Observer Variability in Evaluating Extracranial Carotid Artery Stenosis

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SUMMARY One hundred twenty eight cervical carotid arteriograms were twice viewed by three readers for the evaluation of atherosclerotic disease at the carotid bifurcation. Stenoses were estimated using calipers to the nearest 5% and lesions were qualitatively characterized as smooth, irregular, or ulcerated. The intraobserver correlation coefficient between estimates of percent stenosis was .94 overall and .98 for the internal carotid artery. The average intraobserver variability in estimating percent stenosis was 5.23% for all vessels and 6.04% with a standard deviation of 8.09% for the internal carotid artery. The intraobserver percent agreement at a fixed stenosis is defined as the percent of the time one reader on two readings would read at least the fixed percent stenosis among cases that might be read as having the fixed percent stenosis. The intraobserver percent agreement rate for the internal carotid artery was 95.9% at > 0% stenosis, 90.4% for 50% or greater stenosis, and 96.8% for 100% stenosis (total occlusion). The interobserver correlation coefficient between readers was .92 overall and .97 for the internal carotid artery. The absolute difference in percent stenosis between readers was 7.21% for all vessels and 8.64% for the internal carotid artery with a standard deviation of 9.5%. The interobserver agreement rate for the internal carotid artery at > 0% stenosis was 93.0%, 85.4% for 50% or greater stenosis and 96.8% at 100% stenosis. The addition of oblique views had no statistical effect on estimates of percent stenosis but increased the frequency with which irregularity and ulceration were diagnosed in the internal carotid artery.

CEREBRAL ANGIOGRAPHY remains the major diagnostic tool in evaluating symptomatic patients with extracranial occlusive disease and is also used as a reference standard for evaluating newer noninvasive diagnostic modalities. Although major patient management decisions and evaluations of new techniques and equipment are based on angiographic interpretations, no detailed statistical analysis of observer variability has been performed. This study was designed to assess this variability and in addition to evaluate the contribution of oblique views to the characterization of stenotic lesions of the carotid bifurcation.

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Materials and Methods

The angiograms of 100 consecutive patients who underwent cerebral angiography which included serial biplane filming of the cervical carotid arteries were reviewed. From this population, 64 cases were selected on the basis of having AP, lateral and two oblique views of each carotid bifurcation which were of sufficient technical quality to permit careful evaluation under normal viewing conditions. AP and lateral films were obtained on 10 by 12 inch Schonander changers with the patient supine. The patient was then rotated en bloc 20 degrees away from the side of the catheter and the filming repeated producing "AP" and "lateral" oblique views. The 20 degree angle of rotation was chosen because of its easy reproducibility using standard positioning sponges. Nine ml of conray-60 were injected over 1.5 seconds and films obtained at a rate of 2 per second for 3 seconds. Each case consisting of both the left and right sides was then identified by number and the single best opacified view of the cervical carotid artery in each of the four projections for both sides was selected for viewing. Using standard statistical methods, each of three readers were given a
different set of 16 cases, i.e. 32 carotid bifurcations, to read each week for 8 weeks which provided double reading of all cases for each reader. All three readers are graduates of the university hospital program at which the study was conducted and had at least 3 years experience in performing and interpreting the examinations. Each reader had a slightly different area of special interest: neuroradiology, cardiovascular radiology, and ultrasonography. For the purpose of this study, the distal 5 cm of common carotid artery and the proximal 2 cm of the internal and external carotid arteries were evaluated. For each segment, the reader was asked to estimate the maximum percent diameter reduction to the nearest 5% using calipers. The normal or estimated normal diameter used in this calculation was also recorded to the nearest .5 mm. Because the accuracy of the estimate of percent stenosis is dependent on the estimate of the normal diameter, unsubtract- ed films were used so the observer could if he wished estimate the normal diameter using calcification in the arterial wall as a guide. If stenosis was present, the lesion was characterized as smooth, irregular, or ulcerated. If multiple lesions were present in one segment, the maximum diameter reduction and the most advanced qualitative assessment for the entire segment were recorded. This method of grading is illustrated in figure 1. An ulcerated atherosclerotic plaque is seen involving the distal common and proximal internal carotid artery. Slightly more distal in the internal carotid the narrowing is more severe but has a smooth character. The internal carotid segment would thus be graded by the distal area of stenosis and proximal area of ulceration. An area of irregular narrowing is seen in the proximal external carotid artery. The statistical protocol called for 50% of the cases to be read once with and once without oblique views and 50% of the cases to be read both times either with or without oblique views.

