Original Contributions

Multicenter Validation Study of Real-Time Ultrasonography, Arteriography, and Pathology: Pathologic Evaluation of Carotid Endarterectomy Specimens

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The morphologic description and measurements of endarterectomy specimens are usually believed to be accurate and are used as the gold standard against which the findings of diagnostic procedures are judged. Pathology data on 289 endarterectomy specimens from five participating centers and the corresponding angiography and B-mode ultrasonography data provided a basis for scrutinizing the validity of using the morphologic measurements as a standard. Discrepancies of > 1 mm between pathology and angiography measurements of minimum residual lumen occurred in 35% of the cases and between pathology and B-mode ultrasonography measurements in 64% of the cases. Discrepancies of > 1 mm between pathology- and angiography-measured lesion width occurred in 81% of the cases and between pathology and B-mode ultrasonography measurements in 64% of the cases. The cases representing mismatches of > 1 mm at one participating center were subjected to a rigorous review, with remeasurement of all morphologic features, in an attempt to explain the discrepancies. Various types of artifactual distortion of the specimens, the presence of slit-like and occluded lumens that were likely related to loss of perfusion pressure, and an inability to match planes of interrogation used in angiography and B-mode ultrasonography with pathology planes contributed significantly to the existence of mismatches. On the other hand, fixation and decalcification produced minimal and insignificant distortional changes. We conclude that the acquisition of quantitative data from endarterectomy specimens and the acceptance of morphologic data as a standard are limited by a number of problems that can be defined but have been difficult to resolve. (Stroke 1988; 19:289–296)

The morphologic description and measurements of endarterectomy specimens are usually believed to be accurate and are used as the gold standard against which the findings of diagnostic procedures are compared to assess their validity. Such was the approach used in a multicenter National Institutes of Health–sponsored study to evaluate B-mode ultrasonographic imaging (B-scan) of the carotid arteries. Five clinical centers and one coordinating center collaborated in this study. The main purpose of the study was to assess the accuracy with which B-scan describes lumen diameter, plaque thickness, and percent stenosis within 1.5 cm of the carotid artery bifurcation. The B-scan findings were compared with those obtained by both conventional and digital angiography and by pathologic examination of the endarterectomy specimen. Details about the overall design, the methods for ultrasonography and angiography, and the findings have been published.1-2 This communication focuses on the pathologic examination: how the specimens were processed and measured, how data were obtained and analyzed, and how accuracy of the measurements was evaluated. The emphasis is on accuracy of the pathology measurements and on the technical factors that can interfere with the accuracy of such measurements.

Subjects and Methods

A total of 900 patients who underwent both angiography and B-scan of the carotid arteries for symptoms of cerebrovascular disease were evaluated over an
18-month period. Angiography was performed using the standard retrograde femoral technique in 72% of these patients and using intravenous digital subtraction imaging in 28%. All patients were examined, using a standard protocol, with one of four high-resolution ultrasound machines (Biosound; Diasonics; Horizon Research Lab; Picker). Machine standardization was ensured by circulation of a phantom among the five centers. Angiographic and B-scan images were interpreted by randomly selected, blinded interpreters.

Measurements of the angiographic and B-scan images included standard lumen (SL), minimum residual lumen (MRL), lesion width (LW), and percent diameter stenosis. SL was defined as the arterial diameter 15 mm below the carotid flow divider (the bifurcation of the common carotid artery into the internal and external carotid arteries). In the case of angiography, the lumen was determined by measuring the diameter of the dye column, whereas with B-scan it was determined from the overall image. MRL was defined as the smallest lumen diameter in the internal or common carotid artery on the image that demonstrated the most severe luminal narrowing. Location of MRL was defined by angiography and by B-scan as the distance in millimeters from the flow divider and by pathology as the 3-mm cross-sectional slice in which the smallest lumen was found. Morphometricaly obtained lumen diameters were used whenever the specimen was split or when the pathologist identified artifactual distortion (a marked change from the in vivo state). LW was defined as the total thickness of the near and far walls of the specimen along the plane that showed the maximal thickness at the MRL. On angiograms, LW was estimated by drawing lines between the presumably normal vessel walls proximal and distal to the lesion.

