Coronary Morphologic and Clinical Determinants of Procedural Outcome With Angioplasty for Multivessel Coronary Disease

Implications for Patient Selection

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To assess the likelihood of procedural success in patients with multivessel coronary disease undergoing percutaneous coronary angioplasty, 350 consecutive patients (1,100 stenoses) from four clinical sites were evaluated. Eighteen variables characterizing the severity and morphology of each stenosis and 18 patient-related variables were assessed at a core angiographic laboratory and at the clinical sites. Most patients had Canadian Cardiovascular Society class III or IV angina (72%) and two-vessel coronary disease (78%). Left ventricular function was generally well preserved (mean ejection fraction, 58±12%; range, 18–85%) and 1.9±1.0 stenoses per patient had attempted percutaneous coronary angioplasty. Procedural success (≤50% final diameter stenosis in one or more stenoses and no major ischemic complications) was achieved in 290 patients (82.8%), and an additional nine patients (2.6%) had a reduction in diameter stenosis by 20% or more with a final diameter stenosis 51–60% and were without major complications. Major ischemic complications (death, myocardial infarction, or emergency bypass surgery) occurred in 30 patients (8.6%). In-hospital mortality was 1.1%. Stepwise regression analysis determined that a modified American College of Cardiology/American Heart Association Task Force (ACC/AHA) classification of the primary target stenosis (with type B prospectively divided into type B1 [one type B characteristic] and type B2 [≥two type B characteristics]) and the presence of diabetes mellitus were the only variables independently predictive of procedural outcome (target stenosis modified ACC/AHA score: p<0.001 for both success and complications; diabetes mellitus: p=0.003 for success and p=0.016 for complications). Analysis of success and complications on a per stenosis dilated basis showed, for type A stenoses, a 92% success and a 2% complication rate; for type B1 stenoses, an 84% success and a 4% complication rate; for type B2 stenoses, a 76% success and a 10% complication rate; and for type C stenoses, a 61% success and a 21% complication rate. The subdivision into types B1 and B2 provided significantly more information in this clinically important intermediate risk group than did the standard ACC/AHA scheme. The stenosis characteristics of chronic total occlusion, high grade (80–99% diameter) stenosis, stenosis bend of more than 60°, and excessive tortuosity were particularly predictive of adverse procedural outcome. This improved scheme may improve clinical decision making and provide a framework on which to base meaningful subgroup analysis in randomized trials assessing the efficacy of percutaneous coronary angioplasty. (Circulation 1990;82:1193–1202)

The clinical and anatomic heterogeneity of patients with multivessel coronary artery disease might expectedly lead to differences in short- and long-term outcomes with percutaneous coronary angioplasty (PTCA). Previous short-term follow-up studies have focused on the feasibility and

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*A listing of the principal and coinvestigators is presented in “Appendix.”

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relative safety of PTCA in selected patients with multivessel involvement. As in the 1985–1986 report from the National Heart, Lung, and Blood Institute (NHLBI) PTCA Registry, which found major complications in 9.5% of patients with multivessel disease compared with 5% of patients with single-vessel disease,¹ most reports have found the risk of PTCA to be somewhat higher in patients with multivessel,²–⁸ compared with single-vessel, coronary artery disease.¹ Coronary angioplasty therefore may not be the best form of therapy for all patients with multivessel coronary disease. An increased understanding of the clinical³⁹–¹¹ and anatomic¹²–¹⁵ substrates predisposing patients to acute complications of angioplasty has led to an attempt by the American College of Cardiology and the American Heart Association (ACC/AHA) to systematize the characterization of stenoses considered for coronary angioplasty.¹⁶ This schema has never been formally validated.

Therefore, to aid in choosing appropriate therapy and to provide a rational basis for subgroup analysis in ongoing or anticipated randomized trials, we applied ACC/AHA and other criteria to 350 consecutive patients with multivessel disease undergoing PTCA to ascertain how short-term outcome might best be predicted.

**Methods**

**Patient Population**

Cineangiograms from 100 consecutive patients with stable or unstable angina and multivessel coronary disease (see definitions) undergoing attempted PTCA on or after January 1, 1986, were requested from each of the four participating institutions. Patients with prior coronary bypass surgery or acute myocardial infarction were excluded, and only patients with a life expectancy of ≥1 year were included. Such patients reflected those accepted for coronary angioplasty at each of the clinical sites in 1986 and 1987. Due to a change of study personnel at one clinical center, only 50 qualifying patients were enrolled from that site, and thus results from 350 patients were analyzed.

