Further Comments on the Measurement of Carotid Stenosis From Angiograms

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Background and Purpose  Three different methods for estimating the percentage of reduction in the diameter of the internal carotid artery (ie, stenosis) have been proposed in the literature. Further comparisons of the methods were carried out with the intent of recommending a current standard for determining the percentage of stenosis from angiograms.

Methods  Angiograms from 112 patients were obtained. For each angiogram, stenosis was estimated in the manner of the European Carotid Surgery Trial (ECST) method, the North American Symptomatic Carotid Endarterectomy Trial (NASCET) method, and by a method using the common carotid artery lumen diameter (CC method).

Results  Although there is much discrepancy among the estimates of stenosis arising from the three different methods for any particular patient, it is possible to predict (on average) the percentage of stenosis from one method to another. The relationship between the NASCET and CC methods is linear, with a mean ratio of distal internal carotid artery to common carotid diameter of 0.62 (SD of 0.11). The variability in the diameter of the common carotid artery lumen stabilizes only beyond 2.5 common carotid diameter units (approximately 20 to 30 mm by conventional angiography) proximal to the bifurcation. Unexpectedly, the relationships between both the ECST and NASCET methods and ECST and CC methods were parabolic (P<.001). The reasons underlying these departures from linearity are uncertain.

Conclusions  The comparability of our results with those reported in the literature regarding the CC and NASCET methods provides further evidence of the reproducibility of methods measuring anatomic features that can be visualized on an angiogram. Disease of the internal carotid artery is one of the important causes of ischemic symptoms. Measuring the narrowest portion of the internal artery relative to the normal portion of the same artery, well beyond the bulb, is a logical method. Moreover, benefits of carotid endarterectomy for patients with 70% to 99% stenosis as determined by the NASCET method have been well established in a clinical trial. Converting from the NASCET method to the CC method, given that the CC method is neither superior nor easier to calculate, is not recommended. (Stroke. 1994;25:2445-2449.)

Key Words  • angiography • stenosis • carotid arteries

Three different methods for estimating the percentage of reduction in the diameter of the internal carotid artery (ie, stenosis) have been proposed, two of which are currently being used in clinical trials evaluating carotid endarterectomy for symptomatic patients. Although each method measures the diameter of the residual lumen to determine the maximal narrowing in the same manner, the diameter with which it is compared is chosen at different sites along the carotid artery (Fig 1). The European Carotid Surgery Trial (ECST)1 uses a visual estimate of the presumed normal diameter of the unseen carotid artery bulb wall, at the site of maximal residual lumen narrowing (ECST method). The North American Symptomatic Carotid Endarterectomy Trial (NASCET)2 measures the diameter of the distal normal internal carotid artery well beyond the bulb, at the point where the artery walls become parallel.3 This has been called the NASCET method.4 The third advocated approach measures the diameter of the presumed disease-free portion of the common carotid artery (CC method).4-5 The anatomic shape of the carotid artery, with the carotid bulb being substantially larger than both the internal and common carotid, ensures that the three different denominators will yield three different estimates of stenosis.5,7 The discrepancies among the measuring techniques, while expected, are disconcerting given that the degree of stenosis has been shown in two clinical trials (ECST and NASCET) to be the primary determining factor in assigning both the risk of stroke and the benefits of endarterectomy. Each varies according to the degree of stenosis.2,8 The naive acceptance of a numerical percentage of stenosis is misleading without regard to the method of measurement. In the interests of consistent patient management and uniformity in reporting of treatment results, it is desirable that one method be adopted as the current standard. The purpose of the present study is to further explore and discuss the merits of the three different methods of estimating stenosis; specifically, (1) to examine the mathematical relationships among the three methods, (2) to quantify the variability in the diameter measurements along the common carotid artery, and (3) to estimate the degree of intraobserver and interobserver variability.