Specimen Processing

Endarterectomy specimens from patients who had undergone real-time B-mode ultrasonography and angiography before surgery were received by the pathology department personnel promptly after their removal. Specimens that were received in multiple parts or that were badly distorted were not included in the study; intact specimens and those with a single surgically produced longitudinal slit were included.

The gross specimens, along with a millimeter-scaled ruler, were photographed on 35-mm transparency film and then radiographed for 30 seconds at 30 kV to determine the quantity and distribution of calcium. Because the large amount of calcium in most specimens precluded cross-sectioning, decalcification was carried out using a commercially available decalcifying solution (e.g., Cal-Ex, Fisher Scientific Co., Pittsburgh, Pennsylvania; a mixture of hydrochloric acid and an unspecified chelating agent). This procedure generally required 4–6 hours. After decalcification, the specimens were again photographed.

The specimens were then oriented on a flat surface so that the origin of the external carotid artery faced medially. An India ink line was drawn along the superior wall. An initial cross-sectional cut was made at the flow divider, and this point was designated as the “0” or reference point. In many cases the flow divider could not be located exactly until the first cross-sectional cut was made. Therefore, the thickness of the first slice was adjusted so that all subsequent cross-sectional cuts were made at 3-mm intervals relative to the reference point. Each 3-mm cross-sectional slice was numbered sequentially relative to the reference point (i.e., −3, −6, −n for the common carotid artery segments and +3, +6, +n for the internal carotid artery segments). These serial slices were placed next to each other on a flat surface so that the cephalad aspect of each faced upward. The India ink line was used to obtain consistent orientation of each slice, and the entire array, along with the ruler, was photographed on 35-mm transparency film.

Morphologic Evaluation

The following determinations were made and were recorded on a standard protocol form: 1) specimen length and diameter at 3-mm intervals measured on photographs of the gross specimen, 2) presence or absence of calcification within each segment as shown on the radiographs (no effort was made to quantify the amount of calcification), and 3) site of MRL, specific arterial segment containing MRL, and longitudinal extent of MRL (termed lesion extent) as shown on the photographs. All 3-mm slices containing MRL as well as those adjacent to that segment (both inferiorly and superiorly) were measured for lumen diameter and wall thickness at four different planes (rays) passing through
the center (axis) of the lumen (Figure 1). These planes were 45° to each other and were designated A–A’, B–B’, C–C’, and D–D’. At one center, the measurements were made directly on the tissue slices by using a ×7 micrometer reticule graduated at 0.1-mm intervals.

Distorted endarterectomy specimens with partially collapsed lumens were common whenever there was a longitudinal split or when an eccentric lumen was partially enclosed by a thin wall (<1 mm) (Figure 2, a and b). To compensate for these distortions, all nonround lumens were reconstructed by measuring the lumen perimeter and then calculating the diameter of a circle with a circumference equal to the measured perimeter. The lumen diameter calculated in this manner was used as the MRL.

**Evaluation of Methods**

Experiments were done at two centers to define the effects of fixation and decalcification on specimen size and shape. For these experiments 40 endarterectomy specimens were evaluated in the fresh state, after fixation in 10% neutral buffered formalin for 24–72 hours, and again after decalcification in an acid-chelating agent solution for 6 hours. Specimen contours were traced using a ×6.3 projection lens onto a computer-interfaced digitizing tablet, which was then used to measure length and diameter at 3-mm intervals, perimeter, and integrated total surface area. The average percent change in these parameters was then calculated to compare formalin-fixed versus fresh and decalcified ones.

**Results**

A total of 289 specimens was included in the study (Table 1). Because the quality of some angiograms and some B-scan images precluded obtaining all measurements in every case, the number of cases for some categories in "Results" are less than the total number of specimens enrolled in the study.