**Angioplasty Procedure**

The technique of angioplasty used has been described elsewhere.¹⁷ All patients were pretreated with oral aspirin (80–325 mg daily) and intravenous heparin (10,000 units at the beginning of the procedure). After insertion of arterial and venous sheaths, and the administration of heparin and usually nitroglycerin, preliminary angiography of the coronary artery or arteries to be dilated was performed at least two projections. Dilataion balloons were chosen with an inflated diameter approximately equal to lumen diameter at the site to be dilated. The balloon was positioned across the stenosis and inflated as many times as necessary to produce an optimal angiographic result. The result was angiographically documented in one or more projections best showing the stenosis. If an adequate result was obtained and it was believed safe to do so, further stenoses were dilated sequentially. At the end of the procedure all catheters were removed, but the femoral sheaths were left in place. Sheaths were usually removed 3–4 hours later unless angiographic evidence of a coronary dissection or thrombus was seen, in which case an intravenous infusion of heparin was usually administered overnight. After the procedure, the patients were taken to a postprocedure ward or intensive care unit where they were monitored for a minimum of 18–24 hours. The patients were medicated with oral aspirin and a calcium channel blocking agent and/or nitrate preparation. A 12-lead electrocardiogram was obtained immediately in the event symptoms or signs suggestive of ischemia were present, and if ischemia was suspected, the patients were usually returned for cardiac catheterization and creatine kinase levels were followed. The patients were routinely discharged 1–2 days after the PTCA.

**Clinical Variables**

The following clinical variables were assessed as possible correlates of outcome: age, Canadian Cardiovascular Society classification of angina, clinical site, current smoking, diabetes mellitus (type I or II), elevated cholesterol, gender, hypertension, prior myocardial infarction, and unstable angina.

**Angiographic Analysis**

One of two experienced angiographers at the Angiographic Core Laboratory reviewed the diagnostic and procedural angiograms to determine suitability for study entry and to code for 18 lesion-specific characteristics and 18 patient variables without knowledge of clinical outcome. All quantitative measurements were made using hand-held calipers in orthogonal projections at end-diastole, when possible. Thirty patients were excluded from the study due to non-visualization of a contralateral (e.g., the right coronary artery, when angioplasty was performed in the left anterior descending coronary artery) coronary artery (n=17), the presence of single-vessel disease (n=7), inadequate stenosis visualization (n=4), and angioplasty not performed during the study period (n=2). Additional patients were then requested until each institution’s quota was met.

The following angiographic definitions, based upon those used in the National Heart, Lung, and Blood Institute Bypass Angioplasty Revascularization Investigation (BARI) (BARI Central Radiographic Laboratory Operations Manual, unpublished), were used:

**ACC/AHA Task Force stenosis characteristic type.** The scheme elaborated in Table 1 was used, with the single exception that moderately angulated segments were defined as those subtending a 45–59° angle, and extremely angulated segments were defined as stenoses in segments subtending ≥60° angulation. For
### Table I. Characteristics of Type A, B, and C Lesions

<table>
<thead>
<tr>
<th>Type A Lesions (high success, 85%; low risk)</th>
<th>Little or no calcification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discrete (&lt;10 mm length)</td>
<td></td>
</tr>
<tr>
<td>Concentric</td>
<td>Less than totally occlusive</td>
</tr>
<tr>
<td>Readily accessible</td>
<td>Not ostial in location</td>
</tr>
<tr>
<td>Nonangulated segment, &lt;45°</td>
<td>No major branch involvement</td>
</tr>
<tr>
<td>Smooth contour</td>
<td>Absence of thrombus</td>
</tr>
<tr>
<td>Type B Lesions (moderate success, 60–85%; moderate risk)</td>
<td></td>
</tr>
<tr>
<td>Tubular (10–20 mm length)</td>
<td>Moderate to heavy calcification</td>
</tr>
<tr>
<td>Eccentric</td>
<td>Total occlusion &lt;3 months old</td>
</tr>
<tr>
<td>Moderate tortuosity of proximal segment</td>
<td>Ostial in location</td>
</tr>
<tr>
<td>Moderately angulated segment, &gt;45° &lt;90°</td>
<td>Bifurcation lesions requiring double guide wires</td>
</tr>
<tr>
<td>Irregular contour</td>
<td>Some thrombus present</td>
</tr>
<tr>
<td>Type C Lesions (low success, 60%; high risk)</td>
<td></td>
</tr>
<tr>
<td>Diffuse (&gt;2 cm length)</td>
<td>Total occlusion &gt;3 months old</td>
</tr>
<tr>
<td>Excessive tortuosity of proximal segment</td>
<td>Inability to protect major side branches</td>
</tr>
<tr>
<td>Extremely angulated segments &gt;90°</td>
<td>Degenerated vein grafts with friable lesions</td>
</tr>
</tbody>
</table>

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the purposes of statistical analysis, type A stenoses were coded 1 point, type B stenoses were coded 2 points, and type C stenoses were coded 3 points.

**Bifurcation stenosis.** The stenosis was recorded as a bifurcation stenosis if a branch vessel of medium or large size originated within the stenosis and if the side branch was completely surrounded by significant stenotic portions of the lesion to be dilated.

**Calcification.** Calcification was recorded if readily apparent densities were seen within the apparent vascular wall of the artery at the site of the stenosis.

