Equivalence of Measurements of Carotid Stenosis
A Comparison of Three Methods on 1001 Angiograms

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Background and Purpose
There is confusion about how carotid stenosis should be measured on angiograms. If the results of research based on different methods of measurement of stenosis are to be discussed and the results of clinical trials properly applied to routine clinical practice, measurements made by the different methods must be formally compared.

Methods
The method of measurement of stenosis used in the European Carotid Surgery Trial (ECST), that used in the North American Symptomatic Carotid Endarterectomy Trial (NASCET), and a method based on measurement of the common carotid (CC) artery lumen diameter were compared. Carotid stenosis was measured by two observers, working independently and using the three different methods of measurement, on the angiographic view of the symptomatic carotid stenosis that showed the most severe disease in 1001 patients from the ECST.

Results
The results of using the ECST and CC methods differed from those of using the NASCET method in the classification of stenoses as mild (0% to 29%), moderate (30% to 69%), or severe (70% to 99%) in 51% of measurements. The ECST and CC methods indicated that twice as many stenoses were severe as did the NASCET method, and classified less than a third of the number of stenoses as mild. The results of the ECST and CC methods differed from each other in 15% of measurements. The relations between measurements made by each method to those made by the others were approximately linear, so a simple equation could be derived to convert measurements made by one method to measurements made by the others.

Conclusions
There were major and clinically important disparities between measurements of stenosis made using different methods of measurement on the same angiograms. However, it is possible to convert measurements made by one method to those of another using a simple arithmetic equation.

Key Words • angiography • carotid arteries • diagnosis

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immediately 100 centers in 14 European countries, and comprised 789 selective arterial angiograms, of which 307 were digitally subtracted; 174 aortic arch angiograms, of which 92 were digitally subtracted; 29 intravenous digital subtraction angiograms; and 9 angiograms for which the technique used was not clear. The mean age of the patients studied was 62.1 years (SD, 7.8), and 71% were male. Two independent observers (P.M.R. and R.J.G.) measured the degree of stenosis of the symptomatic carotid artery by using each of the methods detailed in Fig 1. In patients with bilateral symptoms, the most stenosed artery was measured. Measurements were made using a jeweler’s eyepiece graduated in tenths of millimeters on the single angiographic view that showed the greatest stenosis. The same measurement of Dmin was used for each of the methods. Each observer was blind to the measurements made by the other and to the clinical details. No marks indicating the points of measurement were placed on the angiogram films by either observer.

Results

The two observers made a total of 6006 stenosis measurements using each of the three methods. The numbers of stenoses classified as mild (0% to 29%), moderate (30% to 69%), or severe (70% to 99%) by each of the three methods are shown in Table 1. The numbers of stenoses within each group as measured by the ECST and CC methods were similar, but the NASCET method classified three times as many stenoses as mild than did the ECST method, and with the CC method on 92% of the 1024 (99.9%). The CC method and the NASCET method differed for 1025 (51%) measurements, with relative underestimation by the NASCET method on 1024 (99.9%). The CC method and the ECST method differed for 305 (15%) measurements, with no significant bias in either direction.

The relations between measurements made by each of the methods are shown in Table 1. The ECST and NASCET methods differed in the classification of stenoses in 51% of measurements; in 1009 (99.6%) of the 1013 cases in which the results of the two methods differed, the NASCET method underestimated the severity of stenosis compared with the ECST method. The NASCET and CC methods differed for 1025 (51%) measurements, with relative underestimation by the NASCET method on 1024 (99.9%). The CC method and the ECST method differed for 305 (15%) measurements, with no significant bias in either direction.

The plot of ECST measurement versus CC measurement approximately fit a line with a slope of 1.00 and an intercept on the CC axis of 0.0. The lines fitting the plots of ECST versus NASCET and CC versus NASCET are identical, with a slope of 0.6 and an intercept on the ECST and CC axes at -40%. The following equation therefore describes the relation between measurements made by the NASCET method and those made by either the ECST or CC methods: ECST % stenosis or CC % stenosis = 0.6(NASCET % stenosis + 40%). By use of this equation, measurements made by one method can be converted to those expected to be made by the other methods. The equation can then be internally validated by assessing the agreement between the predicted measurements and the actual measurements in categorization of stenosis as mild, moderate, or severe (Table 3). For example,

### Table 1. Number of Stenoses Categorized as Mild, Moderate, or Severe by Three Methods of Measurement

<table>
<thead>
<tr>
<th>Degree of Stenosis</th>
<th>Method</th>
<th>0-29%</th>
<th>30-69%</th>
<th>70-99%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECST (%) of total</td>
<td>278 (14)</td>
<td>1002 (50)</td>
<td>722 (36)</td>
<td></td>
</tr>
<tr>
<td>NASCET (%) of total</td>
<td>896 (45)</td>
<td>776 (39)</td>
<td>330 (16)</td>
<td></td>
</tr>
<tr>
<td>CC (%) of total</td>
<td>294 (15)</td>
<td>953 (48)</td>
<td>755 (37)</td>
<td></td>
</tr>
</tbody>
</table>

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

Two observers made a total of 2002 measurements on 1001 angiograms.