**Effects of Fixation and Decalcification**

Formalin fixation produced variable but minor changes; in some specimens dimensions increased, in others they decreased. The average of such changes for all specimens was an approximately 0.1% decrease in diameter, a 1% decrease in length and perimeter, and a 2% increase in area. This dissociation between linear and area measurements is most likely explained by slight changes in overall shape (configuration became more nearly round).

Decalcification always produced shrinkage. The degree of this change was a 3% decrease in diameter, an approximately 5% decrease in length and perimeter, and a 9% decrease in area (Table 2). To determine whether the degree of shrinkage seen with decalcification was related to the amount of calcium present, the calcium seen on radiographs was semiquantitatively graded on a scale of 0 to 4+. The absence of calcium was graded as 0, involvement of the entire specimen was graded as 4+, and 25%, 50%, and 75% involvement were graded as 1+, 2+, and 3+, respectively. The degree of calcification and the percent change in specimen area were not significantly associated. We concluded that shrinkage due to decalcification is not directly due to removal of calcium.

In another series of experiments carried out at one center, linear and area measurements of decalcified cross-sectional slices were compared with those obtained from microscopic sections prepared from the tissue slices. The specimens consistently shrank 20–30% during paraffin embedding and processing. No attempt was made to determine whether different components of the plaques had different degrees of shrinkage.

**Comparison of Angiography and Pathology Data**

**Minimum residual lumen.** The number of cases in which MRL measured by angiography differed by <1 mm, by 1–2 mm, and by >2 mm from measurements on pathology specimens are presented in Table 3. All centers found that pathology and angiography measurements of MRL differed by <1 mm in approximately 60–70% of the cases. The mean MRL for 289 specimens was 1.8 mm. The mean MRL on angiography was also 1.8 mm, but there was variation in this mean among centers. Two centers had a pathology

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**TABLE 1. Number and Source of Split and Intact Carotid Endarterectomy Specimens**

<table>
<thead>
<tr>
<th>Center</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>All</th>
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<tbody>
<tr>
<td>No. %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Split specimens</td>
<td>19</td>
<td>38</td>
<td>4</td>
<td>11</td>
<td>53</td>
<td>79</td>
</tr>
<tr>
<td>Intact specimens</td>
<td>31</td>
<td>62</td>
<td>33</td>
<td>89</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>62</td>
<td>37</td>
<td>67</td>
<td>44</td>
<td>91</td>
</tr>
</tbody>
</table>

**TABLE 2. Size of 40 Carotid Endarterectomy Specimens Before and After Formalin Fixation and Decalcification**

<table>
<thead>
<tr>
<th>Percent change</th>
<th>Outer diameter</th>
<th>Length</th>
<th>Perimeter</th>
<th>Total area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SD</td>
<td>Mean SD</td>
<td>Mean SD</td>
<td>Mean SD</td>
</tr>
<tr>
<td>Fresh vs. formalin-fixed</td>
<td>-0.14</td>
<td>2.9</td>
<td>-1.2</td>
<td>5.5</td>
</tr>
<tr>
<td>Formalin-fixed vs. decalcified</td>
<td>-3.0</td>
<td>3.0</td>
<td>-4.5</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Outer diameter measured at 3-mm intervals on each specimen.
mean MRL less than the angiography mean MRL (1.8 vs. 2.0 mm, 1.8 vs. 2.2 mm), whereas the other three centers found the pathology mean MRL to be greater than the angiographic mean MRL (1.5 vs. 1.2 mm, 1.9 vs. 1.7 mm, and 1.7 vs. 1.4 mm).

The entire data set for all five centers shows that 35% (101 of 289) endarterectomy specimens had a difference of >1 mm in MRL between the angiography and pathology measurements. These disparate measures indicate a lack of accuracy in either the angiography or the pathology measurements or in both.

