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REVIEWS

Lesion Morphology and Coronary Angioplasty: Current Experience And Analysis

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From July 1, 1990 to February 28, 1991, 533 consecutive patients with 764 target vessels and 1,000 lesions underwent coronary angioplasty. Procedural success was achieved in 92.3%, untoward (major cardiac) events occurred in 3% (0.8% myocardial infarction, 1.3% emergency coronary bypass grafting and 0.9% both; there were no deaths). An unsuccessful uncomplicated outcome occurred in 4.7%. Lesion analysis using a modified American College of Cardiology/American Heart Association classification system showed that 8% were type A, 47.5% were type B and 44.5% were type C (36% of type B and 11% of type C were occlusions).

Angioplasty success was achieved in 99% of type A, 92% of type B and 90% of type C lesions (A vs. B, $p < 0.05$; B vs. C, $p = NS$; A vs. C, $p < 0.01$). Untoward events occurred in 1.2% of type A, 1.9% of type B and 2% of type C lesions ($p = NS$). An unsuccessful uncomplicated outcome occurred in 0% of type A, 6% of type B and 7% of type C lesions (A vs. B, $p < 0.05$; B vs. C, $p = NS$; A vs. C, $p < 0.05$). Among the unsuccessful uncomplicated outcome group, occlusion occurred in 49%: 38% of type B and 59% of type C lesions. With B_1 and B_2 subtypes, success was obtained in 95% and 89.5% and untoward events occurred in 1.5% and 2.3% and an unsuccessful uncomplicated outcome in 3.7% and 8%, respectively. C_1 and C_2 subtyping showed success in 91% and 86%, untoward events in 1.3% and 6% and an unsuccessful uncomplicated outcome in 7.5% and 8.5%, respectively. Among the 764 vessels, success was obtained in 89.5% and untoward events occurred in 2.5% and an unsuccessful uncomplicated outcome in 8%. Assessment of lesion-vessel combinations showed a less favorable outcome with type C lesions and combinations of A-B, B-C and multiple (more than three lesions) type B and C vessels.

Statistical analysis of morphologic factors associated with angioplasty success included absence of (old) occlusion ($p < 0.0001$) and unprotected bifurcation lesion ($p < 0.001$), decreasing lesion length ($p < 0.003$) and no thrombus ($p < 0.03$). The only significant factor associated with untoward events was the presence of thrombus ($p < 0.003$). Predictors of an unsuccessful uncomplicated outcome included old occlusion ($p < 0.0001$) and increasing lesion length (>20 mm) ($p < 0.001$), unprotected bifurcation lesion ($p < 0.05$) and thrombus ($p < 0.03$).

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In 1988, a combined American College of Cardiology/American Heart Association (ACC/AHA) Task Force, in a report entitled *Guidelines for Percutaneous Transluminal Coronary Angioplasty* (1,2), proposed a classification scheme based on morphologic characteristics as a guide for success and risks in performing angioplasty. Lesions were described and categorized into types A, B and C. Type A lesions were associated with "high success (>85%) and low risk," type B lesions were associated with "moderate success (60–85%) and moderate risk" and type C lesions were associated with "low success (<60%) and high risk" (Table 1).

Ellis et al. (3) reported the coronary angioplasty results from four centers, representing their 1986 to 1987 experience, and further modified and codified the ACC/AHA morphologic descriptors. In their study, success and complication rates were 92% and 4%, respectively, for type A lesions; 84% and 4% for type B_1 lesions; 76% and 10% for type B_2 lesions, and 61% and 21% for type C lesions.

Significant technologic progress has occurred with angioplasty equipment in the past 4 years (4–8). This study was initiated during a new device-free interval at our center to analyze current balloon angioplasty results in a consecutive, nonselected series and to evaluate the applicability of the previously reported classification schemes (1–3). In addition, we have proposed further morphologic subtyping of lesions and vessels and discussed the benefits and limitations of

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Table 1. Characteristics of Type A, B and C Coronary Lesions As Defined by the ACC/AHA Task Force

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

*Although the risk of abrupt vessel closure is moderate, in certain instances the likelihood of a major complication may be low as in dilation of total occlusions <3 months old or when abundant collateral channels supply the distal vessel. Table reprinted from Ryan et al. (1,2)

classification schemes versus lesion-specific analyses for evaluation of angioplasty success and risks. Finally, this study may provide a more current basis for comparison of balloon angioplasty results with new devices until randomized trials are available.

Methods

Study patients. From July 1, 1990 to February 28, 1991, 533 consecutive patients underwent coronary balloon angioplasty. There were no exclusions. No stents, lasers or atherectomy devices were utilized in this study. Data were obtained from the medical records and from our ongoing computerized data base. All patient data were prospectively entered and analyzed retrospectively.

Clinical profile. The clinical characteristics of these 533 patients are presented in Table 2. The patients were predominantly male. Seventy-six percent were in Canadian Cardiovascular Society (9) angina class III or IV and 58% presented with unstable angina, as defined previously (10).

Morphologic profile. Of these 533 patients, 251 (47.1%) had single-vessel disease (defined as vessels with lesions of >50% diameter stenosis), 137 (25.5%) had double-vessel disease and 145 (27%) had triple- (or quadruple-) vessel disease. The left ventricular ejection fraction was >0.45 in 425 patients (79.5%), 0.35 to 0.44 in 73 (13.5%), 0.25 to 0.34 in 18 (3.5%) and <0.25 in 17 (3%).

In these 533 patients, 764 vessels with 1,000 lesions were treated with balloon angioplasty, representing 1.5 vessels/patient, 1.3 lesions/vessel and 1.9 lesions/patient. Of the 1,000 lesions, 82 (8%) were type A, 474 (47.5%) were type B and 444 (44.5%) were type C. There were 221 occlusions, 172 (36.3%) of type B (<3 months) and 49 (11%) of type C (>3 months) (Fig. 1).