Methods  One hundred twelve randomly selected patients from NASCET (1988 through 1991) provided carotid angiograms at

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entry into the trial, and this sample formed the basis of the present study. The total set of angiograms consisted of 108 lateral views, 86 anterior-posterior views, and 9 views of the aortic arch. Two independent observers (A.J.F. and N.S.) measured the degree of stenosis of the symptomatic carotid artery (ie, the artery for which the patient was randomized into the trial) using the NASCET method. In addition, the second observer measured the angiograms using the ECST and CC methods. Luminal diameters were measured with either a magnifying eyepiece or a ruler calibrated to the nearest 0.1 mm. Straight-line distances between the maximal narrowing of the residual lumen and the site of the denominator measurements for the NASCET and CC methods were also recorded. The projection for analysis was taken as the one with the greatest percentage of stenosis. Arteries that were regarded as nearly occluded (identified on the angiogram as having delayed internal carotid filling compared with external carotid artery branch filling, a reduced distal lumen, and/or intracranial collateral vessels) were assigned a value of 95% stenosis, since using a denominator measurement in this case is inappropriate.

The effect of carotid disease severity on the dimensions of the artery was also investigated by selecting a subset of 84 lateral view angiograms from the original 108; all dimension measurements required for this analysis were present. Angiograms showing near occlusions were excluded. To overcome the variable effects of film magnification and minification, each residual lumen diameter and straight-line distance measured from the angiogram was divided by the lumen diameter of the common carotid artery measured from the same angiogram before calculating any summary statistics. In the report of results, the means and standard deviations of the ratios were computed. Since the specific purpose was to examine the diameter ratios of the distal internal carotid artery to the common carotid, the disease severity was defined on the basis of the estimated stenosis by the ECST method. Mild to moderate disease was defined as <70% ECST, while ≥70% ECST was considered to be severe disease. Although the choice of method and cut point is somewhat arbitrary, the ECST method was chosen because it is impartial to the other two and has been previously used for the same purpose.4

A subset consisting of 30 angiograms (from the 112 patients) had unobstructed views of the carotid bifurcation and presented the bifurcation in the plane of the film. These angiograms were digitized with a laser film scanner onto a computer to examine the variability of lumen diameter measurements along the common carotid artery. Once digitized, the lumen boundaries of the common carotid artery were manually outlined and then plotted as a graphic boundary plot (Fig 2). Because of magnification and minification effects, there was no absolute length scale available for the angiograms. The images were therefore bilinearly scaled in both the x and y dimensions so that the most proximal part of the common carotid artery visualized on the angiogram had a diameter of 1 unit. The plot was then translated so that the apex of the flow divider (ie, the central point of the bifurcation) coincided with x=0. All plots outlined the boundary of the common carotid artery to more than 3 common carotid diameter units (CCDUs) proximal to the flow divider. The artery was subsequently divided axially into segments of 0.5 CCDU along the x axis. Within each segment, the diameter of the artery was calculated at every 0.1 CCDU by an automated computer algorithm. The algorithm evaluated the diameter of the artery based on the graphic boundary plot, yielding four to six measurements per segment per boundary plot. For each segment, the mean and standard deviation of these measurements were computed.

The relationships among the different methods were assessed using regression analysis, and the intramethod associations were reported in terms of Pearson product-moment correlation coefficients. Intraclass correlations, computed from a one-way ANOVA, were used in reporting the intermethod agreement, interobserver agreement, and intraobserver reliability.

**Results**

The scattergrams shown in Fig 3 illustrate pictorially the relationships among the three measuring techniques. In each figure, the percentages of stenosis are scattered reasonably uniformly across a broad range of values. A closer examination reveals that the relationships with the ECST method do not form a straight line but are parabolic (Fig 3, top and middle). The regression analyses confirmed that the parabolic components were statistically significant for the ECST versus the NASCET...
was tested in the regression analysis, it was found to be nonsignificant (P=.38).

The fitted regression equations, estimates of intermethod agreement, and intermethod association are given in Table 1. The moderate values of intermethod agreement indicate that there is much disagreement among the methods in yielding the same estimate of stenosis for a given patient. Nevertheless, the high values of intermethod association ensure that estimates of stenosis from one method are predictive of the estimates of other methods.

The results regarding the effect of carotid disease severity on the dimensions of the artery are shown in Table 2. The selected ECST cut point yielded two groups of approximately equal size (n=41 and n=43). The discrepancies among the different methods of estimating stenosis are clearly illustrated in the top portion of the table. With respect to the reduction of lumen diameters in the presence of higher levels of stenosis, it is observed that on average the distal-to-common ratio decreases slightly from 0.63 to 0.60. Whether this decrease is solely due to a narrowing of the distal internal carotid artery or is also due to a change in the diameter of the common carotid artery is uncertain. The average ratio of the estimated bulb to the common carotid artery is 1.31 in both groups. The relatively large magnitude of the sample standard deviations clearly indicates that considerable variability exists among individuals; therefore, none of the ratios are exact.