To address the question of the accuracy of pathology measurements, the 30 cases with a >1 mm discrepancy from one center were reviewed and remeasured by two observers. Among these 30 specimens, measurement and clerical errors were found in five; in three of these five, data from the external carotid artery had been used. Two specimens were so badly distorted they should have been categorized as fragmented. Three specimens were described as occluded by pathology but showed a MRL on angiograms of 2.2, 1.6, and 1.4 mm; there was no evidence for an acute event, such as mural thrombus or intramural hemorrhage, which might have occurred between angiography and surgery. Examination of the plaque wall revealed no features to explain why these lumens collapsed in the absence of distending arterial pressure (Figure 2, e). In two specimens the tissue slice had been cut obliquely, and part of the lumen was obscured by the wall of the plaque (Figure 2, d). The morphometric perimeter did not correspond to the actual lumen perimeter, and the measured diameters were incorrect in two planes. Reconstruction was achieved in these cases by drawing an arc to complete that portion of the lumen that was not visible. This procedure resulted in MRL pathology measurements that differed from the angiograms by 0.7 and 0.9 mm. Seven specimens had slit-like lumens (Figure 2, e and f). Morphometric lumen perimeters had been used to determine MRL in all of these seven. It is controversial whether slit-shaped lumens exist in vivo or are artifacts related to loss of distending arterial pressure, and there was no consensus on whether the morphometric perimeter or the measured diameter should be used. In these seven cases, the smallest measured diameter was within 1 mm of MRL measured

![Cross-sectional slices (facing page) from endarterectomy specimens illustrate structural features posing problems with measurements. a: Longitudinal split produced at surgery resulting in distorted lumen. b: In-folding of thin plaque wall in specimen with eccentric lumen. c: Apparently occluded specimen that had lumen at angiography and that showed no structural changes suggestive of acute occlusive event. d: Oblique cross-sectional slice or oblique path of lumen obscuring part of lumen and wall. e, f: Slit-like (void and D-shaped) lumens believed by some to be artifacts due to loss of perfusion pressure.](http://stroke.ahajournals.org/)

**Figure 2.**

![Cross-sectional slices (facing page) from endarterectomy specimens illustrate structural features posing problems with measurements. a: Longitudinal split produced at surgery resulting in distorted lumen. b: In-folding of thin plaque wall in specimen with eccentric lumen. c: Apparently occluded specimen that had lumen at angiography and that showed no structural changes suggestive of acute occlusive event. d: Oblique cross-sectional slice or oblique path of lumen obscuring part of lumen and wall. e, f: Slit-like (void and D-shaped) lumens believed by some to be artifacts due to loss of perfusion pressure.](http://stroke.ahajournals.org/)
TABLE 4. Angiography and B-scan Ultrasonography Location of Minimum Residual Lumen Compared With Pathology Location on Carotid Endarterectomy Specimens

<table>
<thead>
<tr>
<th>Center</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angiography</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A = P</td>
<td>23</td>
<td>17</td>
<td>39</td>
<td>16</td>
<td>36</td>
<td>131 (49%)</td>
</tr>
<tr>
<td>A in adjacent 3-mm P segment</td>
<td>17</td>
<td>10</td>
<td>15</td>
<td>18</td>
<td>29</td>
<td>89 (33%)</td>
</tr>
<tr>
<td>A &gt; 1 segment from P</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>5</td>
<td>22</td>
<td>50 (19%)</td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td>35</td>
<td>64</td>
<td>39</td>
<td>87</td>
<td>270</td>
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<tr>
<td>B-scan ultrasonography</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B = P</td>
<td>11</td>
<td>13</td>
<td>23</td>
<td>11</td>
<td>20</td>
<td>78 (37%)</td>
</tr>
<tr>
<td>B in adjacent 3-mm P segment</td>
<td>19</td>
<td>9</td>
<td>19</td>
<td>11</td>
<td>21</td>
<td>79 (38%)</td>
</tr>
<tr>
<td>B &gt; 1 segment from P</td>
<td>15</td>
<td>5</td>
<td>9</td>
<td>6</td>
<td>18</td>
<td>53 (25%)</td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td>27</td>
<td>51</td>
<td>28</td>
<td>59</td>
<td>210</td>
</tr>
</tbody>
</table>

A, minimum residual lumen by angiography; P, minimum residual lumen by pathologic examination; B, minimum residual lumen by B-scan ultrasonography.

on the angiogram. In 11 of the 30 cases with disparities of > 1 mm, review of the pathology specimens and data could not explain the observed differences in lumen measurements.