The 764 angioplasty target vessels included the left anterior descending artery in 274 (36%), left circumflex artery in 212 (27.5%), right coronary artery in 232 (30.5%), the left main coronary artery ("protected") in 8 (1%) and saphenous vein grafts in 38 (5%). In 576 (75.5%) vessels there was a single lesion: 48 (6%) type A, 303 (39.5%) type B and 225

Table 2. Clinical Profile of 533 Patients (mean age 61 + 11 yr; range 28–88)

	n (%)
Gender (M)	415 (77.9)
Diabetes	78 (14.6)
Hypertension	295 (55.3)
Hypercholesterolemia	316 (59.3)
Previous smoker	209 (39.2)
Current smoker	111 (20.5)
Angina class	
I	3 (0.6)
II	123 (23)
III	252 (47.3)
IV	155 (29.1)
Unstable angina	307 (57.6)
Acute MI	8 (1.5)
Previous MI	251 (47.1)
Previous PTCA	126 (23.6)
Previous CABG	89 (16.7)

CABG = coronary artery bypass graft surgery; M = male; MI = myocardial infarction; PTCA = percutaneous transluminal coronary angioplasty.

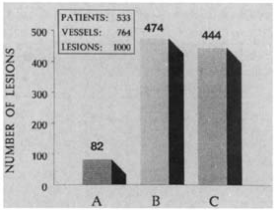

Figure 1. Distribution of morphologic types among 1,000 coronary lesions in 764 target vessels in 533 consecutive patients.

(29.5%) type C. In 157 (20.5%) vessels there were two lesions: 4 (0.5%) had two type A lesions (A-A), 17 (2%) had A-B, 3 (0.4%) had A-C, 50 (6.5%) had B-B, 16 (2%) had B-C and 67 (9%) had C-C combination lesions. In 31 vessels (4%), there were three or more lesions: 8 vessels (1%) had multiple type B lesions or dominant B lesions (for example, two of three lesions were type B) and 23 vessels (3%) had multiple type C lesions or dominant C lesions.

Angioplasty technique, strategy and procedure. Our technique and strategy for coronary balloon angioplasty have been described previously (11–15). The angioplasty strategy was to attempt first to dilate the most severely diseased vessel supplying the greatest amount of ischemic (jeopardized) myocardium. If the lesion in this primary target vessel could not be successfully traversed (for example, an old occlusion) and no untoward event resulted from the dilation attempt, the patient was still included in the series and the case classified as unsuccessful uncomplicated.

Angioplasty was performed in a single vessel in 357 patients (67%), two vessels in 132 patients (25%) and three or four vessels in 44 (8.5%) patients. Left ventricular support was utilized during angioplasty in 43 patients (8%): intraaortic balloon assist in 19 patients (3.5%) and cardiopulmonary support in 24 (4.5%).

Morphologic analysis, classification and definitions. Measurements of lesion severity before and after angioplasty were obtained from cineangiograms by averaging orthogonal projections with programmable digital calipers. Lesion length was measured in the radiographic projection that displayed the least vessel and lesion foreshortening. For example, for a proximal left anterior descending artery lesion, the right anterior oblique (or lateral) projection, rather than a left anterior oblique projection, was selected. Lesions were classified as type A, B or C by using the morphologic characteristics and relevant clinical data initially described by the ACC/AHA Task Force (1,2) and presented in Table 1. Ellis et al. (3) subclassified type B lesions into B_1 ("one adverse characteristic") and B_2 ("≥ two adverse characteristics"). We used this subtyping and also applied it to type C lesions: C_1 lesions had one adverse morphologic characteristic; C_2 lesions had two or more adverse characteristics. If a lesion had morphologic characteristics of more than one type (for example, a 60° angulated [B] and 3-cm long [C] lesion), it was classified as the more severe type (C).

Vessel and Lesion Definitions

The following definitions were used.

Diseased vessel. One in which there was at least one lesion with ≥50% reduction in lumen diameter, irrespective of subserved myocardial segment viability or ischemia. *Single-vessel disease*: one diseased vessel. *Multivessel disease*: two or more diseased vessels.

Target vessel. One in which angioplasty was attempted. All "target" vessels were "diseased," but not all diseased vessels were angioplasty targets. For example, in a patient with multivessel disease, one of the diseased vessels had a 52% stenosis but was not associated with ischemia (by exercise thallium-201 scintigraphy). In another example, also in a patient with multivessel disease, one of the diseased vessels had an (old) occlusion associated with a remote myocardial infarction. The subserved ventricular segment was akinetic (by ventriculography or echocardiography, or both) and failed to "take-up" thallium-201 at 4 and 24 h. In these two multivessel angioplasty cases, these types of vessels were defined as diseased but not targeted.

Bifurcation lesion. A lesion that involved two major arterial branches, the smaller of which was at least of moderate size and otherwise would have been surgically bypassed. This branch originated within the stenosis in the primary artery and, itself, had a ≥50% stenosis at its origin. *Protected*: angioplasty guide wires or catheters were placed in both branches. *Unprotected*: guide wires and catheters could not be or were not placed in both branches.

Calcification. Radiodensities within the vessel wall noted with fluoroscopy (or cinearteriography) at the site of the target lesion.

Eccentric. At least a 75% displacement of the lumen within a lesion in any projection.

Length. A segment with ≥50% lumen encroachment. Most lesions taper at both the proximal and distal ends; and therefore, measurement of the segment that encompasses only the ≥50% encroachment may underestimate the true lesion length. Also, if a long lesion terminated in an occlusion, it was classified only as an occlusion.