The variability of the diameters in the common carotid artery lumens that were digitized is displayed graphically in Fig 4. The mean diameter is greatest at the bifurcation and approaches unit diameter beyond 2.5 CCDUs (ie, beyond approximately 20 to 30 mm by conventional angiography). The mean diameter is greatest near the flow divider (at x=0) because the diameter measured in this region is not strictly the diameter of the common carotid artery but is the diameter of the bifurcation structure. The approach to unit diameter is expected as one traverses the artery proximally because all plots were scaled to unity at the most proximal portion of the common carotid artery. The deviation of the mean from unit diameter, as one approaches the bifurcation, demonstrates the variability in the diameter of the common carotid artery. Between approximately 0.5 and 1.5 CCDUs, the mean artery lumen diameter falls below 1.0. The reduction in diameter for segments within this range may be attributable to either disease processes in this portion of the carotid artery or physiological taper before the bifurcation structure. The variability of the diameter measurements diminishes as one moves further away from the bifurcation, with stabilization in measurement occurring beyond 2.5 CCDUs proximal to the flow divider.

To address the issue of reproducibility of the NASCET method, results from an intraobserver reliability and an interobserver agreement study (using all angiograms from the 112 patients) are displayed in Fig 5, top and bottom, respectively. In both scattergrams, the data points lie in proximity to the line of unity, indicating a high degree of reproducibility. In terms of summary statistics, the degree of intraobserver reliability is 0.95 (95% confidence interval, 0.93 to 0.97), and the degree of interobserver agreement is 0.93 (95% confidence interval, 0.89 to 0.95).

Discussion

This study has found that the relationships of the NASCET and CC methods to the ECST method are parabolic, whereas the relationship between the NASCET and the CC method is linear. Since none of the relationships are one to one, there is much discrepancy among the reported estimates of stenosis as a result of using different...
TABLE 1. Relationships Among the Three Methods of Measuring Stenosis

<table>
<thead>
<tr>
<th>Methods</th>
<th>Regression Equation</th>
<th>Agreement</th>
<th>Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECST vs NASCET</td>
<td>ECST = 55.16 + 0.29NASCET + 0.002NASCET²</td>
<td>0.29</td>
<td>0.93</td>
</tr>
<tr>
<td>ECST vs CC</td>
<td>ECST = 45.27 + 0.14CC + 0.004CC²</td>
<td>0.76</td>
<td>0.93</td>
</tr>
<tr>
<td>CC vs NASCET</td>
<td>CC = 36.20 + 0.62NASCET</td>
<td>0.66</td>
<td>0.94</td>
</tr>
</tbody>
</table>

ECST indicates European Carotid Surgery Trial; NASCET, North American Symptomatic Carotid Endarterectomy Trial; and CC, common carotid artery lumen diameter.

TABLE 2. Means and SDs of Dimensions Measured From the Angiograms

<table>
<thead>
<tr>
<th>Stenosis</th>
<th>&lt;70% ECST (n=41)</th>
<th>&gt;70% ECST (n=43)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Stenosis, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECST method</td>
<td>56.3</td>
<td>9.3</td>
</tr>
<tr>
<td>NASCET method</td>
<td>8.8</td>
<td>23.6</td>
</tr>
<tr>
<td>CC method</td>
<td>42.9</td>
<td>15.4</td>
</tr>
<tr>
<td>Diameter measurement*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>0.57</td>
<td>0.15</td>
</tr>
<tr>
<td>D</td>
<td>0.63</td>
<td>0.12</td>
</tr>
<tr>
<td>E</td>
<td>1.31</td>
<td>0.24</td>
</tr>
<tr>
<td>C</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Straight-line distance*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N to D</td>
<td>5.98</td>
<td>2.14</td>
</tr>
<tr>
<td>N to C</td>
<td>4.50</td>
<td>1.63</td>
</tr>
</tbody>
</table>

*Each residual lumen diameter and straight-line distance measured from the angiogram was divided by the lumen diameter of the common carotid artery measured from the same angiogram before calculating the summary statistics. The data presented are therefore means and SDs of ratios.

methods. Given that the sample of angiograms in this study consisted of a broad range of carotid disease severity, regardless of the method of measurement, and that they originated from many academic centers across North America, it is reasonable to regard our results as generalizable to the angiograms that are regularly encountered in clinical practice.