After the various corrections described above were made on these 30 specimens, pathology and angiography MRL values were within 1 mm in 78 of the 91 cases from this center (86%).

Lesion width. Data from individual centers showed the mean pathology LW to be 1.7–3.4 mm larger than the angiography mean LW. Case-by-case comparison of the data showed that 55% (30–84%) of all LW measurements had a > 2 mm discrepancy between the angiography and pathology measurements (Table 3). The difference between angiography and pathology measurements was > 1 mm in > 80% of the cases from four centers and in 67% of the cases from the fifth center.

Location of minimum residual lumen. The distance of MRL from the flow divider was measured directly on angiograms. In pathology specimens MRL was ascribed to the 3-mm cross-sectional slice that contained the smallest lumen. Table 4 shows the number of cases from each center for which the angiography measurement corresponded to the 3-mm section, for which the angiography measurement fell within an adjacent 3-mm section, and for which the angiography measurement placed MRL beyond an adjacent 3-mm section. For the entire data set, MRL by angiography corresponded to the pathology location in 49%. In 33% angiography placed it within one of the adjacent 3-mm segments, and in 19% the difference was more than one 3-mm segment.

Comparison of B-Mode Ultrasonography and Pathology Data

Minimum residual lumen. The total number of cases from each center and the number of cases in which MRL measured by B-scan and pathology differed by <1, 1–2, and >2 mm are also presented in Table 3. MRL by B-scan differed from the pathology measurement by < 1 mm in 40% of the cases, and there was more variability between centers than for the angiography–pathology comparisons.

The number of cases in which MRL measured by B-scan differed by <1, 1–2, or >2 mm from the pathology measurements categorized as 0.0–1, 1.1–2, 2.1–3, 3.1–4, and >4 mm are presented in Table 5, which shows that differences between B-scan and pathology measurements appear to be independent of the size of the lumen.

The entire data set for all five centers shows that 135 of the 225 cases (60%) had a difference of > 1 mm in MRL. One center had 33 cases in this category. If the accuracy of the pathology measurements contributed to the existence of these mismatches, the same cases identified as having > 1-mm mismatches in the angiography–pathology mismatch should reappear as B-scan–pathology mismatches. Of the 30 mismatches in the angiography–pathology comparisons of cases from

TABLE 5. Differences in B-scan Ultrasonography and Pathology Measurements of Minimum Residual Lumen on Carotid Endarterectomy Specimens

<table>
<thead>
<tr>
<th>Difference</th>
<th>0.0–1</th>
<th>1.1–2</th>
<th>2.1–3</th>
<th>3.1–4</th>
<th>&gt; 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
<td>No. %</td>
</tr>
<tr>
<td>&gt; 1 mm</td>
<td>33</td>
<td>38</td>
<td>23</td>
<td>39</td>
<td>18</td>
</tr>
<tr>
<td>1–2 mm</td>
<td>19</td>
<td>22</td>
<td>18</td>
<td>31</td>
<td>13</td>
</tr>
<tr>
<td>&lt; 2 mm</td>
<td>35</td>
<td>40</td>
<td>18</td>
<td>31</td>
<td>12</td>
</tr>
<tr>
<td>Total (225)</td>
<td>87</td>
<td>59</td>
<td>43</td>
<td>20</td>
<td>16</td>
</tr>
</tbody>
</table>
this center, nine cases recurred in the B-scan—pathology mismatches. In the remaining 24 B-scan—pathology mismatches, angiography had agreed with pathology measurements to within 1 mm. These 24 mismatches were reviewed again by two observers to determine the accuracy of the pathology data and to obtain a control series for the angiography—pathology analysis, which would allow us to determine how often measurement and clerical errors may have occurred in cases that agreed to within 1 mm. Fifteen of the 24 specimens were intact and nine were split; one was occluded, and two had slit-like lumens. No measurement or clerical errors were found in the pathology records.