Occlusion. Total obstruction without anterograde flow Thrombolysis in Myocardial Infarction ([TIMI] flow grade 0); the distal vessel may or may not have been filled through retrograde or anterograde (bridging) collateral flow.

Ostial. Involvement at the *origin* of the right, left anterior descending or left circumflex coronary artery. In some cases, there was involvement of the distal left main coronary artery.

Protected left main artery. A left main artery stenosis in which at least one of the major left coronary branches was

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perfused by a patent graft. The other (target) branch was compromised by the left main artery stenosis.

Tandem lesions. A vessel in which two or more lesions were separated from each other by ≥2 cm of an (apparently) undiseased segment.

Thrombus. An intraluminal filling defect or an occlusion in a vessel associated with an acute ischemic syndrome.

Acute ischemic syndromes. Unstable angina, acute myocardial infarction or angina early after acute myocardial infarction.

Angioplasty Definitions

Success. *Lesion.* Reduction in percent diameter stenosis ≥35%, with a residual stenosis <50% and no untoward event.

Vessel. Successful angioplasty of all stenotic (>50%) lesions in a target vessel.

Procedural. Successful angioplasty in the target vessel without an untoward event during the angioplasty procedure and hospitalization. *Complete* success was defined as procedural success in all "target" vessels. *Incomplete* success was defined as procedural success in at least one, but not all, target vessels (see Angioplasty technique, strategy and procedure). Analysis of complete and incomplete success (that is, revascularization) was also performed with respect to "diseased" vessels (see below).

Untoward event. One or more of the following mutually nonexclusive major cardiac events: Q wave myocardial infarction, emergency coronary bypass surgery or death. These untoward events were invariably associated with target vessel closure after angioplasty.

Unsuccessful uncomplicated. A lesion or vessel in which success was not achieved but in which the angioplasty attempt was not associated with an untoward event (for example, an occlusion that could not be traversed with a guide wire or a calcified lesion that could not be dilated successfully).

Statistical Analysis

All data were entered prospectively into the San Francisco Heart Institute Cardiac Intervention Database (SIR). Continuous variables are expressed as mean values ± SD, and differences were assessed using the Student *t* test. Chi-square analyses or Fisher exact tests were used to compare categoric variables. Logistic regression analyses were performed to determine associations between morphologic factors and procedural outcomes. Statistical analyses were performed with SPSS and BMDP software programs.

Results

Angioplasty results. In these 533 patients, procedural success was achieved in 492 patients (92.3%). Untoward events occurred in 16 patients (3%): acute myocardial infarction in 4 (0.8%), emergency coronary bypass surgery in 7 (1.3%) or both in 5 (0.9%). There were no hospital deaths. An unsuccessful uncomplicated outcome occurred in 25 patients (4.5%) (Fig. 2).

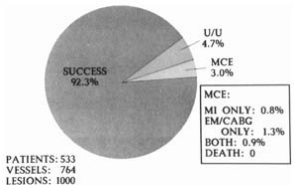

Figure 2. Angioplasty procedural results in 533 consecutive patients. EM/CABG = emergency coronary bypass surgery; MCE = untoward (major cardiac) events; MI = myocardial infarction; U/U = unsuccessful uncomplicated outcome.

Patients and vessels. In the 533 patients with 764 target vessels and 1,015 diseased vessels, procedural outcome is presented in Table 3. In 474 patients (89%), success was achieved in *all* target vessels. The rate of procedural success was lowest (89.5%) in the 357 patients with single-vessel target angioplasty. The most common reason for an untoward event in this cohort was the presence of an intravascular thrombus (associated with an acute ischemic syndrome), and the most common cause of an unsuccessful uncomplicated outcome was an old (>3 months) occlusion. In the 176 patients having multiple-vessel angioplasty, procedural success was achieved in 172 patients (97.5%), untoward events occurred in 3 patients (1.5%) and an unsuccessful uncomplicated outcome in 1 patient (0.5%).

In 320 patients (60%), success was achieved in *all* dis-

Table 3. Target and Diseased Vessels Versus Angioplasty Outcome in 533 Patients (764 target vessels and 1,015 diseased vessels)

	n (%)	Success (%)	Untoward Event (%)	U/U (%)
Target vessel analysis*				
1	357 (66.9)	89.6	3.6	6.8
2	132 (24.8)	97.7	1.5	0.8
3	33 (6.2)	97	3	0
4	11 (2.1)	100	0	0
Total	533 (100)	92.3	3	4.7
Diseased-vessel analysis†				
1	251 (47.1)	92.4	2.4	5.2
2	137 (25.7)	92	5.8	2.2
3	90 (16.9)	92.2	1.1	6.7
4	55 (10.3)	92.7	1.8	5.5
Total	533 (100)	92.3	3	4.7

*Vessels dilated; †vessels diseased, irrespective of number of vessels dilated. (See text for further description.) Untoward Event = major cardiac event; U/U = unsuccessful uncomplicated outcome.

Table 4. Target Vessel and Angioplasty Results (764 target vessels in 533 patients)

Vessel	*n*	Success (%)	Untoward Event (%)	U/U (%)
LAD	274	94.2	1.8	4
LCx	212	91	1.9	7.1
RCA	232	87.5	3.4	9.1
LM	8	100	0	0
SVG	38	84.2	5.3	10.5
Total	764	89.6	2.4	8

LAD = left anterior descending coronary artery; LCx = left circumflex coronary artery; LM = left main coronary artery; RCA = right coronary artery; SVG = saphenous vein graft. Other abbreviations as in Table 3.

