Flow velocity patterns in and distensibility of the carotid artery bulb in subjects of various ages

ROBERT S. RENEMAN, M.D., PH.D., TINY VAN MERODE, M.D., PAUL HICK, E.E., AND ARNOLD P. G. HOEKS, PH.D.

ABSTRACT  Velocity patterns in and distensibility of the carotid artery bulb were studied in younger (20 to 30 years; n = 11) and older (50 to 60 years; n = 9) volunteers without detectable lesions of the cervical carotid arteries by means of a high-resolution, multigate, pulsed Doppler system coupled to a B mode imager. In the bulb the axial velocities were highest on the side of the flow divider, while regions of flow separation and recirculation were observed on the side opposite to this divider. Flow separation and recirculation were less pronounced and less common in the older subjects. Flow separation was not continuously present throughout the cardiac cycle. The distensibility of the carotid arteries was significantly diminished in older subjects, especially in the bulb. The velocity patterns in the carotid artery bulb of younger subjects corroborate the patterns observed in models. The diminished flow separation and recirculation in the older subjects might result from alterations in distensibility at the transition from common to internal carotid artery with increasing age.


IN A RECENT STUDY relating data derived from autopsy specimens to flow patterns and shear stresses as assessed in model bifurcation, Zarins et al. showed that in the carotid artery bulb, maximal intimal thickening and atherosclerotic plaque formation occurred in regions of flow separation and reduced shear stress. These regions were located on the side opposite to the flow divider. Regions with predominantly axial and unidirectional flow velocities and high shear stresses, located on the side of the flow divider, were relatively devoid of these wall changes. A zone of recirculation in the carotid artery bulb opposite to the flow divider was also observed in studies performed on excised human carotid artery bifurcations. In these investigations flow patterns were studied under conditions of steady flow, while undistensible materials and Newtonian fluids were used, conditions quite different from the situation in vivo. Although preliminary studies in models indicate that the flow patterns in the carotid artery bulb are similar under steady and pulsa-

tile flow conditions, certain differences have to be appreciated.

In this study we investigated the flow velocity patterns in the carotid artery bulbs of subjects of various ages by means of a high-resolution, multigate, pulsed Doppler system. With this system velocity profiles at discrete time intervals during the cardiac cycle and instantaneous velocity waveforms at various sites along the ultrasound beam can be recorded on-line. In addition, the system provides on-line information about the relative changes in diameter of arteries during the cardiac cycle, giving insight into the distensibility of these vessels.

Materials and methods

The study was performed on 20 male, normotensive (cuff blood pressure in the supine position <140/90 mm Hg) subjects without history of cardiovascular diseases. They were picked from a group of 350 subjects randomly selected from population registers for other purposes. All invited subjects participated in the study. In none of them could cervical carotid artery disease be detected by the ultrasound Doppler criteria previously described. Two groups of volunteers were investigated. Group 1 consisted of 11 subjects (ages 20 to 30 years, mean 24.6) and group 2 comprised nine subjects (ages 50 to 60 years, mean 53.7). Informed consent was obtained from all subjects before they entered the study.

The principle and features of the high-resolution, multigate, pulsed Doppler system have been described in detail before. For adequate interpretation of the data and accurate measurements, one must be informed of the site of velocity assessment.

From the Departments of Physiology and Biophysics, University of Limburg, Maastricht, The Netherlands.

Supported in part by the Dutch Heart Foundation and Fungo, which is subsidized by the Netherlands Organization for the Advancement of Pure Research.

Address for correspondence: Robert S. Reneman, M.D., Ph.D., Department of Physiology, Biomedical Center, University of Limburg, P.O. Box 616, 6200 MD Maastricht, The Netherlands.

