Long-term Serial Angiographic Studies After Coronary Artery Bypass Surgery

DIANA F. GUTANER, M.D., EDWARD W. ROBERT, M.D., EDWIN L. ALDERMAN, M.D., AND LEWIS WEXLER, M.D.

SUMMARY Twenty-six patients underwent repeat coronary angiography 5–8 years after saphenous vein coronary artery bypass surgery (SVCABG). These patients were selected from the first cohort of 117 patients who had SVCABG because they had obtained essentially complete relief of angina, and because all grafts were patent at initial angiography 11.2 months (mean) after surgery. Of the 39 grafts (1.5 grafts per patient) patent at 1 year, 34 (87.2%) were patent at reexamination 76 months (mean) (range 65–103 months) after SVCABG. Graft occlusion could not be predicted by the early angiographic appearance of the graft itself or its proximal or distal anastomosis. In some cases, narrowing or irregularity consistent with intimal hyperplasia appeared to progress, while in others it developed at late follow-up. Progressive narrowing occurred in 96% (22 of 23 grafted vessels) of the native coronary arteries proximal to the graft anastomosis. Progression to a stenosis >75% or total occlusion was seen distal to the graft anastomosis in eight of 39 grafts (20%). Of 103 non-bypassed major vessels, 56% showed some progression of disease and half of these progressed to significant stenoses (>75% luminal narrowing). There were no apparent predictors to indicate whether progression in nongrafted coronary arteries would occur preferentially in a previously stenotic or nonstenotic vessel, although 80% of vessels with initial stenoses >75% progressed to total occlusion.

THERE HAS BEEN widespread acceptance of saphenous vein coronary artery bypass graft surgery (SVCABG) since it was introduced in 1968.1 Coronary bypass surgery has been of definite value in the symptomatic relief of angina pectoris,2-4 and the results of extended clinical trials, although limited, are encouraging.5-7 The long-term fate of saphenous vein grafts and the native coronary circulation after SVCABG is controversial because of the inexorable tendency of obstructive coronary artery disease to progress.

Patient Selection

Our study group was derived from the first 117 consecutive patients who underwent coronary bypass surgery at Stanford University Medical Center between 1968–1971 (fig. 1). Of the 106 1-year survivors (a mortality rate of 9% at that time), 72 patients (68%) consented to angiography 1–14 months postoperatively (mean 11.5 months). At the initial clinical and angiographic follow-up, 52 patients were virtually asymptomatic (New York Heart Association functional class I or II), while 20 were symptomatic. Details of this study have been previously reported.8

In an attempt to eliminate the bias due to technical
problems inherent in early bypass graft surgery, we limited our study group to patients who had had optimal surgical results: patent grafts and relief of symptoms. Therefore, 41 patients with all grafts patent were selected from the 52 patients who were asymptomatic or had minimal symptoms at 1 year. Twenty-six of these patients have undergone follow-up coronary arteriography at least 5 years postoperatively (range 65-103 months; mean 76 months). One patient who died during reoperation after angiography is included in the study group of 26 patients. Two other patients died of coronary artery disease, and 13 other patients were excluded: two because follow-up angiography was performed less than 5 years postoperatively; nine refused repeat angiography; two for geographical reasons; and two developed intervening illness (one had undergone a pneumonectomy for bronchogenic carcinoma and one suffered a stroke during the initial postoperative angiogram with a residual dense hemiplegia).

There were six late deaths among the 52 patients who were asymptomatic at 1 year. Three of these deaths were in the group of 11 patients with one occluded graft at the initial postoperative evaluation, a much higher percentage (27%) than the three deaths in the larger group of 41 patients with patent grafts (7%) (p = 0.165 by Fisher exact test) (fig. 1).

There were 21 males and five females with a mean age of 57.7 years at the time of surgery (range 44-75 years). The age and sex distribution is representative of the original group of 117 patients. All patients had angina pectoris preoperatively; 21 (81%) had incapacitating stable angina, while five (19%) had unstable angina. Although the majority of these patients were asymptomatic at 1 year, five had mild symptoms. Fifty percent of the patients had recurrent symptoms or worsening of angina during the follow-up period. Angiographic studies were performed a mean of 11.2 months and 76 months postoperatively. Three patients who underwent reoperation 45, 52 and 75 months after initial bypass surgery had additional interval angiography.