This data was analyzed by computer using standard statistical methods with an additional statistic called the "interobserver (or intraobserver) percent agreement for a fixed percent stenosis" which estimates the probability that two readers (one reader on two readings) would agree on the presence of a lesion of a fixed percent stenosis or more among cases that might potentially be read as having at least the fixed percent stenosis.

With a large number of segments read as normal by multiple observers it appears that many segments are not potentially read as having a lesion, e.g. 50% or greater stenosis. Thus for a lesion that might be potentially read as having a fixed amount of stenosis (e.g. 50% or more) what is the probability of reading stenosis of the fixed amount? For such segments let p be the probability of reading such stenosis. For two readers, or the same reader reading twice, we assume the readings are independent, each with the probability of p. For a segment potentially read as having such stenosis:

\[ p_1 = P \{\text{one reader reads the stenosis}\} = 2p(1 - p) \]
\[ p_2 = P \{\text{both readers read the stenosis}\} = p^2 \]

For N (unknown) such segments, let \( N_1 \) be the number of segments with one reader seeing the lesion at the fixed point or more, and \( N_2 \) the number of segments where both readers detect such narrowing. Then estimates of \( P_1 \) and \( P_2 \) are:

\[ \frac{N_1}{N} = 2p(1 - p) = p_1 \]
\[ \frac{N_2}{N} = p^2 = p_2 \]

From this we estimate \( P \) by:

\[ P = \frac{2N_2}{2N_2 + N_1} \]

\( p \) is a conditional probability. It estimates the probability of reading the fixed percent stenosis or more among cases where the fixed percent stenosis or more might be reasonably read. If the large majority of cases in a population were normal, this probability might be much less than the probability two readers would agree on a randomly selected case from the population.

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**Figure 1.** Lateral common carotid angiogram. An ulcerated plaque is seen involving the distal common and proximal internal carotid arteries. An area of smooth narrowing is seen in the more distal internal carotid artery. An area of irregular narrowing is seen in the proximal external carotid artery.
The horizontal distance between the number and the diagonal of agreement represents the degree of difference between the two estimates of percent stenosis.

The number located at 0-0% represents the number of cases considered normal on both readings. The number located at 100%-100% represents the number of cases which were considered normal at both readings (109). The internal carotid artery had the smallest number of cases considered normal on both readings (40) and the largest number of cases considered to be 100% stenotic on both readings (30). The external carotid artery had a broad spectrum of disease and the greatest number of cases in which both readings were considered normal (167).

Changing the probability to a percent, by multiplying \( p \) times 100, we call 100\( p \) the interobserver percent agreement for the fixed percent stenosis if the readings are from two different readers. For comparing the two readings from the same reader, the term intraobserver percent agreement for the fixed percent stenosis is used.

**Results**

Table 1 presents intraobserver agreement as the correlation coefficient between the two estimates of percent stenosis for each reader. The higher the correlation coefficient the greater the agreement. The average intraobserver correlation coefficient was quite high at \(.94\) and was \(.98\) for the internal carotid artery. Table 2 presents an estimate of intraobserver variability and lists the absolute difference in the two estimates of percent stenosis. The mean absolute difference in percent stenosis for the internal carotid artery was \(6.04\)% with a standard deviation of \(8.09\)%.

Average intraobserver correlation coefficient = \( .94\).