**Chronic total occlusion.** A total occlusion (thrombolysis in myocardial infarction [TIMI] flow grade 019), judged to be ≥3 months duration on the basis of clinical and angiographic findings, was coded as a chronic total occlusion.

**Eccentric stenosis.** A stenosis was classified as eccentric when its lumen was in the outer one-quarter diameter of the apparent normal lumen.

**High grade stenosis.** A high-grade stenosis was defined as a diameter narrowing of 80–99% relative to the adjacent normal coronary artery dimension.

**Irregular contour.** A stenosis was classified as having irregular contour if the vascular margin was rough or had a "sawtooth" appearance.

**Jeopardized territory.** All terminal (e.g., distal left anterior descending, diagonal branch) branches of the coronary tree were scored small, moderate, or large depending on their vascular distribution. A medium-sized branch was defined as one that extended 1/4 to 2/3 of the distance from base to apex of the left ventricle in a projection that best elongated the branch. Large and small terminal branches were defined as longer and shorter, respectively, although branches of diameter ≤1.0 mm were generally considered absent. Branches scored as small were assigned 1 point, branches scored as moderate were assigned 2 points, and branches scored as large were assigned 3 points. The jeopardized territory equalled the sum of branches distal to the stenosis dilated, divided by the sum of all terminal branches of the coronary tree.19 For example, the jeopardized territory for a mid–left anterior descending coronary artery stenosis with moderate-sized distal left anterior descending and moderate-sized diagonal branch beyond the stenosis, would be 2+2=4, divided by the sum of all branches of the coronary tree.

**Lesion length.** Lesion length was measured by caliper as the distance from the proximal to distal shoulder of the lesion in the projection that best elongated the stenosis. Stenoses of 10–20 mm length were defined as tubular, and those of &gt;20 length were defined as diffuse.

**Modified ACC/AHA score.** The standard ACC/AHA score was prospectively modified to subdivide type B stenoses into B1 (one adverse characteristic) and B2 (≥two adverse characteristics) on the basis of prior work suggesting the cumulative importance of multiple adverse lesion characteristics.14 For the purpose of statistical analysis, type A stenoses were coded 1 point, type B1 stenoses 2 points, type B2 stenoses 3 points, and type C stenoses 4 points.

**Multivessel disease.** Multivessel coronary disease was defined as the presence of a ≥50% diameter stenosis in two of the three major epicardial coronary vessels, or surgically bypassable branches thereof. When the right coronary artery was nondominant and failed to supply any left ventricular myocardium, the first two moderate- or large-sized obtuse marginal branches of the circumflex were considered to supply one vascular territory, and the distal obtuse marginal branches and the posterior descending coronary artery were said to supply a different vascular territory.

**Ostial stenoses.** A stenosis was classified as "ostial" when it involved the origin of the proximal left anterior descending, left circumflex, or right coronary arteries. When they occurred together, "ostial" and "bifurcation" were counted as only one ACC/AHA class B characteristic.

**Other stenoses.** A stenosis was classified as associated with other stenoses when other ≥50% stenoses were found in the same or adjacent (BARI classification) coronary segment.

**Primary target stenosis.** A primary target stenosis was identified on the basis of the severity and morphologic characteristics of the stenoses,20 their jeopardized territories, the presumed viability of the myocardium subserved, and clinical data when available.

**Segmental contractility.** Segmental left ventricular myocardial contractility was scored normal equal to 3 points, mildly hypokinetic equal to 2 points, severely hypokinetic equal to 1 point, and akinetic or dyskinetic equal to 0 points.

**Stenosis angle.** The vessel angle formed by a centerline through the lumen proximal to the stenosis and
extending beyond it and a second centerline in the straight portion of the artery distal to stenosis was measured in a nonforeshortened view at end-diastole.

Successful dilatation (stenosis success). A successful dilatation was defined as a final result <50% diameter stenosis associated with no major adverse clinical sequelae (death, myocardial infarction, or emergency bypass surgery).

Thrombus. A thrombus was scored if an intraluminal filling defect, largely separated from the adjacent vessel wall, was clearly definable.

Tortuosity. The difficulty in accessing the stenosis to be dilated due to tortuosity proximal to its site was assessed. Stenoses distal to two bends were, in general, scored as moderately tortuous, and those distal to three or more bends were considered to be associated with excessive tortuosity.

Several combined variables were also assessed:

Primary target stenosis ACC/AHA score.

Sum of all stenoses (≥50%) ACC/AHA scores.

Primary target stenosis modified ACC/AHA scores.

Sum of all stenoses modified ACC/AHA scores.

Primary target stenosis modified ACC/AHA score×jeopardized territory.

Sum of all stenoses’ modified ACC/AHA scores×their respective jeopardized territories.

Primary target stenosis modified ACC/AHA score×jeopardized territory×segmental contractility.

Sum of all stenoses’ modified ACC/AHA scores×jeopardized territory×segmental contractility.