Methods
Selective arteriography of the grafts and the native coronary arteries and left ventriculography were per-
formed in all cases by the percutaneous transfemoral approach using Judkins' technique. Thirty-five-millimeter cineangiography was available in all cases, and large film serial angiographic studies were also performed in many cases.

The degree of coronary artery stenosis was estimated as a percentage of luminal narrowing and categorized into the following four groups: 1) no lesion, 2) <75% narrowing, 3) 75–99% narrowing, and 4) total occlusion. Visual estimates of the percent narrowing in vessel diameter were made by two experienced angiographers, first independently and then jointly, to resolve differences. Although there were minor disagreements in the estimate of the percent stenosis, the placement of lesions into the broad categories listed above was not altered. A lesion was considered to have progressed when the estimated increase in stenosis advanced it into the next higher category. Although serial angiographic studies were compared, by present standards the early studies were technically inferior, occasionally making interpretation difficult. Only coronary artery segments that were well-visualized on all three studies were compared.

The only unequivocal sign of graft occlusion was opacification of the orifice and a small proximal segment with no distal filling. Usually, the tip of the catheter would engage the graft orifice and project beyond the aortic wall, but the graft itself could not be seen during contrast injection. In other cases, extensive search with the catheter failed to reveal an orifice, the graft did not opacify on supravalvular aortography, and there were ancillary angiographic findings on selective native coronary injections, such as an absence of “washout” due to graft flow, no retrograde filling of graft, or persistence of collateral flow. These secondary angiographic criteria were necessary to establish nonpatency of the graft.

There were 21 grafts to the left anterior descending and 15 grafts to the right coronary artery. Grafts to these two vessels constituted the majority of bypassed grafts (92%), while the remaining grafts included two to the circumflex and a short graft to the left main coronary artery. In one patient with a “Y” graft, each limb was considered as a separate graft.

We defined nonbypassed vessels as those large enough that today, in the presence of a sufficient degree of stenosis, would be considered for bypass. These include the three major branches — the left anterior descending, circumflex and right coronary arteries — and additional branches supplying about 20% or more of the left ventricular mass, such as diagonal, marginal and posterior descending arteries. In addition, the left main coronary artery was considered as a single vessel for purposes of this study.

Results

Grafts

Thirty-nine grafts were inserted in this group of 26 patients, giving an average of 1.5 grafts per patient. Of the 39 grafts patent at 1 year, five were occluded at late follow-up (two to the left anterior descending, three to the right coronary artery), giving a continued patency rate of 87.2%.

Intimal Hyperplasia

Twelve grafts showed angiographic evidence of intimal hyperplasia at the initial postoperative study, although pathological correlation was available in only three cases. This change consisted of focal or diffuse narrowing within the graft not associated with...
either the proximal or distal anastomoses. The narrowed segments varied in appearance from smooth to irregular and could be either concentric or eccentric. Seven had progressed on the late follow-up study, while five appeared angiographically unchanged. One graft that had both intimal hyperplasia and a proximal stenosis at initial follow-up progressed to total occlusion. Three grafts that appeared normal initially had developed intimal hyperplasia by the time of the late study. One graft that showed intimal hyperplasia contained a large, elongated filling defect at late follow-up, probably a thrombus (fig. 2).

**Figure 3.** Selective left anterior descending coronary graft injections in the right anterior oblique projection at 11 months (m) (left) and 83 months (right) postoperatively show an aneurysm (arrow) involving the distal anastomotic site. At late follow-up the aneurysm contains a filling defect (arrow), probably a thrombus, producing a significant stenosis.