### Table 2. Comparisons of the Categorization of Stenoses as Mild, Moderate, or Severe by Each of Three Methods of Measurement

<table>
<thead>
<tr>
<th>Stenosis by the ECST Method</th>
<th>0-29%</th>
<th>30-69%</th>
<th>70-99%</th>
</tr>
</thead>
<tbody>
<tr>
<td>the NASCET</td>
<td>276</td>
<td>615</td>
<td>5</td>
</tr>
<tr>
<td>Method</td>
<td>2</td>
<td>385</td>
<td>389</td>
</tr>
<tr>
<td>the CC</td>
<td>294</td>
<td>598</td>
<td>4</td>
</tr>
<tr>
<td>Method</td>
<td>0</td>
<td>354</td>
<td>422</td>
</tr>
<tr>
<td>the CC</td>
<td>722</td>
<td>825</td>
<td>83</td>
</tr>
<tr>
<td>Method</td>
<td>3</td>
<td>50</td>
<td>672</td>
</tr>
</tbody>
</table>

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

Two observers made a total of 2002 measurements on 1001 angiograms.

Comparisons between each of the methods in the categorization of stenoses as mild, moderate, or severe are shown in Table 2. The ECST and NASCET methods differed in the classification of stenoses in 51% of measurements; in 1009 (99.6%) of the 1013 cases in which the results of the two methods differed, the NASCET method underestimated the severity of stenosis compared with the ECST method. The NASCET and CC methods differed for 1025 (51%) measurements, with relative underestimation by the NASCET method on 1024 (99.9%). The CC method and the ECST method differed for 305 (15%) measurements, with no significant bias in either direction.

The relations between measurements made by each of the methods are shown in Fig 2. The means of the stenosis measurements made by the two observers were used in compiling the graphs to minimize errors that may have been due to observer variability. In each case there was some spread of measurements, particularly with mild stenosis, but the relations were approximately linear. The plot of ECST measurement versus CC measurement approximately fit a line with a slope of 1.00 and an intercept on the CC axis of 0.0. The lines fitting the plots of ECST versus NASCET and CC versus NASCET are identical, with a slope of 0.6 and an intercept on the ECST and CC axes at -40%. The following equation therefore describes the relation between measurements made by the NASCET method and those made by either the ECST or CC methods: ECST % stenosis or CC % stenosis = 0.6(NASCET % stenosis + 40%). By use of this equation, measurements made by one method can be converted to those expected to be made by the other methods. The equation can then be internally validated by assessing the agreement between the predicted measurements and the actual measurements in categorization of stenosis as mild, moderate, or severe (Table 3). For example,
agreement between the ECST and NASCET methods increased from 49% to 83% when NASCET measurements were transposed to an ECST scale.

The differences between the results of the methods of measurement were accounted for by the use of different denominators. The 95% confidence intervals of the ratio of each denominator to the others are given in Table 4. The ECST denominator was, on average, the same as the measurement of the CCA (common carotid artery) lumen, although the 95% confidence interval of the range of the proportion was 0.71 to 1.41. The distribution of the ECST denominator:CCA ratio was similar for both observers (Fig 3). The ICA:CCA ratio varied with the severity of stenosis, remaining constant up to 70% stenosis as measured by the ECST method (50% by the NASCET method), then falling steadily as stenosis increased (Fig 4).

**Discussion**

The first aim of this study was to determine the frequency with which the three methods of measuring stenosis placed the same patient into different categories of stenosis severity. The differences between the results of the ECST and NASCET methods are considerable. Moreover, these differences are of major clinical importance. Both the ECST and NASCET trials demonstrated that surgery is beneficial in patients with severe stenosis (of 70% to 99%). However, classification using the ECST method results in twice as many stenoses' being classified as severe (Table 1). Conversely, the ECST trial showed that in patients with mild stenosis (less than 30%) surgery is certainly not beneficial and...
may be harmful. Using the limit of 30% stenosis with the NASCET method of measurement, three times as many stenoses are classified as mild as with the ECST method.

The second aim of the study was to define the equivalence of measurements made by the three methods. The disparities between the results of the ECST and NASCET methods can be illustrated using the conversion equation given above. Stenoses of 30% and 70% as measured by the ECST method are approximately 17% and 50%, respectively, as measured by the NASCET method. A stenosis of 70% as measured by the NASCET method is equivalent to a measurement of 50% as measured by the ECST method, of the distal internal carotid artery (ICA) lumen to the common carotid artery (CCA) lumen.