Procedural Outcome

Procedural outcome was assessed at the Data Coordinating Center using data supplied by the individual clinical sites. The following definitions were used:

Procedural success. Reduction in diameter stenosis in one or more stenosis to <50% stenosis associated with no major ischemic complications during hospitalization.

Procedure-related myocardial infarction. Myocardial infarction defined by cardiac enzymes or electrocardiographic changes resulting from procedure-induced ischemia.

Procedure-related death. Death resulting from attempted PTCA.

Procedure-related complications. Death, emergency bypass surgery, or myocardial infarction resultant from attempted PTCA.

Stenosis-related outcomes. Stenosis-related outcomes were defined in a similar manner, except that outcome was related directly to the stenosis(es) dilated. In the event an adverse event could not be related to outcome at a given stenosis, the core angiographer assigned the outcome to the most likely stenosis. This was very infrequently required (see results).

Statistical Analysis

All data were entered in the MAPS Databank at the Data Coordinating Center. Data are expressed as mean±1 SD unless otherwise indicated. χ2 analyses were used to test the differences in categorical variables and unpaired Student’s t tests were used to assess differences in continuous variables. Multiple stepwise linear regression analyses were performed to determine the clinical and angiographic correlates of outcome. For one series of analyses, all simple variables (ACC/AHA score and modified ACC/AHA score excluded) were entered, and for a second series of analyses all variables were entered after forcing the modified ACC/AHA score into the regression equation. A randomly selected cohort of 25 patients was analyzed for interobserver variability of their stenoses’ modified ACC/AHA classification. Analyses were performed using SYSTAT software (System for Statistics, Evanston, Ill.: SYSTAT, Inc.) or SAS software (SAS Institute, Cary, N.C.).

Results

Patient and Stenosis Characteristics

Cineangiograms from 350 patients (1,100 stenoses) were analyzed. The characteristics of the study patients and the stenosis dilated are given in Tables 2 and 3, respectively. Of importance, 72% of the patients had severe (Canadian Cardiovascular Society Class III or IV) angina, the majority of patients (78%) had two-vessel coronary disease, left ventricular function was usually well preserved (ejection fraction, 58±12%), and 1.9 stenoses per patient were dilated. The stenoses dilated were of mixed complexity, with 29% having characteristics suggestive of expected high success and low complication rates (ACC/AHA type A), 61% having characteristics of expected moderate success and complication rates (ACC/AHA type B), and 10% having low success and high-risk characteristics (ACC/AHA type C). All but one (99.7%) of the core lab–determined primary-target stenoses had attempted angioplasty.

Overall Procedural Outcome

Two hundred ninety of 350 patients (82.6%) had at least one stenosis successfully dilated and no major ischemic complications. An additional nine patients (2.6%) had a reduction in diameter stenosis of one or
more stenoses by ≥20%, but with final diameter stenoses 51–60% and no complications. Major complications occurred in 30 of 350 patients (8.6%) (death, 4 of 350, 1.1%; nonfatal emergency bypass surgery, 20 of 350, 5.7%; and nonfatal myocardial infarction without bypass surgery, 6 of 350, 1.7%). Mortality with emergency bypass surgery was 3 of 20 (15%) and one patient died without bypass surgery. Outcome did not differ significantly between clinical sites (site A, stenosis success 79%, complications 11%; site B, stenosis success 82%, complications 9%; site C, stenosis success 88%, complications 7%; site D, stenosis success 82%, complications 6%).

**Correlates of Success (Per Stenosis)**

The relations among clinical angiographic variables and success on a per-stenosis basis are shown in Table 4A. The individual variables that were independent (negative) correlates of success were chronic total occlusion (success in 53%), bend stenosis ≥60° (success in 55%), high-grade stenoses (success in 73%), bifurcation stenosis (success in 77%), and male gender (success in 80%). In their absence, success was obtained in 90.7% of stenoses. Both the ACC/AHA and the modified ACC/AHA scores were highly predictive of stenosis success, but the modified score was somewhat more useful (success in type B1 was 83.6%, success in type B2 was 76.1%, χ²=3.52, p=0.09) (Figure 1). When the modified ACC/AHA score was forced into the stepwise linear regression model predictive of stenosis success, the variables of chronic total occlusion, high-grade stenosis, male gender, bend stenosis ≥60°, and bifurcation stenosis still were significant (p<0.05) correlates of outcome, thus implying they are underemphasized (or not included) in the modified ACC/AHA scoring system. Of the variables not shown in Table 4A, the following had relative risk of dilatation failure ≥1.5: ostial

![Figure 1. Bar graph showing influence of modified ACC/AHA score on stenosis success rate.](http://circ.ahajournals.org/)

**Table 3. Stenosis Characteristics (n=662*)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Stenosis site</th>
<th>Lesion length (mm)</th>
<th>Irregular contour (%)</th>
<th>Bifurcation stenosis (%)</th>
<th>Bend stenosis ≥60° (%)</th>
<th>Bend stenosis 45–59° (%)</th>
<th>Type B1 (%)</th>
<th>Type B2 (%)</th>
<th>Type C (%)</th>
<th>Ostial stenosis (%)</th>
<th>Other stenosis (%)</th>
<th>Percent diameter stenosis (%)</th>
<th>Thrombus (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>71.1±16.0</td>
<td>4.6</td>
</tr>
</tbody>
</table>

*Characteristics of the stenosis dilated.