Received June 22, 1984; revision accepted Nov. 8, 1984.
in relation to the position of the flow divider, the angle between
the axes of the common and internal carotid arteries, and the
angle of interrogation. Hence, in this study the multigate,
pulsed Doppler system was connected to an ATL Mark V B
mode imager with a short focus scanhead. In this configuration
the multigate device, which functionally replaces the single-
gate Doppler device of the ATL system, has the following
characteristics: pulse repetition frequency 16 kHz, emission
frequency 5.2 MHz, emission duration 1.2 μsec, sample inter-
val 0.6 mm, number of gates 64, and lower cut-off frequency
250 Hz. The sample volume of the multigate system in this
combination as measured in vitro was 1.75 mm³ at a range of
15 mm and 1.35 mm³ at a range of 20 mm.

The investigations were performed with the subjects in the
supine position with the head tilted slightly to the contralateral
side. Only the left carotid artery bifurcation was examined be-
cause of a longer entrance length (no anonymous artery) as
compared with the right side. The velocity profiles at discrete
time intervals during the cardiac cycle, the instantaneous velo-
city tracings along the ultrasound beam, and the relative diameter
changes of the artery during the cardiac cycle (Δd/d × 100%)
were recorded on-line at the following sites: common carotid
artery (about 3 cm proximal to the tip of the flow divider),
carotid bulb at the level of the tip of the flow divider (b₀)
and 1 cm more distally (b₁), and internal carotid artery (3 to 4
cm distal to the tip of the flow divider) (figure 1). For recording
of the velocity, the vessels were interrogated in the plane of
the carotid artery bifurcation at angles of 60 degrees (figure 1)
and 90 degrees with the vessel axis (figure 2), and perpendicular
to the plane of the bifurcation (figure 2). The latter is an approxi-
mation because the system does not allow visual control in this
position. Interrogation at an angle of 60 degrees mainly pro-
vides information about the axial flow component, but radial
and tangential components, if any, are recorded as well. Perpen-
dicular interrogations principally measure the radial component
of flow. In our system positive velocities have to be interpreted
as flow away from the probe.

The relative diameter changes were recorded in the plane of
the bifurcation at an angle of 60 degrees. This direction was
used because the assessment of vessel wall displacement is

**FIGURE 1.** Schematic representation of the sites of record-
ing. The situation for measurements in the plane of the bifurcation and interrogation at an angle
of 60 degrees with the vessel axis is depicted, when
the internal carotid artery (i.c.a.) is anterior (superfi-
cial, A) or posterior (B) to the external carotid artery
e(e.c.a.). In this direction mainly axial flow velocity
components are recorded. e.c.a. = common carotid
artery; b₀ = the bulb at the level of the tip of the flow
divider; b₁ = the bulb 1 cm more distally.

**FIGURE 2.** Schematic representation of the interrogations in the plane of the bifurcation at an angle of 90 degrees with the vessel
axis and perpendicular to this plane. In these directions mainly radial flow velocity components are recorded. Abbreviations as in
figure 1.
based on the detection of low-frequency Doppler signals originating from the sample volumes coinciding with the anterior and posterior walls.\textsuperscript{10} To ensure that the initial relative change at the beginning of the cardiac cycle was constant, it was reset to zero by a trigger derived from the R wave of a standard lead of the electrocardiogram. This trigger was also used to mark the start of the cardiac cycle when velocities were recorded. The absolute diameters, which were also measured in the plane of the bifurcation at an angle of 60 degrees, were assessed from the A mode of vessel wall displacement as determined with the multigate system. This A mode is different from the A mode as known in echocardiographic systems because of the rejection of stationary signals (cut-off frequency 5 Hz), and is displayed continuously on a cathode ray tube. The relative diameter changes (Δd/d × 100\%) are independent of the angle of interrogation and can be determined with an absolute accuracy of 0.5\%\textsuperscript{10} comparing favorably with the relative peak excursions observed (see Results). The absolute arterial diameters as obtained are dependent on the angle of interrogation and hence were multiplied by 0.87 (sin 60 degrees).