**Figure 4.** Progression of stenoses in the 39 bypassed coronary arteries was examined both proximal to the graft insertion and distal to the graft insertion. Sixteen occlusions and 23 stenoses >75% were bypassed.
Graft Anastomoses

Eight proximal stenoses (graft to aorta) were seen at 1 year: Five remained unchanged, one showed mild progression, and two progressed to occlusion by the time of the late study. Stenoses at the distal graft anastomoses (graft to coronary artery) involved both the graft (four patients) and the coronary artery at the site of graft insertion (16 patients). Three of the graft stenoses remained unchanged, while one progressed. However, three new stenoses developed, all related to graft pseudoaneurysms. Thirteen of the 16 coronary artery stenoses at the graft insertion appeared unchanged at follow-up (10 of these were related to tenting of the coronary artery at the site of graft insertion). Two progressed, while one showed recanalization of a previously occluded distal anastomosis and subsequent antegrade filling of the distal left anterior descending coronary artery. Three new stenoses had developed in this group at late angiography.

Seven aneurysms appeared in the region of the distal anastomosis at late follow-up: in the coronary artery proximal to the graft insertion in one patient, in the distal graft in four patients, or involving the distal anastomosis in two patients. None of these were present on the preoperative angiograms. At late follow-up three remained unchanged, three appeared to have developed related stenosis (fig. 3) and one had disappeared.

Of the five grafts that subsequently became occluded, appearances were initially unremarkable in two, one had a distal stenosis and two had proximal stenoses. One graft had both a proximal stenosis and evidence of intimal hyperplasia.

Bypassed Vessels (fig. 4)

Progression of disease proximal to the graft occurred in 96% of the 23 grafted vessels with a bypassed stenosis. Twenty-seven (77%) of the 35 grafts with no lesions or stenoses <75% distal to the graft remained unchanged, two developed lesions <75%, three progressed to stenoses >75%, and three became occluded. Two of the four vessels with initial stenoses >75% distal to the graft insertion remained unchanged and two progressed to occlusion. The difference in progress to occlusion between disease proximal and distal to the graft is significant at the 0.001 level (Yates corrected chi-square test).

Nonbypassed Vessels (fig. 5)

In this early surgical group, the majority of grafts were to the left anterior descending or right coronary arteries only, while the current surgical trend is to bypass additional branches, such as the diagonal and marginal branches. Eighty-eight of 103 nonbypassed vessels had no stenoses or stenoses <75% preoperatively. Of these, 48% showed no change. There was some change in 34 (39%), 18 of which progressed to stenoses estimated at 50–75%. Progression to a stenosis >75% occurred in 9%, while occlusion only occurred in 4%. However, of 15 lesions >75%, 80% progressed to occlusion. The difference in occlusion rates for stenoses <75% and >75% in nonbypassed vessels is significant at the 0.001 level (Yates corrected chi-square test). In summary, 56% of the 103 nonbypassed vessels showed progression and, of those, half progressed to >75% stenoses or total occlusion.

Progression of disease in bypassed vessels, whether proximal or distal to the graft, and in nongrafted vessels was then compared. Eighty-seven percent of the 88 nonbypassed coronary arteries with no or <75% stenosis preoperatively either remained without lesions (48%) or progressed to stenoses <75% (39%); only 13% progressed to stenoses >75% or total occlusion. Similarly, there was no change in 77% of the 35 bypassed vessels without lesions or stenoses <75% distal to the graft insertion. Six of the eight vessels that showed change progressed to stenoses >75% or total occlusion. Therefore, there was little difference in the behavior of lesions <75% in nongrafted vessels and coronary arteries distal to the graft; the majority showed no change.
The pattern of progression of preexisting stenoses $>75\%$ was different from that of stenoses $<75\%$. Eighty percent of the 15 nongrafted vessels with preexisting stenoses $>75\%$ progressed to total occlusion. Although there were only four stenoses $>75\%$ distal to the graft, two became totally occluded and two remained unchanged. Ninety-six percent of the 23 bypassed stenoses progressed to total occlusion or to a stenosis greater than pregraft. This appearance may be spurious, however, due to poor perfusion or flow reversal in this segment during injection, rather than to true stenosis or occlusion. Such problems in interpretation make it difficult to compare progression of disease in the grafted coronary arteries proximal to the graft.

