Critical Analysis of the Preoperative and Operative Predictors of Aortocoronary Bypass Patency

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A prospective analysis of the angiographic and operative anatomic and reconstructive variables that influenced graft patency was undertaken at the University of Virginia Medical Center in 50 consecutive patients. Postoperative restudy showed that 18 of the 168 grafts performed were occluded due to venous disease, inadequate run-off, or sequential design error. Angiographic artery size was 27% larger than operative estimations; graft patency significantly increased with increasing distal artery diameter, with decreasing venous conduit diameter, and with good graftability rating of the vessels preoperatively. Ejection fraction, the degree of arterial stenosis, and the source of the saphenous vein conduit (the thigh or the lower leg) had no influence on graft patency. Simple grafts had a 96% patency, while sequential grafts had an 80% patency. When design error for sequential grafts was eliminated, the sequential patency rate rose to 88%. For revascularization of small circumflex vessels, consideration should be given to variation in the sequential grafting technique to improve patency in these vessels.

EVALUATION OF AN INDIVIDUAL in terms of being a "good candidate" or a "poor candidate" for coronary revascularization is usually based on a composite analysis of symptoms, age, bodily habitus, personality, and motivation, as well as coronary arteriographic and ventriculographic findings. Interpretation of such objective signs as stenotic lesions seen on coronary angiography varies from one observer to another, and even the same individual will grade the same stenosis differently on different occasions.[5,6] Such interobserver and intraobserver variability is a significant problem.[5,6] Similarly, the assessment of the distal vessel in terms of suitability for bypass grafting (graftability) also varies. A distal vessel with a large internal diameter (2 mm or larger) free of local or distal disease is optimal for grafting and one presumes these vessels have a better chance of long-term patency;[2,13] whereas the smaller vessel (1.0–1.5 mm internal diameter) with local or diffuse distal disease is felt to have a lower chance of long-term patency, and is regarded as less suitable for grafting.[17]

For the last 12 years, simple coronary venous bypass grafts have been used extensively; in recent years, in the quest for "total revascularization," some centers have been using sequential grafting techniques described eight years ago by Bartley and Bigelow[3,4] and popularized by Sewell[16] and Grondin.[10] Green[8] recommended the use of lower leg saphenous vein for the bypass conduit, because it was more accustomed to a higher hydrostatic pressure and thus less distensible. Whether coronary vein graft patency varies with the type of revascularization technique, or with the source of the venous conduit (thigh vs leg saphenous vein), is not well understood.

In an attempt to evaluate the scientific accuracy of such predictors of graft patency as graftability and degree of coronary arterial stenosis; to compare the angiographic sizing of coronary arteries with the operative sizing of the same vessels; to compare thigh vein graft patency with lower leg vein graft patency; and to evaluate graft patency with different reconstruction techniques, a group of patients at the University of Virginia was studied prospectively with pre- and postoperative arteriography.

Materials and Methods

Angiographic Evaluation

Between May 14, 1979 and January 28, 1980, the preoperative coronary arteriograms, the operative findings, and the postoperative arteriograms in 50 consecutive study patients undergoing coronary artery bypass grafting were analyzed. Patients with concomitant valvular heart disease or ventricular aneurysms were

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TABLE 1.

Graftability	Stenosis
0 = Good	0 = Nl
1 = Fair	1 = 0–25%
2 = Poor—small distal vessel	2 = 25–49%
3 = Poor—distal lesion	3 = 50%
4 = Poor—lesion at site of graft	4 = 50–69%
5 = Uncertain—vessels filled by collaterals only	5 = 70%
	6 = 90%
6 = Uncertain—vessel not visualized	7 = 99%
7 = NA (absent)	8 = Total occlusion

Graftability: Categories 0–7 describe the graftability ratings consistently applied to all distal vessels.

Stenosis: Categories 0–8 represent the numerical degree of vessel stenosis. This is measured by caliper comparison of the stenosis with the native vessel immediately distal to the stenosis.

excluded from this analysis. A single cardiologist made a blind analysis of all patients' coronary arteriograms, recording independently and without knowledge of clinical or operative findings the degree of stenosis of each vessel by caliper calibration and the internal diameter of each distal vessel by caliper comparison of the luminal diameter with the tip of the angiographic catheter. The graftability of each vessel was designated according to the criteria outlined in Table 1. This cardiologist matched his evaluation with the official report of the catheterizing cardiologist, and when there was a discrepancy, an independent cardiologist evaluated the angiogram, and, finally, all three cardiologists gave a consensual reading for that patient.

Intraoperative Evaluation

The operative technique was quite standardized: myocardial protection entailed core cooling to 28 C, iced saline in the pericardial well, and infusion of cold crystalloid cardioplegic solution into the aortic root every 15–30 minutes. At surgery the internal diameter of all vessels grafted was measured using calibrated probes, the external diameter of all vein grafts, whether simple or sequential, was measured, and the source of the vein for each graft (thigh saphenous vs lower leg saphenous vein) was noted along with the revascularization technique (simple graft vs sequential graft). The internal mammary artery was not used in this series, and 168 anastomoses were performed (an average of 3.4 grafts per patient). Continuous suture technique was used in all anastomoses.