The velocity profiles, the instantaneous velocity tracings, and the relative diameter changes could be observed on-line on a cathode ray tube. The trigger derived from the R wave of the electrocardiogram was displayed as well. The variables as recorded during several consecutive cardiac cycles (usually 10) showed only minimal variations on a beat-to-beat basis (figure 3). From this series three cycles were selected, plotted on a x/y recorder (Philips), and used for further analysis. This procedure was followed for each sampling position and each sampling angle. The reproducibility of the variables as measured at a given position and under a certain angle is usually good. Only a limited number of velocity profiles during one cardiac cycle, generally 10 to 20 out of 256, is presented for the sake of clarity. The velocity profiles at discrete time intervals during the cardiac cycle and the relative diameter changes during this cycle as simultaneously recorded in the common carotid artery are shown in figure 3. The quadrature audio signal of the sound gate and the pulse code of the R wave of the electrocardiogram were stored on magnetic tape (Racal; 0 to 10 kHz, -3dB) for off-line spectrum analysis with a Medasonics spectrum analyser.

Only instantaneous velocity waveforms that were consistent in several gates and in all cardiac cycles recorded were considered as real velocity patterns. Differences in absolute diameters, relative diameter changes during the cardiac cycle, and pulse pressures between the two groups were evaluated for statistical significance by applying Student’s pooled t test. Differences in relative changes in diameter and absolute diameters between the common carotid artery and the carotid artery bulb within each group were evaluated for statistical significance with Student’s t test for paired data.

Results

The pulse pressure as measured in the brachial artery with the cuff method was 45.0 ± 10.5 mm Hg in group 1 and 42.2 ± 8.7 mm Hg in group 2, a nonsignificant difference.

In group 1 subjects the internal carotid artery was situated anterior (superficial) to the external carotid artery in five cases and posterior to this artery in the

**FIGURE 3.** Axial velocity profiles at discrete time intervals during the cardiac cycle and the relative diameter changes during this cycle as simultaneously recorded in the common carotid artery of a younger (A) and an older (B) subject. Three consecutive cardiac cycles are depicted. The negative deflection represents the trigger derived from the R wave of the electrocardiogram. Note the symmetric and flat velocity profiles that show only slight variations on a beat-to-beat basis. The arrow in the schematic drawing indicates the direction of flow. Abbreviations as in figure 1.
remaining six cases. The angle between the axis of the internal carotid artery and the extended axis of the common carotid artery was 10.8 ± 5.2 degrees (mean ± SD). In group 2 subjects the internal carotid artery was anterior to the external carotid artery in seven cases and posterior to this artery in only two cases. In this group the angle between the axis of the internal carotid artery and the extended axis of the common carotid artery was 12.6 ± 3.5 degrees (mean ± SD).

The absolute diameters and the relative diameter changes during the cardiac cycle in groups 1 and 2 are presented in table 1. At all levels the average arterial diameter tended to be larger in group 2 than in group 1, but the widening at the level of the bulb, relative to the more distal part of the internal carotid artery, was similar in both groups (14.8% in group 1 and 14.5% in group 2). At all levels the relative diameter increase during the cardiac cycle was significantly larger in group 1 than in group 2. In group 2 the diminished relative magnitude of arterial wall displacement during the cardiac cycle was most pronounced in the carotid artery bulb. In group 1 the relative diameter increase during the cardiac cycle was more pronounced in the bulb than in the common carotid artery, while the opposite was observed in group 2.