The regression coefficients for the relationship between the CC and NASCET methods are similar to those reported by Rothwell et al.3 The ratio of the distal internal carotid artery to the common carotid (0.62) is also similar to those reported by others (0.60,4 0.65,5 0.69,10 0.7011). These results, in addition to the high intraobserver reliability (0.95) and interobserver agreement (0.93) of the NASCET method, provide further evidence of the reproducibility of methods that measure anatomic features that can be visualized on an angiogram. Some have derided the "negative" stenosis yielded by the NASCET method.5 12 However, this is an accurate reflection of the finding that there are patients who present with ischemic symptoms in the territory of the carotid artery, where the diameter of the distal internal carotid artery is still less than the narrowest portion of the lumen within the carotid bulb. In effect, there may be some bulb narrowing, but the residual lumen at the site of stenosis is still larger than the outflow in the internal carotid artery. Whether endarterectomy can prevent any further ischemic events occurring from these lesions is to be decided by the ongoing clinical trials.

The dissimilarity among the estimated ratios of bulb lumen to common carotid as reported by us and by others (1.31, 1.00,4 1.19,5 1.11,10 1.1611) makes this method of measurement dubious. Moreover, it leads to some uncertainty about the ability to translate the results from the ECST1 to the NASCET2 results and vice versa. For example, using the regression equation from Rothwell et al,4 a 70% stenosis determined by the ECST method would be regarded as 50% by the NASCET method. The regression equation derived in this paper would yield a NASCET method stenosis of 40%.

The reasons underlying the departure from linearity of the relationships with the ECST method are uncertain. One would expect the relationships to be linear, very much like the relationship between the CC and NASCET methods. We may only hypothesize that the parabolic nature of the data is due to either observer error in estimating the outline of the carotid bulb and/or a change in the anatomic dimensions of a partially diseased bulb. The latter would imply that the estimated ratio of bulb lumen to normal artery (either distal internal or common carotid) may not be constant across all degrees of disease severity. This may partially ex-

![Graph of mean diameter and standard deviation of the segments of the common carotid artery. Each data point represents the mean value calculated from 30 angiograms. Both the mean diameter and variability of the common carotid artery stabilize beyond 2.5 common carotid diameter units (CCDU) proximal to the bifurcation.](image-url)
plain why, although our ratio (1.31) overestimated and that of Rothwell et al (1.00) underestimated the ratio reported for normal arteries (1.19). The data points on the scattergrams in both studies were not linear but lay along a parabolic curve.

The variability in the diameter measurements along the common carotid artery indicates that one must make measurements relatively distant from the bifurcation (beyond 2.5 CCDUs, ie, approximately 20 to 30 mm by conventional angiography) to be fairly certain that the artery is disease-free. Measurements close to the bifurcation may lead to spurious estimates of stenosis. On the other hand, the anterior wall of the proximal common carotid may be less clearly visualized because of the catheter position. This is due to the dilution of contrast medium with unopacified blood distorting the contrast image of the artery, especially anteriorly. Contrast is heavier than blood and therefore lies posterior in the artery.

Therefore, given that the distance required to obtain a valid denominator measurement for the CC method is approximately as far from the bifurcation as for the NASCET method, and given that the two methods are highly correlated, one question is the value of introducing a new method of measurement that appears to be no better or easier to calculate than the NASCET method. In fact, there are just as many problems in selecting the best portion of the common carotid artery to measure as there are in selecting the distal normal portion of the internal carotid artery. We agree that one may convert from the NASCET method to the CC method, but why do it? Disease of the internal carotid artery is one of the important causes of ischemic symptoms. Measuring the narrowest portion of the internal carotid artery relative to the normal portion of the same artery, well beyond the bulb, is a logical method.

The clinical results from using a strict method of measurement, such as the 70% to 90% severe stenosis by the NASCET method, have been well received and respected. At this time, the adoption of the NASCET method is becoming more widespread and appears to have become the current standard in a majority of major North American medical centers. To add another method, in which 70% stenosis means something quite a bit lower than the 70% of the NASCET method, will send many patients through the unnecessary cost and risk of endarterectomy for which there may be no evidence of benefit.

Acknowledgments

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