**Table 4A. Correlates of Success (Per Stenosis)**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Successful dilatation (n=539)</th>
<th>Unsuccessful dilatation (n=123)</th>
<th>Univariate p value</th>
<th>Simple variable analysis: Multivariate p value</th>
<th>Overall multivariate p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified ACC/AHA score</td>
<td>2.08±.93</td>
<td>2.69±.97</td>
<td>&lt;0.001</td>
<td>...</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bend stenosis ≥60° (%)</td>
<td>3.2</td>
<td>12.4</td>
<td>0.006</td>
<td>&lt;0.001</td>
<td>0.016</td>
</tr>
<tr>
<td>High-grade stenosis (%)</td>
<td>22.1</td>
<td>35.8</td>
<td>0.004</td>
<td>&lt;0.001</td>
<td>0.009</td>
</tr>
<tr>
<td>Chronic total occlusion (%)</td>
<td>3.0</td>
<td>11.4</td>
<td>0.005</td>
<td>&lt;0.001</td>
<td>0.008</td>
</tr>
<tr>
<td>Bifurcation stenosis (%)</td>
<td>22.4</td>
<td>31.4</td>
<td>0.067</td>
<td>0.005</td>
<td>0.041</td>
</tr>
<tr>
<td>Male gender (%)</td>
<td>69.9</td>
<td>76.4</td>
<td>0.130</td>
<td>0.008</td>
<td>0.016</td>
</tr>
<tr>
<td>ACC/AHA score</td>
<td>1.75±.58</td>
<td>2.10±.59</td>
<td>&lt;0.001</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Bend stenosis ≥65° (%)</td>
<td>19.2</td>
<td>33.3</td>
<td>0.004</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Moderate tortuosity (%)</td>
<td>8.7</td>
<td>14.4</td>
<td>0.073</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Lesion length (mm)</td>
<td>4.9±3.7</td>
<td>5.7±3.9</td>
<td>0.092</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

*Multivariate coefficients for single variables (modified ACC/AHA score omitted): bend stenosis ≥60°, -0.279; high grade stenosis, -0.127; chronic total occlusion, -0.892; bifurcation stenosis, -0.097; male gender, -0.087; constant, 1.02.

†Excludes ACC/AHA and modified ACC/AHA scores.

ACC/AHA, American College of Cardiology/American Heart Association Task Force stenosis characteristics.
Table 4B. Correlates of Major Ischemic Complications (Per Stenosis)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Complication group (n=46)</th>
<th>No complication group (n=616)</th>
<th>Univariate analysis: Multivariate p value</th>
<th>Overall multivariate p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified ACC/AHA score</td>
<td>2.93±.95</td>
<td>2.13±.95</td>
<td>&lt;0.001</td>
<td>...</td>
</tr>
<tr>
<td>Bend stenosis ≥60º (%)</td>
<td>25.6</td>
<td>3.3</td>
<td>0.002</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Excessive tortuosity (%)</td>
<td>13.2</td>
<td>3.7</td>
<td>0.005</td>
<td>0.008</td>
</tr>
<tr>
<td>Bifurcation stenosis (%)</td>
<td>35.9</td>
<td>23.2</td>
<td>0.111</td>
<td>0.021</td>
</tr>
<tr>
<td>ACC/AHA score</td>
<td>2.24±.60</td>
<td>1.79±.59</td>
<td>&lt;0.001</td>
<td>...</td>
</tr>
<tr>
<td>Bend stenosis ≥45º (%)</td>
<td>41.0</td>
<td>20.3</td>
<td>0.001</td>
<td>...</td>
</tr>
<tr>
<td>Moderate tortuosity (%)</td>
<td>21.0</td>
<td>8.9</td>
<td>0.014</td>
<td>...</td>
</tr>
<tr>
<td>Diabetes mellitus (%)</td>
<td>38.5</td>
<td>20.0</td>
<td>0.022</td>
<td>...</td>
</tr>
<tr>
<td>Patient age (yrs)</td>
<td>61.2±10.9</td>
<td>58.4±11.1</td>
<td>0.085</td>
<td>...</td>
</tr>
</tbody>
</table>

*Multivariate coefficients for single variable analysis (modified ACC/AHA score omitted): bend stenosis ≥60º, 0.29; excessive tortuosity, 0.12; bifurcation stenosis, 0.05; constant, 0.03.
†Excludes ACC/AHA and modified ACC/AHA scores.

stenosis, thrombus, and excessive tortuosity. Of the type B and C characteristics, only stenosis eccentricity bore no apparent relation to likelihood of success (relative risk of failure <0.10).