**Discussion**

Although there have been several reports evaluating angiographic changes in patients with aortocoronary bypass grafts,\(^{11-18}\) there have been few long-term serial angiographic studies reported in the literature.\(^{19-23}\) The first group of 400 patients who underwent bypass surgery at Stanford has undergone extended clinical follow-up.\(^{24, 25}\) Our study group was derived from the initial 117 patients.\(^6\) In an attempt to eliminate the adverse influence of technical problems that may have been present in early bypass graft surgery, we selected the 41 patients with patent grafts at 1 year follow-up study. A graft that was patent at 1 year was considered free from errors in surgical technique, which are thought to influence early graft attrition rate.

There is probably some bias inherent in the selection of this initial group for surgery, seven (20\%) having single-vessel coronary artery disease. However, all 26 patients suffered from incapacitating angina preoperatively. Because the number of grafts was restricted to one or two per patient during this period, a significant number of nonbypassed vessels are available to evaluate progression of atherosclerotic disease and to compare with the grafted native coronary arteries. A better understanding of the progression of disease is central for determining current attitudes of management, particularly the requirement for more complete myocardial revascularization.\(^6\)

**Grafts**

Late graft occlusion could not be predicted from the appearance of the graft or its anastomoses on the early follow-up angiograms. Although the majority of the proximal stenoses remained unchanged at late follow-up (fig. 6), even tight stenoses remained patent, while a few progressed (fig. 7). Although previous reports have shown stabilization of graft intimal hyperplasia beyond 1 year,\(^{12}\) we found progression and even evidence of newly developed hyperplasia at 5–8-year follow-up (figs. 7 and 8). However, pathologic confirmation of intimal hyperplasia was only obtained in the three patients who underwent reoperation, while the angiographic appearance was used as evidence of intimal hyperplasia in the remainder. The majority of stenoses involving the distal anastomosis, including tight stenoses that one might predict would progress to occlusion, remained unchanged and patent (fig. 9). One graft showed recanalization of a tight stenosis of the distal anastomosis, with subsequent antegrade filling of the left anterior descending artery.

One interesting facet was the presence of aneurysms at follow-up angiography that were not present preoperatively (fig. 3). We considered these aneurysms to be related to the surgical technique that led to the development of a false aneurysm at the distal anastomosis (fig. 3). Compromise of the graft lumen was seen at late follow-up in several patients, probably师范大学
Figure 7. Selective right coronary graft injections are shown in the left anterior oblique projection. The mild proximal stenosis (arrow) is shown at postoperative study of 11 months (m) (left) progressed to a significant stenosis (arrow) at 79 months (right). Considerable progression of the irregularity due to intimal hyperplasia extending throughout the body of the graft and involving the distal anastomotic site is seen between the two studies.
due to thrombus formation in the aneurysm. One aneurysm had disappeared at late follow-up, although a linear lucency remained, suggesting the presence of an intimal flap.

Native Bypassed Vessels

Other investigators have shown that progression of disease occurs proximal to graft insertion, and our study confirms these findings. Early reports have suggested acceleration of the disease process distal to the graft insertion, but other series have not supported these findings. Although a small percentage of our patients had progression of stenosis, other preexisting stenoses, even tight stenoses, showed little change (fig. 7) at late follow-up. Our findings do not suggest acceleration of the occlusive disease distal to graft insertion.

Nonbypassed Vessels

Finally, of the nonbypassed vessels that currently would be considered suitable for bypass, half showed progression of occlusive disease and, of those, half progressed to a significant stenosis or total occlusion (fig. 10). Again, there were no apparent predictors to

**Figure 8.** Selective left anterior descending graft angiograms in the lateral projection show evidence of development of intimal hyperplasia (arrowhead) in its midportion at 72 months (m) after bypass surgery (right). In addition, a high-grade stenosis (arrow) at the distal graft anastomosis had developed at late follow-up angiography (right), where there had only been a minor tenting deformity postoperatively (left). This graft progressed to occlusion at 79 months postoperatively.