After two to three months of convalescence and conventional physical rehabilitation, patients were readmitted to the hospital for cardiac assessment. At this time, most patients were walking two to five miles daily. After repeat coronary arteriography, the same investigator interpreted all coronary arteriograms in terms of the state of the native circulation, the ventricular wall motion and global ejection fraction, and graft patency.

Not all patients who underwent coronary revascularization were included in this study. Patients whose original coronary arteriograms were performed at other centers were excluded, and although all patients otherwise were asked to participate in this study, not all agreed to the protocol. Accordingly, this report analyzes 50 consecutive patients completing the three stages of the study–operation–restudy protocol.

Results

Graft Patency

Both simple and sequential grafting techniques were used. There were 88 simple grafts, with an overall patency rate of 96%. The patency rate of all venous conduits, both simple and sequential, was 93.6%. Thirty-seven conduits were used for 80 distal sequential anastomoses, or 2.2 distal anastomoses per conduit were performed with the sequential technique. There were 40 side-to-side sequential anastomoses, with an overall patency rate of 83%, and 40 end-to-side sequential anastomoses, with an overall patency of 75%. The total patency rate for all sequential anastomoses was 80%. There were 18 occluded grafts among the 168 distal coronary anastomoses, for a total graft patency rate of 89.3% (Fig. 1).

Causes of Graft Occlusion

The causes of graft failure were a) venous disease in six patients (33.3%), b) inadequate run-off in five grafts

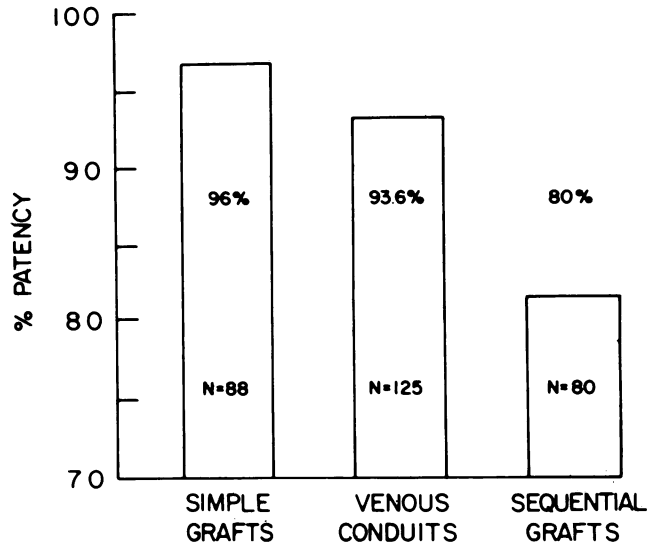

FIG. 1. Graft patency: the overall patency of simple grafts, venous conduits, and sequential grafts are compared.

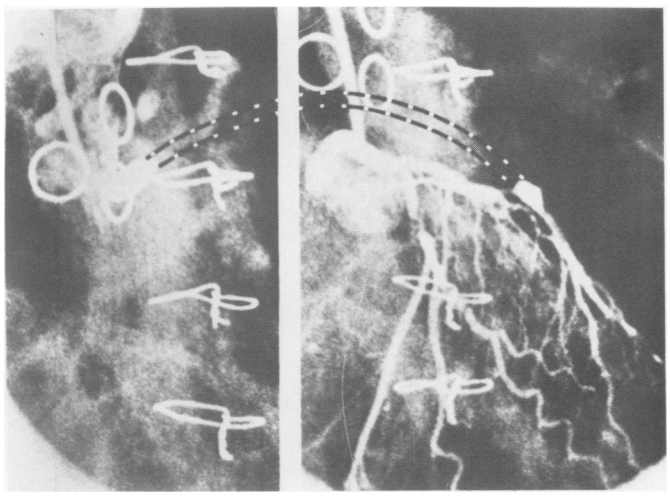

FIG. 2. Both proximal and distal anastomoses of this graft to the LAD are patent, inculcating venous disease as the cause of graft occlusion.

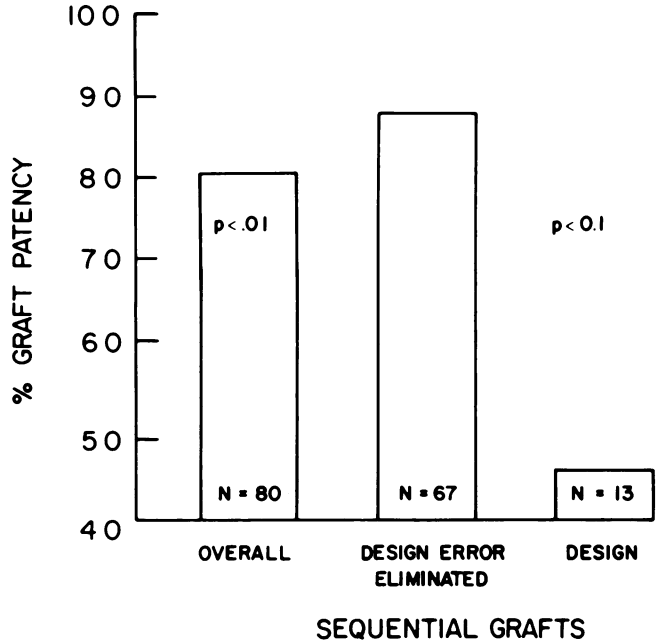

FIG. 3. Sequential grafts: while the overall sequential patency was 80%, when the design error had been eliminated, the patency rose to 88%; whereas in those 13 instances of design error, graft patency was 46.2%.