Figures 2, 3, and 4 display observer variability and plots the percent stenosis of the first reading along the ordinate against the percent stenosis at the second reading along the abscissa at 5% intervals from 0 to 100% stenosis. The number located at 0-0% represents the number of cases considered normal on both readings while the number located at 100%-100% represents the number of cases considered to be totally occluded on both readings. The diagonal which connects the 0-0% and the 100-100% points is termed the diagonal of agreement. The sum of the numbers along this diagonal divided by the total number of readings \( \times 100\) represents the \% agreement to the nearest 5% stenosis. The horizontal distance between the number and the diagonal of agreement represents the degree of difference between the two estimates of percent stenosis. From these figures it can be noted that the common carotid artery had relatively few lesions considered to be hemodynamically significant and a relatively large number of cases which were considered normal at both readings (109). The internal carotid artery had the smallest number of cases considered normal on both readings (40) and the largest number of cases considered to be 100% stenotic on both readings (30). The external carotid artery had a broad spectrum of disease and the greatest number of cases in which both readings were considered normal (167).

Table 3 presents the intraobserver percent agreement at specific points of clinical interest. From this table it can be seen that for the internal carotid artery which has the most clinically significant disease the >0% stenosis intraobserver agreement percent is 95.9%, the 50% or greater percent stenosis boundary interobserver agreement percent is 90.4% and the 100% stenosis intraobserver agreement percent is 96.8%.

In table 4, the effect of classification on intraobserver variability is shown. The five group classification is the one that we are currently using to evaluate noninvasive ultrasonic methods and is thought to represent no disease, minimal disease, mild disease but not hemodynamically significant, hemodynamically significant disease, and total occlusion. Using this five group classification, the percent agreement for all three vessels was 82.5%. The six group classification was based on the assumption that diameter reductions of one half or one quarter might be more readily estimated. However, it can be seen the percent agreement fell to 74.1%.

Table 5 begins the discussion of the interobserver variability and displays the correlation coefficient between readers for each case for each reading. Correlation coefficients for the internal carotid artery are again quite high, being .97, and the average interobserver correlation coefficient for all vessels is .92.

Table 6 displays the absolute difference in estimates of percent stenosis between readers for each case. The average absolute difference in percent stenosis for the internal carotid artery was \(8.64\)% with a standard deviation of \(5.23\)%.
FIGURE 2. Intraobserver variability in estimating percent stenosis in common carotid artery. Plotted at 5% intervals from 0 to 100% stenosis, N = 384 comparisons: Each of three readers first reading versus second reading on two sides for 64 cases.

FIGURE 3. Intraobserver variability in estimating percent stenosis in the internal carotid artery. Plotted at 5% intervals from 0 to 100% stenosis. N = 384 comparisons: Each of three readers first reading versus second reading on two sides for 64 cases.

FIGURE 4. Intraobserver variability in estimating percent stenosis in the external carotid artery. Plotted at 5% intervals from 0 to 100% stenosis. N = 384 comparisons: Each of three readers first reading versus second readings on two sides for 64 cases.
TABLE 5 Correlation Coefficient for Each Estimate of Percent Stenosis for Each Case Between Readers (N = 1,536)

<table>
<thead>
<tr>
<th>Artery</th>
<th>Reader 1 vs 2</th>
<th>Reader 1 vs 3</th>
<th>Reader 2 vs 3</th>
<th>Average by vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common carotid</td>
<td>.83</td>
<td>.87</td>
<td>.85</td>
<td>.85</td>
</tr>
<tr>
<td>Internal carotid</td>
<td>.96</td>
<td>.97</td>
<td>.97</td>
<td>.97</td>
</tr>
<tr>
<td>External carotid</td>
<td>.92</td>
<td>.94</td>
<td>.94</td>
<td>.93</td>
</tr>
</tbody>
</table>

Average interobserver correlation coefficient for all vessels = .92.