In the common carotid artery the velocity profile as recorded in the axial direction was generally symmetric and no retrograde flow was observed in this direction at any time during the cardiac cycle in either group 1 or group 2 (figure 3). The axial velocity profile as recorded in the carotid artery bulb was generally skewed, with the highest velocities on the side of the flow divider (figure 4, table 2). This skewness was most pronounced early in systole. Skewness of the axial velocity profile was associated with retrograde flow on the side of the bulb opposite to the flow divider (figure 4) in 81.8% of the cases in group 1 but only in

![Figure 4](http://circ.ahajournals.org/)

**FIGURE 4.** Axial velocity profiles at discrete time intervals during the cardiac cycle as recorded in the common and internal carotid arteries and proximally and more distally in the bulb of a young subject. The arrow represents the trigger derived from the R wave of the electrocardiogram. Note the skewed velocity profile (arrowhead) toward the flow divider and retrograde flow (open arrow) on the opposite side in systole at both levels in the bulb. Retrograde flow is not observed in the common and internal carotid arteries. The arrows in the schematic drawing indicate the direction of flow. Abbreviations as in figure 1.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Absolute diameters (d) and relative diameter changes during the cardiac cycle (Δd/d × 100%) in young and old subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CCA</td>
</tr>
<tr>
<td>Group 1</td>
<td>(20–30 yr; n = 11)</td>
</tr>
<tr>
<td>d (mm)</td>
<td>6.2 ± 0.5</td>
</tr>
<tr>
<td>Δd/d (%)</td>
<td>9.6 ± 1.3A</td>
</tr>
<tr>
<td>Group 2</td>
<td>(50–60 yr; n = 9)</td>
</tr>
<tr>
<td>d (mm)</td>
<td>6.4 ± 1.0</td>
</tr>
<tr>
<td>Δd/d (%)</td>
<td>5.6 ± 0.9</td>
</tr>
</tbody>
</table>

Data expressed as mean ± SD.
CCA = common carotid artery; b₀ and bₜ₁ = proximal and distal in the carotid artery bulb, respectively (see figure 1);
bₘₕₓ = maximal value in the bulb at either b₀ or bₜ₁; ICA = internal carotid artery.
Significantly different from group 2: a₂p < .0001; b₂p < .0005; c₂p < .01.
Significantly different from the CCA in this group: d₂p < .001; e₂p < .01; f₂p < .05.
TABLE 2
Flow patterns as recorded in the carotid artery bulb in young and old subjects

<table>
<thead>
<tr>
<th></th>
<th>Group 1 (20–30 yr; n = 11)</th>
<th>Group 2 (50–60 yr; n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest velocities near flow divider</td>
<td>10/11 (90.9%)</td>
<td>6/9 (66.7%)</td>
</tr>
<tr>
<td>Signs of flow separation and recirculation opposite to flow divider</td>
<td>11/11 (100.0%)</td>
<td>5/9 (55.6%)</td>
</tr>
<tr>
<td>Axial or radial</td>
<td>11/11 (100.0%)</td>
<td>5/9 (55.6%)</td>
</tr>
<tr>
<td>Axial and radial</td>
<td>8/11 (72.7%)</td>
<td>2/9 (22.2%)</td>
</tr>
</tbody>
</table>

33.3% of the cases in group 2. Retrograde flow started during the deceleration phase and changed into forward flow again later during the cardiac cycle (figure 5). The triphasic pattern of the velocity waveform is indicative of flow separation and recirculation. Skewed velocity profiles as well as flow separation and recirculation could be observed proximally (b₀) or distally in the bulb (b₁), or at both levels. In this small population the presence or absence of skewness of the axial velocity profile was not clearly related to the angle between the axes of the common and internal carotid arteries. The axial velocities in the carotid artery bulb, as measured by the mean frequency processor in the Doppler system, were low (peak average velocity around 1 kHz). No differences between the two age groups could be detected. In all but one case in group 1 the axial velocity profile was symmetric again in the internal carotid artery. At this site retrograde flow was never observed.