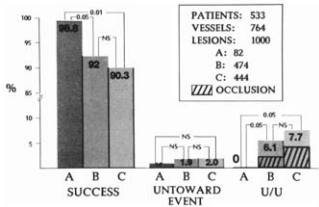

Figure 3. Angioplasty outcome versus lesion type in 533 patients. U/U = unsuccessful uncomplicated outcome.

eased vessels. Of the 1,015 diseased vessels, 251 were not targeted for angioplasty. Of these 251 vessels, 166 (66%) were (old) occlusions associated with a previous myocardial infarction; the infarcted left ventricular segment had a negative thallium-201 uptake with exercise and redistribution (4 and 24 h). The other 85 diseased, but not targeted, vessels had a stenosis >50% and usually <60% but were not associated with ischemia (by exercise and redistribution thallium-201 scintigraphy). There was no difference in angioplasty procedural success (92%) in patients with single-, double-, triple- or quadruple-vessel disease.

Vessels. Among the 764 target vessels, angioplasty success was achieved in 685 (89.5%), an untoward event occurred in 18 (2.5%) and an unsuccessful uncomplicated outcome occurred in 67 (8%). Angioplasty results with specific target vessels are presented in Table 4.

In the 38 target saphenous vein grafts, there were 49 lesions, 46 stenoses and 3 occlusions. Overall angioplasty success was 84%, untoward events occurred in 5% and an unsuccessful uncomplicated outcome occurred in 10.5%. Twenty-nine of the grafts with 38 lesions were >4 years old; 27 of these grafts were not occluded and 2 were occluded. In these 27 grafts, there were 36 lesions and 24 (67%) of these, were associated with a filling defect and an acute ischemic syndrome. Of these 24 older acute stenoses, success was achieved in 91.5% and untoward events occurred in 4% and an unsuccessful uncomplicated outcome in 4%. In the 12 older but nonacute lesions, the success rate was similar (91.5%), but there were no complications (0%), although unsuccessful uncomplicated outcome was higher (8.5%). Among the nine grafts with 10 lesions <4 years old, 3 lesions were associated with thrombus and an acute ischemic syndrome and one graft was occluded. Angioplasty success was achieved in all (100%) of these newer grafts and lesions. Of the three occluded grafts, one had successful angioplasty, one was complicated and one was associated with an unsuccessful uncomplicated outcome. Intragraft infusion of urokinase was used in all grafts with thrombus or occlusions in patients with an acute ischemic syndrome.

Lesions. In the 1,000 lesions, success was achieved in 918 (92%) and an untoward event occurred in 19 (2%). Among the 82 type A lesions, success was achieved in 81 (99%) and an untoward event occurred in 1 (1%). Among the 474 type B lesions, success was achieved in 436 (92%) and untoward events occurred in 9 (2%). Among the 444 type C lesions, success was achieved in 401 (90.5%) and untoward events occurred in 9 (2%). There was an unsuccessful uncomplicated outcome in 63 lesions (6.5%): no (0%) type A lesions, 29 (6%) type B lesions and 34 (7.5%) type C lesions. Of these 63 lesions, 31 (49%) were occlusions: 11 (38%) of the 29 type B lesions and 20 (59%) of the 34 type C lesions. These results are summarized in Figure 3 and in the modified classification scheme in Table 5. Subtype B_1 lesions were associated with a 95% and B_2 lesions with an 89% successful outcome. Success was achieved in 91% of subtype C_1 and 86% of C_2 lesions. Subtyping showed similar untoward event rates in type A (1.2%), B_1 (1.4%) and C_1 (1.3%) lesions, whereas type B_2 (2.3%) and C_2 (5.6%) lesions had a higher incidence of untoward events.

The effect of specific lesion morphology on angioplasty outcome is presented in Tables 6 and 7. There was a lower success rate and a higher unsuccessful uncomplicated outcome with longer lesions; however, there was no increase in untoward events with longer lesions. There was no significant difference in success rates with lesions of various angulations (<45°, 45° to <90°, ≥90°), although there was a slight increase in complication rates with greater angulation.

Table 5. Lesion Morphology and Angioplasty Results (533 patients; 1,000 lesions)

Lesion Type	*n*	Success (%)	Untoward Event (%)	U/U (%)
A	82	98.8	1.2	0
B	474	92	1.9	6.1
B_1	215	94.9	1.4	3.7
B_2	259	89.6	2.3	8.1
C	444	90.3	2	7.7
C_1	373	91.2	1.3	7.5
C_2	71	85.9	5.6	8.5
Total	1,000	91.8	1.9	6.3

Abbreviations as in Table 3.

Table 6. Specific Lesion Morphology and Angioplasty Results (779 lesions, excluding occlusions)

Lesion Morphology	*n* (%)	Success (%)	Untoward Event (%)	U/U (%)
Length (mm)				
"Discrete" (<10)	365 (46.9)	95	2.1	2.9
"Tubular" (10–20)	278 (35.7)	91.4	0	8.6
"Diffuse" (>20)	136 (17.4)	88.9	0	11.1
Eccentric				
Yes	475 (61)	95.6	1.1	3.4
No	304 (39)	92.1	2.6	5.3
Angulated				
<45°	543 (69.7)	94.1	1.3	4.6
45–<90°	158 (20.3)	94.9	2.5	2.6
≥90°	78 (10)	93.6	2.6	3.8
Bifurcation				
No	656 (84.2)	95.1	1.4	3.5
"Protected"	17 (2.2)	94.1	0	5.9
"Unprotected"	106 (13.6)	88.7	3.8	7.5
Calcification				
Yes	140 (18)	91.4	3.6	5
No	639 (82)	94.8	1.3	3.9
Ostial				
Yes	14 (1.8)	92.9	0	7.1
No	765 (98.2)	95.2	1.7	3.1
Thrombus				
Yes	82 (10.5)	90.2	7.3	2.4
No	697 (89.5)	94.7	1	4.3
Graft lesions				
No	733 (94.1)	94.1	1.6	4.3
Yes	46 (5.9)	93.5	2.2	4.3
<4 yr	10 (1.3)	100	0	0
≥4 yr	36 (4.6)	91.7	2.8	5.5

Abbreviations as in Table 3.