Thus, among 33 cases from one center with a B-scan—pathology difference in MRL of > 1 mm, 12 were identified in which the accuracy of the pathology data probably contributed to the discrepancy.

Lesion width. The total number of cases from each center and the number of cases in which LW measured by B-scan and pathology differed by > 1 mm are also presented in Table 3. A difference of < 1 mm was found only in about one third of the cases. Another third agreed to within 2 mm, and the final third differed by > 2 mm.

All five centers found the mean pathology LW to be 0.5–1 mm larger than the corresponding mean B-scan measurement. The entire data set for all five centers shows that 132 of 206 cases (64%) had a difference of > 1 mm. The 39 cases from one center with a difference of > 1 mm were reviewed and measured again by two observers. No measurement or clerical errors were found. Splits in the specimen, the shape of the lumen, obliqueness of cross-sectional slices, and other problems associated with the accuracy of lumen measurements had no consequence in obtaining accurate LW in these 39 specimens.

Location of minimum residual lumen. The location of MRL in relation to the flow divider on B-scan images corresponded to the same 3-mm pathology segment in 78 of 210 cases (37%). In 38% of the cases MRL was located in an adjacent segment, and in 25% of the cases the location was more than one 3-mm segment from the B-scan site (Table 4).

Discussion

"How good is pathology as a gold standard in the assessment of endarterectomy specimens?" is the main question addressed in our study. To that end, pathologists at the five centers met initially to standardize the protocol for processing and measuring the specimens and for recording the data; later, on the basis of accumulating experience, we met to refine the methods and to resolve problems that were encountered. Our review of the pathology techniques and results identified issues in three categories: theoretical concerns about the possible impact of techniques on accuracy; mismatches of pathology, angiography, and B-scan data for which an explanation could be found; and data discrepancies that, although identified, could not be resolved satisfactorily. Our approach in assessing the accuracy of pathology measurements was to analyze reasons for differences in measurements between angiography and pathology data and between B-scan and pathology data. A difference of < 1 mm in MRL and LW was arbitrarily designated as acceptable, and differences of > 1 mm were considered to reflect a lack of accuracy in either the pathology or diagnostic procedure measurements. The mismatches of > 1 mm at one center were subjected to a rigorous review with measurement of all morphologic features again and an attempt to identify an explanation for the discrepancy.

The effects of fixation and decalcification on plaque morphology fall into the first category. Our analysis revealed that formalin fixation did not significantly shrink endarterectomy specimens. This finding is consistent with previous reports that formalin does not change the dimensions in human coronary arteries or shrink most tissues. Decalcification, irrespective of the amount of calcium removed, resulted in shrinkage of 5–10%. Since lumens, lesion widths, and reference distances were measured only to the nearest 0.5 mm, however, adding 10% to each of these measurements would not change the data enough to affect our interpretation.

In the second category are problems related to measurement and clerical errors, which were relatively few in number and easily resolved, and to distortion of the specimens. Fragmented specimens were not included in our study, but even nonfragmented specimens frequently showed varying degrees and types of distortion. These included surgically split specimens, ones with an eccentric lumen and in-folding of a thin wall along one side of the lumen, obliquely cut cross-sectional slices, and nonround specimens and lumens resulting from compression of plaque, which contained atheronecrotic material. The decision to reconstruct such distorted specimens appears to have been reasonable. This approach of circularizing not only increased the accuracy of measurements by recreating the in vivo state but also allowed more cases to be accepted into our study. In two centers, only 3 of 44 and 14 of 67 specimens were intact; most had been split longitudinally.