In the common and internal carotid arteries the instantaneous velocity as recorded along the ultrasound beam at an angle of 90 degrees in the plane of the bifurcation, representing the radial flow component, was nonpulsatile in nearly all cases. In the common carotid artery the average velocity in this direction was often just above or below zero, while inconsistencies between consecutive gates could be observed. In the internal carotid artery the average radial velocities were generally higher and clearly above zero. Similar

![Figure 5](http://circ.ahajournals.org/)

**FIGURE 5.** Instantaneous velocities as recorded at various sites along the ultrasound beam at the same sites and in the same subject as in figure 4. The arrow represents the trigger derived from the R wave of the electrocardiogram. Note the triphasic pattern of the velocity waveform in the bulb on the side opposite to the flow divider (open arrow) with forward flow early in systole followed by retrograde flow, starting during the deceleration phase, and forward flow again later during the cardiac cycle. This pattern is indicative of flow separation and recirculation as depicted in the schematic drawing. In this drawing recirculation is shown only at the level of b₀. The arrow in the schematic drawing indicates the main direction of flow. Abbreviations as in figure 1.
patterns were observed when the instantaneous velocity was recorded perpendicular to the plane of the bifurcation. In this direction, however, the radial component of flow was occasionally more pulsatile. In the carotid artery bulb a variety of velocity patterns was observed when recording in the radial direction. The instantaneous velocity could be pulsatile or nonpulsatile. Under pulsatile conditions the direction of flow was either from the probe or showed a triphasic pattern with flow away from the probe early in systole followed by flow toward the probe, starting during the deceleration phase, and flow away from the probe again later during the cardiac cycle (figure 6). The latter pattern was found only on the side opposite to the flow divider. This indicates that at this site, blood is also recirculating in the radial direction. In the carotid artery bulb flow separation and recirculation on the side opposite to the flow divider was more common and more pronounced in group 1 than in group 2 (table 2). The flow patterns most commonly observed in the carotid artery bifurcation are depicted schematically in figure 7.

**Discussion**

Although three-dimensional phenomena are described on the basis of two-dimensional measurements, the data as obtained in this study provide insight into the complicated flow pattern in the carotid artery bulb in man. In the bulb of young, asymptomatic subjects without evidence of cervical carotid artery lesions, the axial velocity profile is generally skewed, with the highest velocities near the flow divider. This skewness is most pronounced early in systole. Flow separation generally occurs on the side opposite to the
flow divider, as indicated by the occurrence of retrograde flow in the axial direction at this site in the bulb. The period of retrograde flow is usually followed by forward flow later during the cardiac cycle. These observations, in combination with the commutating flow in the radial direction, are indicative of areas of recirculation on the side opposite to the flow divider. The finding that blood recirculates in both the axial and radial direction suggests the presence of helical flow. The observation that in both the axial and radial direction retrograde flow does not start before the deceleration phase suggests that flow separation is not continuously present throughout the cardiac cycle.

Since the velocity differences observed in the radial direction are very small, the question can be raised as to whether these differences are real or a consequence of changes in the angle of incidence between the ultrasound beam and the direction of blood flow. This question is pertinent because deviation of 5 degrees from the normal induces an axial Doppler shift in the radial recording of 261 Hz in case of a maximum frequency of 3 kHz, a realistic figure considering the peak average frequency of 1 kHz found in the bulb (see Results). Moreover, slight deviations from 90 degrees may easily occur when recording perpendicular to the plane of the bifurcation because the Doppler system does not provide visual control in this position. Despite these conditions, the alternating velocity direction as observed in the radial recording opposite to the flow divider, is likely to be real because it is consistently present in only a limited number of gates. When resulting from differences in angulation, the axially induced velocity changes are expected to occur in most of the gates and would be more pronounced near the flow divider where the axial velocities are highest. Besides, similar velocity changes are observed at the same site in the vessel when recordings are made at an angle of 90 degrees in the plane of the bifurcation, a sampling position that can be accurately controlled on the cathode ray tube.