Correlates of Complications (Per Stenosis)

The relations between clinical and angiographic variables and stenosis complications are shown in Table 4B. The individual variables that were independently predictive of complications were bend stenosis ≥60º (34% complications), excessive tortuosity (19% complications), and bifurcation stenoses (9% complications). In their absence, complications occurred in only 2.8% of stenoses attempted. Both the ACC/AHA and the modified ACC/AHA scores were predictive of likelihood of complications, but the modified score was particularly useful in stratifying type B stenoses, which had a marginally acceptable overall risk of 6.7%. These stenoses could be divided into type B1 (one type B characteristic) with a 4.4% risk of complications and type B2 (≥two type B characteristics) with a 9.7% risk of complications (χ²=4.33, p=0.03) (Figure 2). When the modified ACC/AHA score was forced into the model, the variables bend stenosis ≥60º and excessive tortuosity still added significant predictive information. Of the variables not shown in Table 4B, the following had relative risk of complications ≥1.5: thrombus, chronic total occlusion, ostial stenosis and stenosis calcification. Of the class B and class C characteristics, only stenosis eccentricity and high-grade stenosis had no apparent relation to the likelihood of complications (relative risk <1.0).

Correlates of Procedural Success

Selective univariate (including all variables with p≤0.15) and all independent predictors of procedural success are shown in Table 5A. The modified ACC/AHA score of the primary-target stenosis (univariate p=0.002) and the absence of diabetes mellitus (univariate p=0.007) were both strongly correlated with, and the only independent predictors of, procedural success. When the primary-target stenosis was type A, 91% of procedures were successful; when the target stenosis was type B1, 86% of procedures were successful; when the target stenosis was type B2, 79% of procedures were successful; and when the target stenosis was type C, only 68% of procedures were successful. Procedural success was achieved in 74% of diabetic patients compared with 87% of nondiabetic patients.

Correlates of Procedural Complications

Selected univariate and all independent predictors of procedural complications are shown in Table 5B. Again, the modified ACC/AHA score of the primary-target stenosis and the presence of diabetes were the only independent predictors of complications. When the primary-target stenosis was type A, complications occurred in 2.4% of patients; when it was type B1, complications occurred in 8% of patients; when it was type B2, complications occurred in 10% of patients; and when it was type C, complications occurred in 17.5% of patients. Complications occurred in 15.4% of diabetic patients, compared with 5.8% of nondiabetic patients.

Interobserver Variability

For the 57 stenoses analyzed, there was complete agreement in 33 (58%), disagreement by one classification (e.g., A or B2 compared with B1) in 20 (35%), disagreement by two classification units in
four (7%), and disagreement by three classification units in none.

Discussion

In 1988, almost one-half million patients underwent a coronary revascularization procedure in the United States, approximately 50% of whom had coronary angioplasty. Nonetheless, criteria are scant to estimate the likelihood of procedural success with coronary angioplasty in patients with multivessel disease, given the diversity of clinical syndromes, natural history, coronary anatomy, and ventricular function.

Comparative randomized data on the efficacy of coronary angioplasty versus bypass surgery in such patients will not be available until the 1990s. Even then, overall results may not be directly applicable for any given individual patient, and at present such trials lack adequate background information on which to base reasonable and statistically meaningful subgroup analyses. Recent studies assessing the results of coronary angioplasty in patients with multivessel disease have found procedural success rates of 84–95% and complication rates of 2–9%. These results reflect the composite outcome in a selected yet heterogeneous population. Relatively few studies have attempted to assess the determinants of procedural outcome with coronary angioplasty, and in most, patients with multivessel disease comprised a minority of patients studied. Prior studies have, however, defined stenosis characteristics that predisposed to complication: long stenoses, stenoses at points of vessel angulation or branching, thrombus, diffuse disease, and high-grade stenosis. Certain patient characteristics have also been associated with risk: advanced age, female gender, congestive heart failure, unstable angina, and multivessel coronary disease. It would have to be presumed that these adverse risk factors might well be important in patients with multivessel disease, but their overall impact has not been defined in this population. These factors have been amalgamated into the recently published ACC/AHA Task Force report (see Table 1), yet this scheme is largely untested at present. In the current study, 1,100 stenoses (662 of which were dilated) from 350 consecutively treated patients were evaluated to determine prospective determinants of procedural outcome. Procedural success was achieved in 85% of patients and major complications (death, myocardial infarction, pump failure, and emergency bypass surgery).