Unprotected bifurcation lesions were associated with a significantly lower success rate and higher complication and unsuccessful uncomplicated rates than protected bifurcation lesions. Lesion calcification was associated with a slightly lower success and a higher untoward event rate. The peak

Table 7. Lesion Severity and Angioplasty Results

Morphology	*n* (%)	Success (%)	Untoward Event (%)	U/U (%)
Severity (%)*				
≥95	23 (3)	87	0	13
85–94	133 (17)	94.7	1.5	3.8
75–84	193 (24.8)	94.8	2.1	3.1
65–74	267 (34.3)	94.4	1.9	3.7
<65	163 (20.9)	93.9	1.2	4.9
Occlusions				
No	779 (77.9)	94.2	1.7	4.1
Yes	221 (22.1)	83.3	2.7	14
<3 mo.	172 (17.2)	87	3.1	9.9
<1 week	99 (9.9)	86.9	4	9.1
1 week–3 mo.	73 (7.3)	87.6	2.7	9.7
>3 mo.	49 (4.9)	59.2	0	40.8

*Excluding occlusions. Abbreviations as in Table 3.

Table 8. Lesion Morphology and Vessel Outcome With Angioplasty (533 patients, 764 target vessels, 1,000 lesions)

Lesion Type	*n*	Success (%)	Untoward Event (%)	U/U (%)
A only	48	97.9	2.1	0.0
B only	303	91.1	2.3	6.6
C only	225	86.2	2.2	11.6
A-A	4	100.0	0	0
A-B	17	88.2	5.9	5.9
A-C	3	100	0	0
B-B	50	94	0	6
B-C	16	68	0	31.2
C-C	67	94	3	3
Multiple B	8	75	0	25
Multiple C	23	82.6	8.7	8.7
Total	764	89.6	2.4	8

Abbreviations as in Table 3.

pressure required to fully inflate a balloon in a calcified lesion was 11 ± 5 atm versus 9 ± 2 atm for noncalcified lesions ($p < 0.0001$). Ostial lesions (including right coronary artery, left anterior descending coronary artery and protected left main coronary artery) had a slightly lower success rate than nonostial lesions, but there were only 14 of the former in this study. The presence of intravascular thrombus was associated with a significantly lower success and a higher untoward event rate. All patients with this finding presented with an acute ischemic syndrome.

There were a total of 221 occlusions; 172 were <3 months old and 49 were >3 months old. The age of an occlusion was usually estimated from a clinical event (for example, myocardial infarction or significant acceleration in anginal pattern). In type C occlusions (>3 months), there was a significantly lower success rate due to inability to traverse the obstruction, which resulted in a very high rate of unsuccessful uncomplicated outcome.

The results of lesion type versus percent diameter stenosis demonstrate the numeric effect of (100%) occlusions, which are included by definition only in types B and C. The percent diameter stenoses before and after angioplasty in type A lesions were 65.4 ± 14 and 16.9 ± 13, 72.9 ± 15 and 21.1 ± 18 in type B lesions, and 77.9 ± 16 and 23.6 ± 23 in type C lesions, respectively.

Lesions and vessels. The effect on angioplasty outcome of lesion types within vessels is presented in Table 8. A single lesion was present in 576 vessels and two or more lesions in 188 vessels. Although there are low numbers in some subsets, vessels with certain lesion types (for example, type C) and tandem lesion combinations (for example A-B, B-C, multiple B and multiple C) appeared to have a less favorable angioplasty outcome.

Lesions and abrupt closure. With 27 lesions, there was evidence of a significant flow-limiting intimal disruption, dissection or filling defect after angioplasty. Prolonged (5 to 20 min) balloon inflation reestablished flow in eight vessels. The other 19 lesions caused an untoward event. Of these, 2

Table 9. Morphologic Factors Associated With Angioplasty Success

	p Value	
	Univariate Analysis	Multivariate Analysis
Absence of occlusion (>3 mo.)	0.0001	0.0001
Absence of unprotected bifurcation lesion	0.0010	0.0037
Decreasing lesion length	0.0030	0.0070
Type A, B, C*	0.0363	—
Modified A, B, C*	0.0103	—
No thrombus	0.0255	—
Graft lesion	—	—
Ostial lesion	—	—
Angulated lesion	—	—
Calcification	—	—
Lesion severity	—	—

*Analyses were performed with and without type A, B, C classification included, with identical results.

Table 11. Morphological Factors Associated With Angioplasty Unsuccessful Uncomplicated Outcome

	p Value	
	Univariate Analysis	Multivariate Analysis
Occlusion (>3 mo.)	0.0001	0.0001
Increasing lesion length	0.0010	0.0010
Unprotected bifurcation lesion	0.0460	0.0031
Type A,B,C*	0.0313	—
Modified A,B,C*	0.0283	(0.1142)†
Thrombus	0.0255	—
Eccentricity	—	—
Graft lesion	—	—
Ostial lesion	—	—
Angulated lesion	—	—
Calcification	—	—
Lesion severity	—	—

*Analyses were performed with and without type A, B, C classification included, with identical results. †Included in regression model, but $p < 0.05$ when all factors were entered.

lesions (with dissection) did not respond favorably to 20-min balloon inflation. Of the remaining 17 lesions, 5 occurred in arteries in which prolonged inflation could not be tolerated. Because these five vessels were small in caliber or tortuous or the lesions were angulated, or both, perfusion balloons were not suitable. Thrombus was present (before angioplasty) in 9 of these 19 lesions associated with an untoward event. The 9 patients with these lesions were among 34 patients with an acute ischemic syndrome and thrombus during this study period who were included in a double-blind multicenter placebo-controlled randomized trial of intracoronary urokinase (TAUSA trial). Which of these patients received urokinase is not known to us. The remaining 3 of the 19 lesions that caused an untoward event were in arteries that occluded after transfer of the patient from the catheterization laboratory, and the patient was sent directly to surgery.