The flow patterns as found in the carotid artery bulb of young subjects are similar to those observed in a model under pulsatile flow conditions but with undistensible material and Newtonian fluids.\(^6\) In this model a continuously changing region of separation was observed opposite to the flow divider with vortices varying in size and energy level. High axial velocities near the flow divider and areas of flow separation and reversal on the side of the bulb opposite to this divider were also observed under conditions of steady flow in rigid models\(^1\)\(^-\)\(^2\) and studies on undistensible vessels in vitro.\(^4\) In this situation, however, the region of separation is fixed and a well-defined stable secondary flow structure can be observed.

In the carotid artery bulb of the older subjects the axial velocities are generally also higher near the flow divider, but flow separation and recirculation on the side opposite to this divider are less common and less pronounced than in the younger subjects. This difference between younger and older subjects cannot readily be explained on the basis of a more favorable diameter transition from common to internal carotid artery in the younger subjects. In this group the transition was more gradual than in the older subjects in whom the carotid artery bulb was slightly wider than the common carotid artery, a situation favoring recirculation. It cannot be excluded that in the older subjects the carotid artery bulb is smaller than measured because of intimal thickening on the side opposite to the flow divider,\(^3\) creating a situation less favorable for recirculation. The diameter of the cervical carotid arteries as found in this study, however, are in good agreement with those measured in postmortem specimens\(^5\)\(^-\)\(^6\) and are only slightly smaller than the diameters obtained from angiograms\(^1\) and ultrasound pulsed echocardiographic techniques,\(^13\) considering the accuracy of the various methods. The tendency to record larger diameters at older age is in keeping with the findings of Fujishiro and Yoshimura.\(^14\)

The skewness of the axial velocity profile in the carotid artery bulb can be considered as a curvature effect because the internal carotid artery branches from the common carotid artery at an angle. The average axial velocities as measured in the carotid artery bulb of both young and old subjects are relatively low, which is in agreement with previous results obtained with continuous wave Doppler systems.\(^15\)

A striking difference between the older and younger subjects is the reduction in arterial wall displacement during systole, especially at the level of the carotid artery bulb, in the older age group. In both age groups the relative increase in diameter of the common carotid artery during systole is in good agreement with the value previously published from our laboratory.\(^16\) The average relative diameter increase in the younger subjects as found in these studies is smaller (9.6% vs 14.2%) than that reported by Arndt et al.\(^1\) This difference may be explained by the amplitude dependency of the pulsed echo displacement technique as used by these investigators. Amplitude dependency can easily lead to overestimation of the relative diameter changes. The displacement method used in this study is amplitude independent over a wide range of amplitudes.\(^10\)
Since the pulse pressure as measured in the brachial artery is not significantly different in both age groups, one may assume that the reduction in arterial wall displacement during systole in older subjects reflects a reduced arterial distensibility. It is unlikely that diminished distensibility as such can be held responsible for the less pronounced and less commonly observed flow separation and recirculation on the side of the bulb opposite to the flow divider in the older subjects. These phenomena, after all, have been clearly demonstrated in models and studies in vitro with rigid materials with the same properties along the bifurcation (see above). When assuming a constant pulse pressure along the common and internal carotid arteries, differences in increase in relative diameter during systole may be interpreted as differences in distensibility. Hence, in the younger subjects the bulb can be considered to be more distensible than the common carotid artery. The opposite is observed in the older subjects. These differences in distensibility at the transition from common to internal carotid artery may explain the differences in flow separation and recirculation between both age groups. Further investigations are required to rate these findings at their true value.

The difference in distensibility between the common carotid artery and the carotid artery bulb in the younger subjects probably cannot be explained on the basis of structural differences because the wall of this artery and the wall of the major part of the bulb have a mainly elastic structure. The wall of the bulb, however, is thinner so that larger wall tensions are developed at comparable pressures and diameters. The more pronounced distensibility of the carotid artery bulb probably facilitates the functioning of the baroreceptors, which are located mainly in the proximal part of the bulb. In this light the reduced distensibility of the bulb in older subjects might explain the decreased baroreceptor sensitivity at this age.