**Figure 9.** Selective left anterior descending graft angiograms in the left anterior oblique projection show a significant stenosis at the distal graft anastomosis (arrow), which at the late postoperative study of 73 months (m) (right) persists unchanged as a tight stenosis (arrow).
indicate whether progression of disease in nongrafted coronary arteries will occur preferentially in a nonstenotic or a stenotic vessel, but the majority of those with initial stenoses greater than 75% progressed to occlusion.

Acknowledgments

The authors appreciate the assistance of Byron W. Brown, Jr., Ph.D., Professor of Biostatistics, for the statistical analyses, and Marie Graham for preparation of the manuscript.

References

21. Lawrie GM, Lie JT, Morris GC, Beazley HL: Vein graft paten-
Influence of Aortic Insufficiency on the Hemodynamic Significance of a Coronary Artery Narrowing

ROBERT L. FELDMAN, M.D., WILMER W. NICHOLS, PH.D., CARL J. PEpine, M.D., AND C. RICHARD CONTI, M.D.

SUMMARY The coronary hemodynamic effects of controlled aortic insufficiency (AI) were studied in 10 dogs. Coronary blood flow (CBF), before and during reactive hyperemia (RH) with graded coronary diameter narrowings (CN), aortic (Ao) and left ventricular (LV) pressures (P), and aortic blood flow (AoF) were recorded. Opening an adjustable basket catheter, positioned across the aortic valve, created reversible AI quantitated from phasic AoP. AI was regulated so that mean CBF was similar with or without AI. During AI, heart rate and systolic AoP were unchanged, but diastolic AoP declined 14 mm Hg (mean) and end-diastolic LVP increased 8 mm Hg, both p < 0.05. With CN ≥ 85%, mean CBF decreased with or without AI. Coronary resistance was similar with or without AI. During AI with no CN, peak RH CBF declined significantly and was similar to peak RH with 70% CN without AI. Furthermore, AI with 60% CN caused additional reduction in peak RH and was similar to peak RH with 80% CN without AI.

These data suggest that CBF reserve, exposed during RH, is decreased during AI. With AI, a given CN has coronary hemodynamic properties similar to higher degrees of CN without AI. These results may relate to clinical findings of ischemia in patients with AI and no or moderate CN.

AORTIC INSUFFICIENCY (AI) is sometimes accompanied by clinical findings that suggest ischemia, including angina pectoris. Although these findings may imply severe valvular disease and a poor prognosis, they do not necessarily indicate accompanying severe coronary artery disease. Why angina accompanies AI without severe coronary disease is unclear. Altered coronary blood flow (CBF) with or without an associated increase in myocardial work was suggested from previous experimental observations. The possible influence of these AI-related hemodynamic alterations on the coronary hemodynamic properties of a given coronary artery narrowing have, to our knowledge, not been described.

The purpose of this investigation was to study coronary hemodynamics and aortic and left ventricular pressures during reversible AI in an animal model. CBF with graded coronary artery narrowings was examined before and during reactive hyperemia. The magnitude of AI was controlled using a basket-catheter instrument that was positioned across the aortic valve and did not damage the aortic valve cusps. Thus, the magnitude of AI could be controlled so that large CBF and systemic hemodynamic changes were avoided. Furthermore, the aortic valve could be made transiently insufficient, permitting measurements with or without AI in close temporal relation in any given dog.

From the Division of Cardiology, Department of Medicine, University of Florida, and the Veterans Administration Medical Center, Gainesville, Florida.

Supported in part by grants from the American Heart Association, Florida Affiliate, the Southern Medical Association, and the Veterans Administration.

Dr. Feldman is a Research Fellow of the American Heart Association, Florida Affiliate.

Address for reprints: Robert L. Feldman, M.D., Box J-277, Division of Cardiology, University of Florida, Gainesville, Florida 32610.

Long-term serial angiographic studies after coronary artery bypass surgery.
D F Guthaner, E W Robert, E L Alderman and L Wexler

Circulation. 1979;60:250-259
doi: 10.1161/01.CIR.60.2.250
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1979 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/60/2/250

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org/subscriptions/