Table 10. Morphologic Factors Associated With Angioplasty Complications

	p Value	
	Univariate Analysis	Multivariate Analysis
Thrombus	0.0033	0.0060
Occlusion	—	—
Unprotected bifurcation lesion	—	—
Type A, B, C*	—	—
Modified A, B, C*	—	—
Eccentricity	—	—
Ostial lesion	—	—
Angulated lesion	—	—
Calcification	—	—
Lesion severity	—	—

*Analyses were performed with and without type A, B, C classification included, with identical results.

Outcome analyses. Univariate and multivariate statistical analyses of lesion morphologic factors and angioplasty outcome are presented in Tables 9 to 11. The absence of occlusion (>3 months), decreasing lesion length, absence of unprotected bifurcation stenosis, absence of thrombus, and classification types A, B and C were significant predictors of success by univariate analysis; the first three factors were also predictive by multivariate analysis. The only morphologic factor significantly associated with an untoward event was the presence of an intravascular thrombus. An unsuccessful uncomplicated angioplasty outcome was statistically associated with the presence of an old occlusion, increasing lesion length, an unprotected bifurcation lesion, the presence of thrombus and lesion classification types A, B and C; the first three factors were also significantly associated with outcome by multivariate analysis.

Discussion

Angioplasty balloons and other devices interact directly with vascular lesions, in contrast to coronary surgery, which, with the exception of endarterectomy, bypasses them. Therefore, it has been appropriate to focus on lesion morphology as an important predictor of angioplasty outcome. The relation of lesion morphology to angioplasty outcome has been known for many years. The more complex the morphology in multivessel disease (13) or single-vessel disease (16), the less favorable the initial (and later) results of coronary angioplasty. The ACC/AHA Task Force angioplasty guidelines (1,2) acknowledged these observations, classified various lesions into three groups (types A, B and C) and estimated success rates and assessed risk for each category (Table 1). Ellis et al. (3) further defined, modified and codified this classification scheme. Both reports reflected angioplasty outcome in the years from 1986 to 1988.

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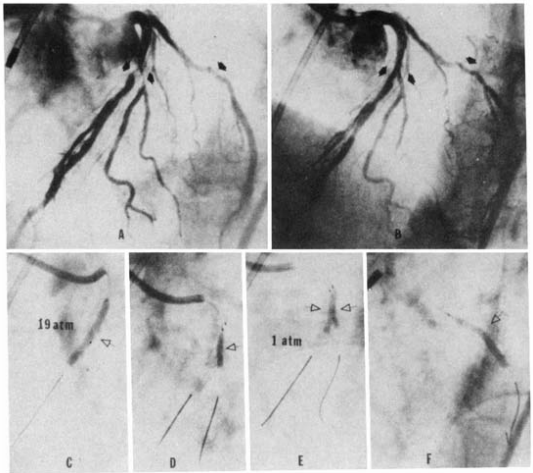

Figure 4. A, Before angioplasty showing severe *bifurcation* stenoses (arrows) of the left anterior descending coronary artery and a major diagonal branch and a moderately severe stenosis (arrow) involving *angulation*, 45° in the left anterior oblique and 90° in the right anterior oblique (not shown) projections, in the left circumflex artery. B, After angioplasty. C, Two balloon-on-a-wire devices placed through a 7F large lumen guiding catheter. There is a 2.5 mm polyethylene terephthalate balloon (arrow) inflated to 19 atm necessary to "dilate" a *calcified* lesion in the left anterior descending artery. D, A 2-mm balloon (arrow) inflated in the diagonal branch of the left anterior descending artery. E, Both balloons (arrows) are inflated to 1 atm. F, A 2.5-mm balloon (arrow) is inflated in the left circumflex artery stenosis.

Advances in Angioplasty Technique

Since that time, there have been significant advances in angioplasty technology (4–8). *None* of the guiding or dilation catheters or guide wires used during the study period of the present report were clinically available before 1988. Dilation catheters are currently 30% to 50% lower in profile and, with additional coating, are more trackable. Monorail and balloon-on-a-wire devices (17,18), longer balloons (30 to 40 mm) and perfusion balloons (19) have become available. Balloon material has improved. Polyethylene terephthalate is thinner and therefore affords a lower profile; this material has increased conformability for angulated lesions, greater strength for calcified lesions (burst point approximately 20 atm) and lower compliance, permitting more accurate sizing (20,21) than is possible with polyethylene, polyvinylchloride and polyolefin copolymer (22).

It is not uncommon for patients to have complex lesions with multiple adverse morphologic characteristics. A case is presented with three unattractive (B or C) morphologic findings: bifurcation lesion, calcification and angulation. The patient was successfully treated with a polyethylene terephthalate balloon-on-a-wire device (Fig. 4).

Lesion Morphology

Diffuse disease. A lesion ≥2 cm long, although initially (1,2) classified as type C ("success <60%, high risk"), was not a major predictor of an unfavorable outcome, even in the mid-1980s. In a report by Goudreau and coworkers (23) (coinvestigators in the study of Ellis et al. [3]) of their 1983 to 1987 experience, vessels with "diffuse disease" were further subclassified into type I (entire vessel involved), type II (lesion ≥2 cm long) and type III (three or more tandem lesions). All of these types of "diffuse disease" were associated with vessel and clinical success of approximately 90%. Also, Ellis et al. (3) did not find lesion length to be a statistically significant predictor of outcome. In our study, there were lower angioplasty success rates as lesions lengthened, but our success rate for type II lesions was 89%, similar to the rate reported by Goudreau et al. (23). There were nine type I lesions in our study; long balloons were used in all of them and all were successful. Others (24) have noted improved angioplasty success with long lesions when longer balloons were utilized. Long, irregular lesions have also been linked to unstable angina (10) and therefore, for other reasons (see below) as well, these lesions may have a less favorable angioplasty outcome. In our study, in addition to the long lesions, there were 188 target vessels with tandem lesions. Vessels with certain combinations of lesions appeared to have an unfavorable impact on angioplasty outcome, namely, A-B, B-C, multiple B and multiple C patterns.

