td></td>
<td>[91%]</td>
<td>[79%]</td>
</tr>
<tr>
<td></td>
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 Depths are given as mean values with ranges; velocities and PIs are shown as mean ±2SD.
the influence of gender on blood flow velocity in the basal cerebral arteries, the results from the left- and right-side studies were combined and averaged. Blood flow velocity was higher in the anterior (A1, M1) than in the posterior (VA, BA, P1, P2) cerebral circulation, and the velocity in women was significantly higher than that in men, with the exception of the P2. The PIs did not significantly differ between men and women (Table 2).

<table>
<thead>
<tr>
<th>Study</th>
<th>Gender</th>
<th>n</th>
<th>A1</th>
<th>M1</th>
<th>P1</th>
<th>P2</th>
<th>VA</th>
<th>BA</th>
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<tr>
<td>Martin et al17</td>
<td>M, F</td>
<td>32</td>
<td>66</td>
<td>83</td>
<td>84</td>
<td>55</td>
<td>98</td>
<td>94</td>
</tr>
<tr>
<td>Baumgartner et al18</td>
<td>M</td>
<td>16</td>
<td>60</td>
<td>67</td>
<td>83</td>
<td>83</td>
<td>100</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>17</td>
<td>58</td>
<td>66</td>
<td>68</td>
<td>68</td>
<td>100</td>
<td>95</td>
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<tr>
<td>Current study</td>
<td>M</td>
<td>70</td>
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<td>F</td>
<td>42</td>
<td>58</td>
<td>73</td>
<td>68</td>
<td>63</td>
<td>93</td>
<td>79</td>
</tr>
</tbody>
</table>

**Table 3. Identified Intracranial Arteries in Current and Previous Studies.**

**Discussion**

This study shows TCCD to be very successful in identifying the basal cerebral arteries in elderly men. In contrast, examinations in elderly women are considerably hindered by unsuitable temporal windows. In a survey reviewing conventional transcranial Doppler results from 60 laboratories in the United States, percentages for failure to access the temporal window ranged between 0% and 65% (mean 16%). Limited data on vessel detection in elderly subjects using the more advanced TCCD device have been published. Only 2 other TCCD studies report on window failure in patients older than 60 years. Martin et al17 found 9 inadequate temporal windows (14%) in 32 healthy volunteers, but no details were given about the number of arterial segments imaged in each sex. Identification rates ranged from 55% for the P2 to 98% for the intracranial VAs. Baumgartner et al18 showed that the detection rate of cerebral arteries decreased in old age, but they did not find a large difference between men and women, probably because of small patient numbers (Table 3).

Because patients with transient ischemic attack or stroke were not included in this study, we do not think that insonation failure was caused by occlusion of intracranial vessels. The most probable explanation for temporal window failure is hyperostosis of the temporal bone, which is influenced by age, gender, and race. A likely explanation for not obtaining signals despite a penetrable acoustic window is severe hypoplasia or aplasia of basal cerebral arteries, which is not uncommon. Aplasia of the M1 or BA is extremely rare, but aplasia
or hypoplasia of the A1 or VA, for example, is found in 1% to 4% and 5% of subjects, respectively. In the male patients we studied, this might explain the slightly worse detection rate of the A1 compared with the M1, P1, or P2.

The suboccipital window was found to be unsuitable in 6% of men and 5% of women in this study. Marinoni et al12 used conventional transcranial Doppler on 624 patients and found an 11.2% and 5.7% absence of suboccipital windows in men and women, respectively. They attributed this difference to the increased attenuation of the ultrasound beam caused by the larger and thicker tendons of males. In this study, detection of the VAs was equally successful, but the identification rate of the basilar artery was lower in women than in men. We assume that this difference is caused by short, stiff, arthrotic necks in elderly women, preventing adequate flexion of the head needed to insonate the deep-set basilar artery. Another reason could be the smaller cross-sectional area of the foramen magnum in females.25

Little has been published about cerebral blood flow velocities in elderly atherosclerotic subjects with no neurological deficits. On comparison with TCCD17-18 and conventional transcranial Doppler studies26-29 in healthy volunteers of the same age, we found blood flow velocities to be 10 to 20% higher. Owing to the precise positioning of the sample volume and assessment of the angle of insonation, TCCD provides velocity values that are closer to the true values than those derived with conventional transcranial Doppler.30-33 Vascular narrowing of the cerebral arteries due to general atherosclerosis in our patients might also explain why we found higher velocities than those in the comparable studies of Martin et al17 and Baumgartner et al.18 Another reason might be compensatory vasodilatation of the brain tissue as a pathophysiological mechanism in atherosclerotic patients. Finally, technical differences between the ultrasound devices and their instrumentation should also be mentioned as a possible factor. The large SDs in the mean intracranial blood flow velocities found in this study and by other researchers17,18,26-29 show that a broad range of velocities can still be considered normal (Table 2). This is important for all investigators of cerebral hemodynamics and especially for those who use velocity criteria for the definition of intracranial arterial stenoses or detection of collateral flow. Interindividually different diameters of the basal cerebral arteries34 are probably the most important cause of the broad range of velocities, because flow velocity is inversely related to vessel diameter. Another cause is the inverse association between velocity and both hematocrit and fibrinogen concentrations, which explains 29% of the variance in mean velocity.29 Most transcranial ultrasound studies in healthy volunteers report higher velocities in women than in men.17,18,28,35-37 However, Martin et al17 and Vriens et al28 reported that this difference disappeared in elderly subjects.
In summary, our data show that in white men >60 years of age, TCCD is very successful, with vessel identification rates exceeding 90%. In white women of the same age there is a much higher failure rate, due to impenetrable temporal windows. Visualization of all major intracranial vascular segments is possible in only one third of women >60 years. Investigators of cerebral hemodynamics have to take into account that in subjects without cerebrovascular disease a broad range of intracranial blood flow velocities exists and that intracranial blood flow velocities are higher in women than in men. One answer to the problem of impenetrable temporal windows might be provided by ultrasound contrast-enhancing agents. The use of these relatively expensive agents, however, is of limited value in elderly men, because the vessel detection success rate in this group is already >90%.

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References