The approximately linear relations between measurements made by each of the three methods allows simple conversion equations to be derived. These conversions are not exact, because there is a spread of measurements around the line to which they are fitted, but the internal validation suggests that they work reasonably well. Moreover, the spread of measurements decreases as the clinical importance of accurate measurement increases: i.e., with moderate and severe stenosis. The disagreement in categorization of stenosis according to the ECST and NASCET methods is decreased threefold after conversion of the NASCET measurements to ECST measurements. Conversion from NASCET measurements to CC measurements works equally well. That an error of categorization remains for about 15% of stenoses must be interpreted in light of the 16% to 20% interobserver variability of each of the methods in assigning stenoses to these categories. Even if the conversion equations were perfect, observer variation in the individual measurements would limit the agreement after conversion to less than 90%. Ideally, if the results of studies based on different measurements of stenosis were compared, the angiograms would be remeasured using the same method. However, this is often not practical, and conversion equations will be required.

The close approximation of the results of the ECST and CC methods indicates that the ECST denominator is, on average, the same as the measurement of the CCA lumen. Two previous studies using angiograms reported a mean ratio of the bulb lumen to the CCA lumen of 1.19.7,10 This has recently been misinterpreted as a "fixed anatomical relationship."11 In fact, in both studies the ratio of 1.19 was far from fixed, having a standard deviation of 0.09 in one7 and 0.19 in the other.10 In other words, the ratio varied from less than 1.0 to more than 1.4. These studies used only normal angiograms and, of particular importance, involved measuring the diameter of the bulb at its widest point. The ECST method of measurement of stenosis uses the lumen diameter at the point of maximum stenosis, which is not infrequently outside the bulb. Moreover, even when the maximum stenosis is within the bulb it seldom coincides exactly with the widest point. The ratio of the ECST denominator to the measurement of the CCA lumen diameter will clearly vary with the site of the stenosis and will usually be less than 1.2. In the present study the ratio of the ECST denominator to the CCA lumen, in 1001 bifurcations, varied from 0.7 to 1.4, and the average ratio was 1.00, both observers' results having similar distributions.

Collapse of the ICA distal to tight stenoses has been noted previously.12 With the NASCET method, any stenosis distal to which the ICA is collapsed is classified as a stenosis of 95%.13 Despite attempts to define criteria for determining exactly when the ICA should be

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**Table 3. Actual Agreement in the Categorization of Stenosis as Mild, Moderate, or Severe Between Each of Three Methods and Agreement After Conversion of Measurements Made by the First Method to Those Made by Second**

<table>
<thead>
<tr>
<th>Methods</th>
<th>Actual Measurements</th>
<th>Converted Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASCET and ECST</td>
<td>49</td>
<td>83</td>
</tr>
<tr>
<td>CC and ECST</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>NASCET and CC</td>
<td>49</td>
<td>87</td>
</tr>
</tbody>
</table>

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

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**Table 4. Ratios and Confidence Intervals of Each of the Denominators of Three Methods of Measuring Stenosis Compared With the Others**

<table>
<thead>
<tr>
<th>Denominator Compared With the Others</th>
<th>Ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECST denominator and CCA lumen</td>
<td>1.00</td>
<td>0.71-1.41</td>
</tr>
<tr>
<td>ECST denominator and ICA lumen</td>
<td>1.68</td>
<td>1.11-2.55</td>
</tr>
<tr>
<td>CCA lumen and ICA lumen</td>
<td>1.68</td>
<td>1.15-2.44</td>
</tr>
</tbody>
</table>

ECST indicates European Carotid Surgery Trial; CCA, common carotid artery; ICA, internal carotid artery. See Fig 1 for description of ECST denominator.
regarded as collapsed, the judgment must remain somewhat subjective, and there is likely to be observer variability. In the present study a steady reduction of the ICA lumen, compared with the CCA lumen, begins at about 70% stenosis as measured by the ECST method (50% stenosis by the NASCET method). Moreover, collapse of the ICA is marked in some patients but not in others, so groups of patients with similar stenosis measurements according to the ECST or CC methods might have a different measurement according to the NASCET method. This inconsistency of measurement of severe stenoses is a problem of using the NASCET method. Given the difficulty some observers have with estimation of the normal bulb lumen in the ECST method, the CC method would appear to have the fewest drawbacks. The CCA is usually well visualized on angiography, is without overlapping vessels, and is rarely severely affected by atheroma. Most importantly, the CC method is the most reproducible of the three.

In the present study major differences between the results of three methods of measurement of carotid stenosis were demonstrated on the same angiograms. These differences have important implications for clinical practice. However, the relations between measurements made by the three methods are approximately linear, and conversions can be made using the equation given above. These data provide the basis for informed debate about which method of measurement of stenosis should be adopted as the standard. The choice of a standard method should depend on the ability to use it to predict ipsilateral ischemic stroke and on its reproducibility. It is essential that a single method eventually be adopted by all. An enormous amount of effort has been put into determining which patients benefit from carotid endarterectomy. It would be a great pity if, research having come this far, the results of these trials were obscured by argument and confusion about how stenosis should be measured in routine clinical practice.

Acknowledgments

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