Angulation. Angulated lesions were associated with high angioplasty complication rates in the past; lesions with ≥90°

angulation were classified as type C (1,2). Earlier balloon iterations were nonconformable and, when inflated in vessel bend-points would (suddenly) straighten out, exerting additional noncoaxial stress, thus placing the vessel at risk of dissection. With the advent of conformable balloons, notably polyethylene terephthalate and thinner-walled polyethylene, the angioplasty outcome of angulated lesions has significantly improved (25). In our study, even with lesions angulated at ≥90°, the success rate was 94%, although there was a slightly higher complication rate in this cohort. Conformable balloons, either of polyethylene terephthalate or thinner-walled polyethylene, were used in all cases with angulated lesions ≥45°.

Bifurcation. In this study, bifurcation lesions in which both branches were protected with angioplasty guide wires, dilation catheters or balloon-on-a-wire devices had a high success rate (94%) and were without complication. However, if branches, adjacent to stenoses, were not protected, the success rate was lower and the complication rate was higher, as in other reports (26–29).

Calcification. With the availability of high pressure balloons in our center, calcified lesions were associated with a high angioplasty success rate (91%), but complications were more common with calcified lesions. In addition, 5% of these calcified lesions would not favorably respond (that is, achieve lumen diameter <50%) to balloon inflation pressures >16 atm. High pressure balloons have been reported (30, 31) to increase success rates with calcified lesions (see Addendum).

Severity of stenosis and occlusion. In our study, lesion severity, save for those ≥95%, did not appear to affect angioplasty outcome (success rate 94% to 95%). Lesions of ≥95% or occlusions have been reported (32) to be associated with lower angioplasty success rates.

Meier (33) called occlusions "a different animal." We agree, and, furthermore, the animal may have several subtypes (34–37). Occlusions span the spectrum from a recent occlusive thrombus associated with an acute ischemic syndrome to an old organized occlusion. Between these extremes are occlusions that are neither acute nor old. Although occlusions may have a somewhat similar angiographic appearance (and be given the same "code"), they reflect a different underlying pathology and therefore may yield different angioplasty results. Acute or subacute thrombotic occlusions are probably associated with plaque fissuring (38) and resultant platelet activation sequences (39). A higher angioplasty complication rate has been reported (10, 40) with these lesions, and this was evident in our study. In contrast, in our analysis, old occlusions had a very high incidence of unsuccessful uncomplicated outcome but were otherwise virtually risk free.

Grafts. If occlusions are a different species, saphenous vein grafts are a different phylum, and within this cohort there is considerable heterogeneity. The various pathologic changes in these venous conduits—which were "designed" to carry blood at approximately 5 mm Hg, not 70 to 80 mm Hg—have been discussed in detail elsewhere (41,42). Newer vein graft lesions are usually associated with a fibrointimal hyperplastic reaction, often at the distal anastomotic site, and have been reported (43–46) to have high angioplasty success and low complication rates as well as lower restenosis rates. The atherosclerotic disease in older vein grafts is usually diffuse and friable and may be associated with thrombus deposition. Instrumentation may cause distal embolization (43). In general, we (43,44) and others (45–48), have avoided angioplasty in these grafts.

However, there may be a specific subset of older (and occasionally newer) saphenous vein grafts that appear to have "diffuse" disease or are occluded, but they are *clinically* associated with an acute ischemic syndrome. In these patients, we and others (49–51) have employed an intragraft infusion of urokinase, usually a bolus dose followed by overnight drip infusion, which has lysed the thrombus and uncovered the underlying stenosis that was the nidus for the occlusion. This clinicomorphologic presentation has been associated with favorable angioplasty outcome (49–51).

Abrupt closure. The only statistically significant predictor of untoward events after angioplasty in our study was the presence of an intravascular thrombus associated with an acute ischemic syndrome. However, when abrupt vessel closure occurs, whether due to thrombus, intimal disruption or dissection, serious untoward events are not uncommon (52–56). In our study, prolonged balloon inflation was successful in salvaging nearly one third of these occluded arteries, obviating the need for surgery in these patients, in accord with another report (57). In the setting of an acute ischemic syndrome, urokinase before (58) or after (59) complicated angioplasty may be salutary (see Addendum).

Complete versus incomplete revascularization. In our study, complete revascularization of all "diseased" vessels was achieved in 60% and incomplete revascularization in 40% of patients. Yet, there was no significant difference in angioplasty outcome (success 92%, untoward events 3%) in patients with single- versus multivessel disease, whether there was complete or incomplete revascularization. These observations are in concert with previous reports (60–62).

In a comprehensive study of multivessel disease by O'Keefe et al. (63) from the Mid-America Heart Institute, procedural success occurred in 92% and serious complications in 2.9% of patients. Revascularization was complete in 58% and incomplete in 42%. These findings are nearly identical to our results. In the report of O'Keefe et al. (63), chronic occlusions accounted for 20% of cases of incomplete revascularization. In our study, occlusion was noted in 38% of all diseased vessels, 66% of nontarget vessels and 49% of the target vessels with an unsuccessful uncomplicated outcome.