TABLE 6 Absolute Difference in Estimates of Percent Stenosis Between Readers for Each Case for Both Readings (N = 1,536)

<table>
<thead>
<tr>
<th>Artery</th>
<th>Mean</th>
<th>S.D.</th>
<th>Mean</th>
<th>S.D.</th>
<th>Mean</th>
<th>S.D.</th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common carotid</td>
<td>6.56</td>
<td>7.64</td>
<td>6.33</td>
<td>7.06</td>
<td>6.91</td>
<td>7.17</td>
<td>6.60</td>
<td>7.30</td>
</tr>
<tr>
<td>Internal carotid</td>
<td>9.36</td>
<td>10.05</td>
<td>7.48</td>
<td>8.47</td>
<td>9.08</td>
<td>9.82</td>
<td>8.64</td>
<td>9.50</td>
</tr>
<tr>
<td>External carotid</td>
<td>7.29</td>
<td>9.25</td>
<td>6.60</td>
<td>8.25</td>
<td>5.31</td>
<td>7.71</td>
<td>6.40</td>
<td>8.46</td>
</tr>
</tbody>
</table>

Average interobserver variability in estimating percent stenosis = 7.21%.

TABLE 7 Interobserver Agreement at Specific Points of Clinical Interest

<table>
<thead>
<tr>
<th>Artery</th>
<th>Percent agreement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0% stenosis or greater</td>
<td>50% or greater 100% stenosis</td>
</tr>
<tr>
<td>Common carotid</td>
<td>80.2% (1196) 42.9% (42) - (0)</td>
</tr>
<tr>
<td>Internal carotid</td>
<td>93.0% (1415) 85.4% (548) 96.8% (128)</td>
</tr>
<tr>
<td>External carotid</td>
<td>83.1% (914) 83.3% (210) 80.8% (31)</td>
</tr>
</tbody>
</table>

*Percent of the time that the second estimate of percent stenosis would agree on at least the fixed level of stenosis with the first estimate on cases that might be read as having stenosis of the given level or above.

For each case, one reader’s estimate is plotted against another. As expected, there is more scatter about the diagonal of agreement and a decrease in the percent agreement. The overall distribution of estimates of percent stenosis is similar to that seen with the intraobserver data.

The effect of classification on interobserver variability of estimates of percent stenosis is shown in table 8. Again, the five-group classification yields the highest percent agreement (73.8%). Table 9 displays the effect on interobserver variability of using the average value of 2 readers’ estimates of % stenosis rather than a single estimate. When compared to the results in table 8, there is improvement in all classifications (47.9% versus 38.5%, 80.9% versus 73.8%, and 79.9% versus 62.8%). The percent agreement between reader pairs now approaches the intraobserver variability results seen in table 4 (47.9% versus 48.9%, 80.9% versus 82.5%, and 79.9% versus 74.1%). Using the sign test the difference in estimates of percent stenosis between the first and second readings for reader pairs was compared to the difference in the two estimates of percent stenosis for the other reader. The values were -2.0, -2.83 and -3.63. All were statistically significant at the p < .05 level and the last two values were significant at p < .005 and p < .0002. We conclude for these radiologists that two readers give a more precise reading than a single reader. Substitution of computer-derived estimates of percent stenosis based on the measurements recorded to the nearest 0.5 mm did not improve the intra- or interobserver results.

The last phase of the study evaluates the effect of oblique views. Table 10 shows the effect of oblique views on the estimate of percent stenosis. In 288 of the comparisons (50%), the percent stenosis was equal whether all four views or only the AP and lateral views were used. In 157 (27%) the estimate of percent stenosis was greater when all four views were used and in 131 (23%) the estimates were less. No statistically significant effect was observed.

Table 11 shows the effect of the addition of oblique views on the qualitative assessment of stenotic lesions in the internal carotid artery. In 134 cases (69.8%) there was agreement between four views and two views. However, in 42 cases (21.9%) the lesion was considered more advanced with the addition of oblique views while the reverse was true in only 16 cases.

A total number of comparisons in which one or both readings were at or above the point of interest.

The effect of classification on interobserver variability of estimates of percent stenosis was 7.21%. As expected, these values are higher than those observed with the intraobserver comparisons.