### Table 5A. Correlates of Procedural Success

<table>
<thead>
<tr>
<th>Variables</th>
<th>Procedural success (n=289)</th>
<th>Procedural failure (n=61)</th>
<th>Univariate p</th>
<th>Multivariate p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary target stenosis modified ACC/AHA score</td>
<td>2.2±0.9</td>
<td>2.7±1.0</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Diabetes mellitus (%)</td>
<td>16.1</td>
<td>34.5</td>
<td>0.007</td>
<td>0.003</td>
</tr>
<tr>
<td>Primary target stenosis ACC/AHA score</td>
<td>1.8±1.6</td>
<td>2.1±0.6</td>
<td>0.002</td>
<td>...</td>
</tr>
<tr>
<td>Primary target stenosis modified ACC/AHA score×jeopardized territory</td>
<td>63±36</td>
<td>76±43</td>
<td>0.028</td>
<td>...</td>
</tr>
<tr>
<td>Sum of stenoses modified ACC/AHA scores</td>
<td>7.2±3.1</td>
<td>8.1±3.4</td>
<td>0.055</td>
<td>...</td>
</tr>
<tr>
<td>Primary target stenosis modified ACC/AHA×jeopardized territory×segmental contractility</td>
<td>163±108</td>
<td>192±128</td>
<td>0.099</td>
<td>...</td>
</tr>
<tr>
<td>Sum of stenosis ACC/AHA scores</td>
<td>5.9±2.3</td>
<td>6.5±2.5</td>
<td>0.109</td>
<td>...</td>
</tr>
<tr>
<td>Sum of stenoses ACC/AHA scores×jeopardized territory</td>
<td>168±81</td>
<td>187±96</td>
<td>0.149</td>
<td>...</td>
</tr>
</tbody>
</table>

Multivariate coefficients: Primary target stenosis modified ACC/AHA score, -0.071; diabetes mellitus, -0.148; constant, 1.03. ACC/AHA score, American College of Cardiology/American Heart Association Task Force stenosis classification.

### Table 5B. Correlates of Major Ischemic Procedural Complications

<table>
<thead>
<tr>
<th>Variables</th>
<th>Complication group (n=30)</th>
<th>No complication group (n=320)</th>
<th>Univariate p value</th>
<th>Multivariate p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary target stenosis modified ACC/AHA score</td>
<td>2.8±0.9</td>
<td>2.3±1.0</td>
<td>0.002</td>
<td>0.006</td>
</tr>
<tr>
<td>Diabetes mellitus (%)</td>
<td>38.5</td>
<td>17.5</td>
<td>0.036</td>
<td>0.016</td>
</tr>
<tr>
<td>Primary target stenosis ACC/AHA score</td>
<td>2.2±0.5</td>
<td>1.8±0.6</td>
<td>0.002</td>
<td>...</td>
</tr>
<tr>
<td>Primary target stenosis modified ACC/AHA score×jeopardized territory</td>
<td>81±39</td>
<td>64±37</td>
<td>0.025</td>
<td>...</td>
</tr>
<tr>
<td>Sum of stenoses' modified ACC/AHA scores×jeopardized territory</td>
<td>207±98</td>
<td>168±82</td>
<td>0.035</td>
<td>...</td>
</tr>
<tr>
<td>Sum of stenoses' modified ACC/AHA scores</td>
<td>8.4±3.3</td>
<td>7.2±3.1</td>
<td>0.070</td>
<td>...</td>
</tr>
<tr>
<td>Primary target stenosis modified ACC/AHA×jeopardized territory×segmental contractility</td>
<td>207±127</td>
<td>164±110</td>
<td>0.074</td>
<td>...</td>
</tr>
<tr>
<td>Sum of stenoses' modified ACC/AHA scores×jeopardized territory×segmental contractility</td>
<td>524±307</td>
<td>423±224</td>
<td>0.080</td>
<td>...</td>
</tr>
<tr>
<td>Sum of stenoses' ACC/AHA scores</td>
<td>6.7±2.5</td>
<td>5.9±2.4</td>
<td>0.116</td>
<td>...</td>
</tr>
</tbody>
</table>

Multivariate coefficients: Primary target stenosis modified ACC/AHA score, 0.041; diabetes mellitus, 0.088; constant, 0.08. ACC/AHA, American College of Cardiology/American Heart Association Task Force report stenosis classification.
emergency bypass surgery, or myocardial infarction) occurred in 8.6% of patients. These figures, while within the range of those previously reported, are not as favorable as many prior reports. This may reflect patient selection bias or a tendency in the literature to publish favorable results. Nonetheless, each of the participating clinical sites had been chosen for participation in the NHLBI Bypass Angioplasty Revascularization Investigation trial, owing in part to recognized excellence in the performance of complex coronary angioplasty. The results might have been more favorable if the procedural results from only the highly experienced operators from these centers were analyzed.23

The results of this comprehensive analysis suggest that while the current ACC/AHA criteria provide adequate stratification of low (type A: success in 92%, complications in 2%) and high risk (type C: success in 61%, complications in 20%) stenoses, the scheme provides inadequate information for the clinically important and most frequently encountered intermediate (type B: success in 80%, complications in 7%) stenoses. Important and significant information within this intermediate risk group could be readily obtained by dividing it into stenoses with only one type B characteristic (type B1: success in 84%, complications in 4%) and those with ≥ two type B characteristics (type B2: success in 76%, complications in 10%). When this four-tier schema was applied to each patient’s primary target stenosis, it was the most powerful predictor of overall procedural outcome of any variable tested (p<0.001 for both success and complications). Importantly, none of the traditional discriminators of outcome in patients with coronary disease, in particular the number of diseased vessels, predicted outcome (stenosis success in two-vessel disease was 82.4%, in three-vessel disease, 83.9%; complications in two-vessel disease were 8.0%, in three-vessel disease 9.8%).