However, in the study of O'Keefe et al. (63), the group with incomplete revascularization had total in-hospital complications four times more frequently than did patients with complete revascularization: death 4.5 times, myocardial infarction 2.6 times and need for surgery 24 times more

often. All of these factors were statistically significant. Perhaps these variations between our study and the study of O'Keefe et al. (63) can be explained by certain differences in strategy as well as our definition of procedural outcome, which included the entire hospital period, not just the procedure (catheterization laboratory). Yet the report of O'Keefe et al. (63) covered a much longer period (1980 to 1989), including the early era, and they had many more patients with multivessel disease than were present in our study.

Prevalence of lesion type. In our study, only 8% of the 1,000 coronary lesions were type A. The relative paucity of these lesions in our current experience may derive from the fact that the vast majority of our patients treated with angioplasty in our institution are referred by cardiologists who, themselves, perform coronary angioplasty. Therefore, our caseload represents more complex lesions and patients. The frequency distribution of our type A, B and C lesions is quite similar to the current pattern in another major angioplasty referral center (G. Roubin, University of Alabama, Birmingham, personal communication).

Limitations of This Study

This study is an observational report of a nonselected, nonexclusive consecutive series of patients who underwent balloon angioplasty. There is a possibility of bias if cases are selected from a pool of patients available at a particular center; however, this study reports results on a consecutive series of all patients undergoing coronary angioplasty. A second level of bias concerns the pool of patients who might have been referred to a particular center because of geography, reputation and other factors. In our institution, we are unable to control for this type of selection bias, and that may explain our frequency distribution of type A, B and C lesions. Therefore, we cannot be certain that our angioplasty findings and results can be generalized to all other angioplasty centers.

Limitations of Classification and Codification Schemes

A primary goal of this study was to analyze our current angioplasty results and to compare them with the success-risk percentages in types A, B and C proposed by the ACC/AHA Task Force (1,2) and others (3) and to evaluate specific morphologic factors in predicting outcome. The concept of universal classification is an excellent one, but our data suggest that the success and complication rates associated with the original morphologic descriptors (types A, B, and C) are not typical of results that are currently achievable with contemporary balloon technology. For example, in our present study, type C lesions ("<60% success, high risk") (1,2) were associated with widely disparate angioplasty results. Angulated (≥90°) lesion success was 94% with a 2.6% risk, long (>2 cm) lesion success was 89% and old (>3 months) occlusion success was 59%; the two latter types, though, were *without* "risk."

Morphologic type. In addition, some morphologic types (for example, long lesions) might not have been assigned to the proper classification type (that is, type C). Goudreau et al. (23), during the 1983 to 1987 era, demonstrated angioplasty success in approximately 90% (not <60%) in very complex long lesions. Should "degenerated vein grafts with friable lesions" (1,2) have been included at all in the original type A,B,C scheme? With the previously noted exceptions, these grafts have been considered specific contraindications for angioplasty (4,6,42–47,64). Some vessel anatomic descriptors, "readily accessible, moderate or excessive tortuosity of proximal segment" (1,2), are not strictly lesion characteristics; rather, they indicate technical or procedural caveats.

Coding system. There are problems intrinsic to the coding scheme (3) that make it less useful in predicting outcome. The ACC/AHA Task Force type A,B,C, classification scheme (1,2) was developed for descriptive purposes as a *guideline*, not as a basis for a mutually exclusive coding system (3). Some lesions may have characteristics of more than one type, for example, a discrete (type A), calcified (type B), 90° angulated (type C) lesion. How can one classify these lesions and, more important, codify them? Codification requires specific and exclusive criteria.

Conclusions

The 1988 ACC/AHA Task Force (1,2) should be commended for updating and enlarging the guidelines for performance and the selection of patients and lesions for coronary angioplasty. Included in that report was a lesion classification scheme that (undoubtedly) was meant as a general guide for lesion success-risk at that time; however, estimated percentages of success were added to types A, B and C. A subsequent study (3), also representing this era (1986 to 1987), appeared to substantiate some but not all of the Task Force's estimates of success and risks.

Unfortunately, the results of these 1986 to 1988 balloon angioplasty reports, as well as even older (1985 to 1986) angioplasty studies in a broad spectrum of clinical and morphologic settings (65), have been used as comparative yardsticks of success and risks in a more selective population of patients and lesions that have undergone new device procedures. These types of new device comparisons and other problems have been the subject of considerable concern (66–75).

At present, we recommend refraining from the use of a classification system that groups a motley array of lesions with heterogeneous morphologic patterns and very dissimilar angioplasty results. In any case, the categorization of lesions into types A, B and C (1,2) as a guideline for angioplasty success and risk is not current. Perhaps because of new balloon angioplasty technology, our lesion-specific data analysis (1990 to 1991) does not fit the success-risk

predictors of the earlier classification scheme. Instead, one might consider analyzing specific lesion morphology with respect to angioplasty outcome, whether with balloons or new devices. It is our present position that it is more accurate, with regard to lesion morphology, to specify rather than classify.

Whether it would be better to discard the A,B,C classification scheme completely or to overhaul it remains to be seen. Perhaps other centers will analyze their recent data, and a new classification system will emerge. It is evident that what was considered an "unfavorable" lesion for balloon angioplasty 4 to 6 years ago has changed considerably. New devices will sooner find legitimate niches if comparative analyses of angioplasty data are current and lesion specific. We hope that the results of lesion-matched prospective randomized trials will be available in the near-future.

Addendum

Since the completion of our study, three new patients with "undilatable" calcified lesions were successfully treated with high speed rotational atherectomy. Also, since the end of the study period, two patients who had postangioplasty dissection that could not be corrected with prolonged balloon inflation, and who would otherwise have been sent for emergency surgery, underwent successful deployment of an endovascular prosthesis (stent).

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