TABLE 4 Effect of Classification on Intraobserver Variability

<table>
<thead>
<tr>
<th>Artery</th>
<th>21 groups*</th>
<th>5 Groups†</th>
<th>6 Groups‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common carotid</td>
<td>46.9</td>
<td>81.5</td>
<td>75.3</td>
</tr>
<tr>
<td>Internal carotid</td>
<td>41.4</td>
<td>83.3</td>
<td>72.7</td>
</tr>
<tr>
<td>External carotid</td>
<td>58.3</td>
<td>82.8</td>
<td>74.2</td>
</tr>
<tr>
<td>All three</td>
<td>48.9</td>
<td>82.5</td>
<td>74.1</td>
</tr>
</tbody>
</table>

*0 to 100% stenosis at 5% intervals.
†0, 1-9, 10-49, 50-99, 100% stenosis.
‡0, 1-24, 25-49, 50-74, 75-99, 100% stenosis.
$Percent of the time cases were placed into the same grouping.

Figure 5, 6, and 7 plot estimates of percent stenosis for each case on a scale of 0 to 100% at 5% intervals.

The last phase of the study evaluates the effect of oblique views. Table 10 shows the effect of oblique views on the estimate of percent stenosis. In 288 of the comparisons (50%), the percent stenosis was equal whether all four views or only the AP and lateral views were used. In 157 (27%) the estimate of percent stenosis was greater when all four views were used and in 131 (23%) the estimates were less. No statistically significant effect was observed.

Table 11 shows the effect of the addition of oblique views on the qualitative assessment of stenotic lesions in the internal carotid artery. In 134 cases (69.8%) there was agreement between four views and two views. However, in 42 cases (21.9%) the lesion was considered more advanced with the addition of oblique views while the reverse was true in only 16 cases.
Interobserver variability and percent stenosis in the common carotid artery. Plotted at 5\% intervals from 0 to 100\% stenosis. N = 1,536 comparisons: Each of
three readers first reading versus the other
readers second reading, and first reading versus first reading, and second reading versus first and second reading, on two sides for 64 cases. Note that the data points are not from independent samples; the same reading appears in four comparisons.

Discussion

It is concluded from this study that trained observers using calipers have an acceptable rate of agreement in estimating percent stenosis in the extracranial carotid system. This is particularly true in the internal carotid artery where most clinically significant disease is found. For the internal carotid artery the intraobserver and (interobserver) agreement rates were 95.9\% (93\%) at > 0\% stenosis, 90.4\% (85.4\%) for 50\% or greater stenosis, and 96.8\% (96.8\%) for 100\% stenosis. The observer agreement rates reported in this study are higher than those reported by other authors. Yerushalmay reported an agreement of 80\% for the same observers and an agreement of 69.9\% for pairs of readers when six readers twice viewed 150 pairs of serial chest radiographs to assess interval change in patients with pulmonary tuberculosis. Felson et al reported 78\% agreement between observers when radiologists were asked to determine the presence or absence of pneumoconiosis. Norden et al reported an 80\% agreement rate between two radiologists assessing the changes of chronic pyelonephritis on excretory urograms. Chikos et al found intraobserver agreement 80\% of the time when 10 radiologists were asked to assess total heart size on frontal and lateral chest radiographs. McLachlan and Bennett reported 76\% to 85\% agreement.
Our methodology seems less well suited for detecting small differences in percent stenosis. The application of computer methods is now only beginning. Dodge’s group\textsuperscript{19} has developed a computer method for digitizing coronary arteriograms. A pair of radiographs made perpendicular to each other are projected on a large screen marked off in x-y coordinates at a 5-fold magnification. The lesions are then traced in outline by three trained observers. Normal portions of the

Table 8 Effect of Classification on Interobserver Variability

<table>
<thead>
<tr>
<th>Artery</th>
<th>Percent agreement $%$</th>
<th>21 groups*</th>
<th>5 groups†</th>
<th>6 groups‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common carotid</td>
<td>35.0</td>
<td>68.8</td>
<td>62.2</td>
<td></td>
</tr>
<tr>
<td>Internal carotid</td>
<td>30.1</td>
<td>75.0</td>
<td>59.4</td>
<td></td>
</tr>
<tr>
<td>External carotid</td>
<td>50.4</td>
<td>77.5</td>
<td>66.7</td>
<td></td>
</tr>
<tr>
<td>All three</td>
<td>38.5</td>
<td>73.8</td>
<td>62.8</td>
<td></td>
</tr>
</tbody>
</table>

*0 to 100% stenosis at 5% intervals.
†0, 1–9, 10–49, 50–99, 100% stenosis.
‡0, 1–24, 25–49, 50–74, 75–99, 100% stenosis.
§Percent of the time cases were placed into the same grouping.