The rather flat axial velocity profiles in the common and internal carotid arteries in both age groups confirm the results of earlier reports from Keller et al. and our own laboratory. The fast deceleration of blood flow in the middle third of the common carotid artery after the systolic peak, as observed by the former investigators, was not seen in the axial velocity profiles as recorded in this study. This can be explained by a difference in the site of measurement because we recorded our velocity profiles about 3 cm proximal to the tip of the flow divider, and the fast deceleration could be observed only over a distance of approximately 2 cm from this divider. The continuous flow in the internal carotid artery as recorded at an angle of 90 degrees in the plane of the bifurcation and perpendicular to this plane indicates the presence of a continuous radial flow component in this artery, especially since the behavior of velocities is coherent in adjacent gates. This radial flow component is probably a curvature effect. The less consistent and less pronounced continuous flow component in the radial direction in the common carotid artery is likely to be an artifact. These low velocities, after all, cannot be measured unambiguously at the cut-off frequency of 250 Hz in our instrument. The slight pulsatility occasionally seen in the radial flow component recorded perpendicular to the plane of the bifurcation may be explained by a deviation of the angle of interrogation from 90 degrees, which results in the recording of axial flow velocity components as well. The existence of areas of recirculation in the common and internal carotid arteries is very unlikely because neither retrograde flow in the axial direction nor commutating flow in the radial direction could be observed in these vessels.

It has been shown that in the carotid artery bulb, atherosclerotic lesions are most commonly found opposite to the side of the flow divider. Although no conclusions can be drawn from our findings about the relationship between flow velocity patterns and the formation of atherosclerotic lesions, the results favor the idea that the formation of these lesions is associated with low rather than high wall shear stress and with areas of flow separation and deviation from axially orientated, unidirectional flow.

Detection of disturbances in the flow pattern have been widely used to diagnose carotid artery lesions with either continuous wave or pulsed Doppler systems combined with audio spectrum analysis. The normally occurring, complicated flow patterns in the carotid artery bulb, however, induce spectral changes (figure 8) that are probably difficult to distinguish from those induced by atherosclerotic lesions. The Doppler spectra as depicted in this figure are similar to those recently reported by Phillips et al. in a presumably normal, young subject. Because the velocity pattern is undisturbed in the internal carotid artery 3 to 4 cm distal to the flow divider in asymptomatic subjects, one may argue that disturbances in the flow pattern as induced by vascular lesions in the carotid artery bulb can be diagnosed at the former site. One should realize, however, that flow disturbances, even those induced by lesions associated with more than 60% diameter reduction, have disappeared that far downstream from a lesion. An additional problem is that the sample volume cannot be made sufficiently small to distinguish normal from slightly diseased arteries on the
basis of spectral broadening when measuring at this site in the internal carotid artery.\textsuperscript{3}

In conclusion, our findings demonstrate that in the carotid artery bulb of subjects without detectable lesions of the cervical carotid arteries, the axial velocities are highest on the side of the flow divider whereas regions of flow separation and recirculation are observed on the side opposite to this divider. Flow separation and recirculation are less pronounced and less common in older subjects. Flow separation is not continuously present throughout the cardiac cycle. The findings in younger subjects corroborate previous observations in models and studies in vitro. The distensibility of the cervical carotid arteries is significantly diminished in older subjects, especially at the level of the bulb. It is possible that the diminished flow separation and recirculation in older subjects result from alterations in distensibility at the transition from common to internal carotid artery with increasing age.

We are indebted to Dr. Harold Wayland, Pasadena, CA, for reading the manuscript and for his critical comments, and to Mariet de Groot and Jos Heemskerk for typing the manuscript.

References

Flow velocity patterns in and distensibility of the carotid artery bulb in subjects of various ages.
R S Reneman, T van Merode, P Hick and A P Hoeks

Circulation. 1985;71:500-509
doi: 10.1161/01.CIR.71.3.500

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/71/3/500