Problems for which no satisfactory solution was found related to the presence of slit-like and occluded lumens, to the loss of distending arterial pressure, and to the matching of planes of interrogation used by the diagnostic procedures with those used for measuring morphologic features. There is no consensus as to whether slit-like lumens exist in vivo. The work of Glagov and Zarins with pressure-fixed human coronary arteries supports the view that lumens are almost always round. On the other hand, it is conceptually difficult to accept that a slit-like lumen surrounded by thick, heavily calcified, and fibrotic plaque could assume a circular shape even in the presence of high intraluminal pressure. There was also no obvious explanation for a few cases in which the lumen of the specimen was occluded but in which angiography demonstrated a patent lumen. Possibly some change occurred within the plaque between the time of arteriography and surgical removal, but this was not
of the four planes measured by pathology best
wall where it is assumed to be free of disease, to draw
between the flow divider and the location of maximum
changes within their planes of interrogation.

corresponded to the planes of interrogation used during
plaques usually encroach not only on the lumen but also
ferred rather than measured. The standard procedure is
plaque wall or to the difficulty of matching planes of

due to an inability of B-scan to demonstrate the entire
surgeons and has been described by angiographers and
ultrasonographers.8 Since the anatomic relation of
these two vessels to each other is the basis for defining
the planes used in measuring the endarterectomy
specimens, it seems unlikely that angiographic or
B-scan planes can be precisely correlated with mor-
phologic ones. Selection of a pathology plane with the
thickest wall allowed us to determine whether angiog-
raphy and B-mode ultrasonography can identify the
most marked dimensional changes in the vessel rather
than how accurately these modalities can demonstrate
changes within their planes of interrogation.

From our study, certain measurements made on
specimens can be considered accurate: 1) the distance
between the flow divider and the location of maximum
luminal stenosis and 2) the lesion width. Discrepancies
in the location of the maximum stenosis between
pathology and angiography or B-scan were probably
due to an inability of these imaging modalities to
demonstrate the entire plaque wall or to the difficulty of matching planes of
interrogation. LW as defined by angiography is in-
ferred rather than measured. The standard procedure is
to measure the lumen at some point along the vessel
wall where it is assumed to be free of disease, to draw
a line 1 mm on each side of the contrast dye column,
and then to extend the two parallel lines so that they
encompass the region of luminal stenosis. Since
plaques usually encroach not only on the lumen but also
extend peripherally to form a bulge, angiographic
inferences about LW are seldom meaningful.

In our study, comparisons of angiography with
pathology data and B-scan with pathology data were
intended to identify mismatched cases, which could
then be used to determine the accuracy of pathology
methods, but our findings also allowed analysis of the
relative accuracy of angiography versus B-scan. For
example, data from all five centers show that angiog-
raphy and pathology measurements of MRL agree to
within 1 mm in 65% of the cases, whereas B-scan
accomplishes this in only 40% of the cases. On the other
hand, B-scan measurements of LW agree more closely
with pathology measurements than does LW inferred
by angiography. Other statistical analyses and inter-
pretation of angiography and B-scan data derived from
the multicenter study have been published.1

In summary, acquisition of quantitative data from
endarterectomy specimens is neither simple nor trivial.
Our study has approached this task in a more detailed
manner than any previously published comparisons of
angiography with pathology or B-mode ultrasonogra-
phy with pathology. A number of problems remain to
be resolved, however, before pathology measurement
can be accepted as a gold standard for determining the
sensitivity and specificity of diagnostic procedures.
Since there is much current interest in the capability of
noninvasive diagnostic procedures, such as ultrasonog-
raphy and nuclear magnetic resonance imaging, to
characterize atherosclerotic plaque components as well
as plaque progression and regression, an awareness of
problems associated with the evaluation of morpho-
logic features will become increasingly important.

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Key Words • angiography • endarterectomy • pathology •
ultrasonic diagnosis
Multicenter validation study of real-time ultrasonography, arteriography, and pathology: pathologic evaluation of carotid endarterectomy specimens.
E A Schenk, M G Bond, T H Aretz, J N Angelo, H Y Choi, T Rynalski, N F Gustafson, A S Berson, J J Ricotta and M W Goodison

doi: 10.1161/01.STR.19.3.289

*Stroke* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/19/3/289

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