Table 9 Effect of Using the Average of Two Readers’ Estimates of Percent Stenosis on Interobserver Variability (N = 769)

<table>
<thead>
<tr>
<th>Artery</th>
<th>Percent agreement $%$</th>
<th>21 groups*</th>
<th>5 groups†</th>
<th>6 groups‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common carotid</td>
<td>49.2</td>
<td>81.8</td>
<td>80.2</td>
<td></td>
</tr>
<tr>
<td>Internal carotid</td>
<td>42.4</td>
<td>81.0</td>
<td>77.3</td>
<td></td>
</tr>
<tr>
<td>External carotid</td>
<td>52.1</td>
<td>79.9</td>
<td>82.3</td>
<td></td>
</tr>
<tr>
<td>All three</td>
<td>47.9</td>
<td>80.9</td>
<td>79.9</td>
<td></td>
</tr>
</tbody>
</table>

*0 to 100% stenosis at 5% intervals.
†0, 1–9, 10–49, 50–99, 100% stenosis.
‡0, 1–24, 25–49, 50–74, 75–99, 100% stenosis.
§Percent of the time cases were placed into the same grouping.

TABLE 10 Effect of the Addition of Oblique Views on the Estimate of Percent Stenosis

<table>
<thead>
<tr>
<th>Artery</th>
<th>Percent stenosis*</th>
<th>4 views &gt; 2 views</th>
<th>4 views = 2 views</th>
<th>4 views &lt; 2 views</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common carotid</td>
<td>57</td>
<td>88</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>Internal carotid</td>
<td>61</td>
<td>82</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>External carotid</td>
<td>39</td>
<td>118</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>157</td>
<td>288</td>
<td>131</td>
<td></td>
</tr>
<tr>
<td>Percent</td>
<td>27%</td>
<td>50%</td>
<td>23%</td>
<td></td>
</tr>
</tbody>
</table>

*Comparison of the percent stenosis with and without oblique views for each case for reader (N = 576).

TABLE 11 Effect of the Addition of Oblique Views on the Description of the Stenotic Lesion in the Internal Carotid Artery (N = 192)

<table>
<thead>
<tr>
<th>All four views</th>
<th>None</th>
<th>Smooth</th>
<th>Irregular</th>
<th>Ulcer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two views</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>none</td>
<td>21</td>
<td>8</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>smooth</td>
<td>5</td>
<td>55</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>irregular</td>
<td>2</td>
<td>24</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>ulcer</td>
<td>4</td>
<td>5</td>
<td>34</td>
<td></td>
</tr>
</tbody>
</table>

Note: 42 cases (21.9%) considered more advanced with all 4 views, 16 cases (8.3%) considered more advanced with 2 views ($p < 0.001$).
artery both proximal and distal to the diseased segment are included. The computer then calculated the diameter, percent stenosis, cross sectional area, and the length and mass of the atheroma. Their methodology may prove difficult in evaluating the proximal internal carotid artery because of the normal variability in size and shape of this segment.

The other significant finding in this study is that the additional views do not significantly change the estimates of percent stenosis. DeWeese et al. noted there was close agreement between the angiographic assessment and the degree of narrowing seen on gross pathologic inspection. If mild degrees of narrowing are managed conservatively then oblique views would not seem indicated. We recommend that oblique views of the carotid bifurcation be obtained when detection of ulceration would alter patient management or the additional information would be useful in the basic study of this disease.

References
Observer variability in evaluating extracranial carotid artery stenosis.
P M Chikos, L D Fisher, J H Hirsch, J D Harley, B L Thiele and D E Strandness, Jr

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