The impact on procedural outcome of each individual component defining a type B or type C stenosis is not equal. Despite the fact this study is the largest of its kind, it lacks statistical power to adequately differentiate the relative importance of several variables, particularly when they occur at a low frequency in the study group. However, even when the modified ACC/AHA score was considered, the variable high-grade stenosis (80–99% diameter stenosis by calipers, roughly corresponding to 90–99% by visual inspection9) imparted a highly significant lower likelihood of success (p=0.004). Of all the morphologic variables tested, only stenosis eccentricity had no relation to success or complications. These data suggest, therefore, that high-grade stenosis should be added and stenosis eccentricity can be deleted from the list of type B characteristics. Furthermore, the variables diabetes mellitus, chronic total occlusion, stenosis bend ≥ 60°, excessive tortuosity, and bifurcation stenosis still imparted significant prognostic information beyond that supplied by the four-tier stratification system and should be regarded as particularly important prognostic characteristics. A useful estimate of the likelihood of success or complications from these data for any individual clinical situation may be made by simple addition of the coefficients for variables listed in Tables 4A and 4B (e.g., for a high-grade bifurcation stenosis, success=1.02 [constant]−0.127−0.097=0.796; complications=0.03 [constant]+0.05=0.08). Thus, such a patient could be expected to have an 80% likelihood of success and an 8% likelihood of major complications.

Limitations

In considering these results, certain limitations of the study should be considered. First, the majority of these patients had two-vessel coronary disease and well-preserved left ventricular function and do not reflect the distribution of coronary artery involvement and functional impairment of all patients with multivessel coronary disease.24 In patients with a larger number of severe stenoses, the importance of the morphology of the primary target stenosis relative to that of all, or multiple, stenoses would be expected to decrease. Second, assessment of coronary artery morphology is subjective,14 and the use of these data to assist in clinical decision making will require strict attention to the details of the definitions used. Given the multiplicity of morphologic criteria evaluated in the modified ACC/AHA system, it is not surprising that variability in its assessment was noted. Variation by one classification (e.g., A or B2 compared with B1) was observed in 35% of lesions. However, variation by more than one classification, which would have a much greater impact on the assessment of prognosis, was uncommon. Nonetheless, interobserver variability must be recognized as a major limitation to this method. Third, the method of defining primary target stenosis was somewhat arbitrary. Nonetheless, all but one of the core lab–determined primary-target stenoses had attempted angioplasty. Fourth, the multiple comparisons made increase the likelihood of observing a spurious correlation. Prospective evaluation of this scheme in a large validation sample would be useful. Fifth, conclusions regarding suitability of patients for coronary angioplasty must also consider comparative long-term efficacies with other forms of treatment, and little data are available in this regard.6,25–27 Sixth, this is not a randomized comparison of treatments, and definitive statements regarding the efficacy of PTCA versus bypass surgery must await carefully randomized comparisons of prospectively defined subgroups of patients in this heterogeneous population. Finally, improved results with angioplasty may result from use of the new available, somewhat lower profile balloons, or the concomitant use of intracoronary stents,28 laser balloon angioplasty,29 and other evolving adjunctive techniques.

Nonetheless, these data suggest good short-term results can be obtained with coronary angioplasty performed by experienced operators in patients with multivessel disease in whom the important stenosis(es) has type A or B1 characteristics. However, when the important stenoses have type B2 or type C
characteristics, particularly in the presence of diabetes, chronic total occlusion, bend ≥60°, high-grade stenosis, or excessive tortuosity subserving a large mass of viable myocardium, the results suggest other forms of revascularization be very strongly considered. These data also provide the framework upon which to base prospective subgroup evaluation in randomized trials comparing standard coronary angioplasty to other treatment modalities in patients with multivessel coronary disease.

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Appendix

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St. Louis University, St. Louis, Mo. Principal investigator: Michel G. Vandormael, MD; Co-investigators: Ubaydullah Deligonul, MD; Kathy Galan, RN; Sue Taussig, RN.

University of Alabama, Birmingham, Ala. Principal investigator: Thomas M. Bulle, MD; Co-investigator: Joan Anderson, RN.

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Angiographic Core Laboratory: Principal investigator: Stephen G. Ellis, MD; Co-investigators: Thomas M. Bulle, MD; Darrell DeBowey, MS.

Data Coordinating Center: Principal investigator: Stephen G. Ellis, MD; Co-investigators: M. Anthony Schork, PhD; Robert Bagen, PhD.

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