(27.8%), and c) conceptual errors in sequential graft design in seven grafts (38.9%). Failures in the first category (a) resulted from the use of a disproportionately large venous conduit size (6 mm or larger) when small distal arteries (1.0–1.25 mm diameter) were being revascularized, as well as angiographic identification of the vein as the cause of graft occlusion (Fig. 2). In the five grafts in the second category (b), attempts were sometimes made to revascularize small arteries (1.0–1.5 mm diameter) which had severe local and diffuse distal disease. This severe limitation of graft runoff was felt to be the cause of graft occlusion. When the sequential design of the seven grafts in the third category (c) resulted in the terminal artery grafted (end-to-side anastomoses) being as large as or larger than the diameter of the previous artery grafted (side-to-side anastomoses), the patency rate of the terminal graft was 88%. If the terminal artery was smaller than the previously grafted artery (this occurred in 13 instances), the patency of the terminal grafts was 46.2%! The authors regarded this latter, unsatisfactory result as a conceptual design error (DE) that predisposed towards graft occlusion (Fig. 3).

Predictors of Graft Patency

The overall graft patency in the 50 patients has been clearly defined in Figure 1. To purify the accuracy and significance of each of the preoperative and operative predictors of graft patency, other causes of graft occlusion that would skew the influence of each predictor have been excluded, and the significance of each predictor on graft patency has been analyzed.

Degree of Arterial Stenosis

The influence of the degree of arterial stenosis on subsequent graft patency is outlined in Figure 4. There is no significant difference in the patency rate with vary-

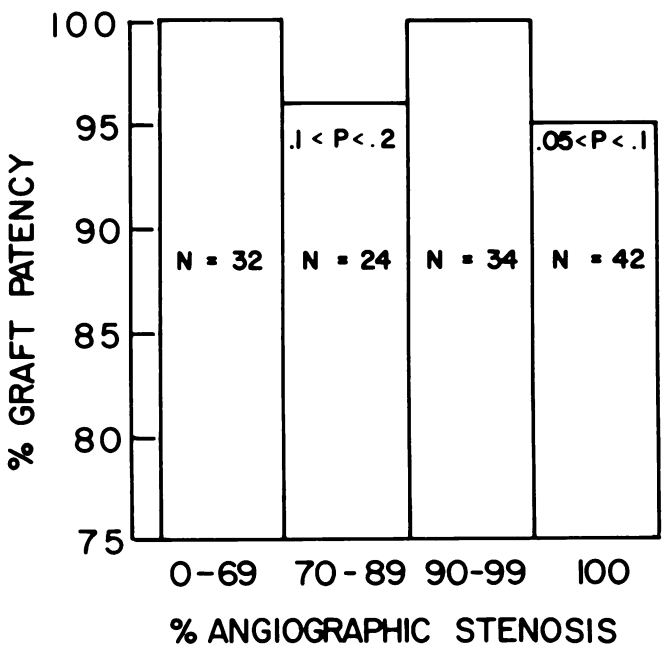

FIG. 4. There is no significant difference in graft patency related to the degree of arterial stenosis. Interestingly, revascularization of vessels with stenosis less than 70% resulted in 100% patency.

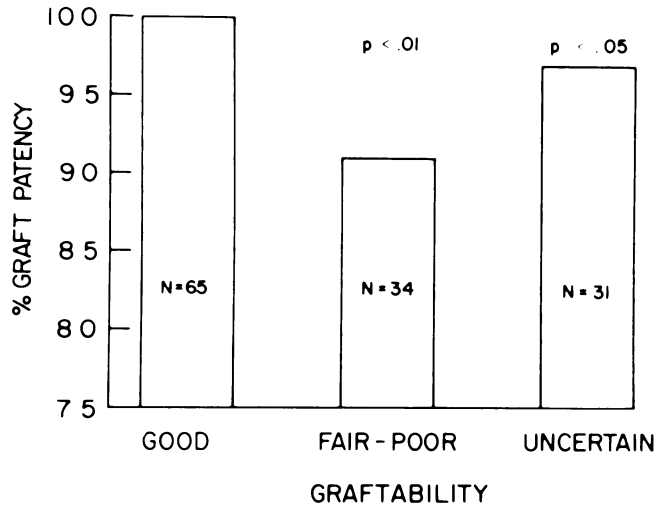

FIG. 5. Graftability is a significant predictor of graft patency: good graftability vessels had 100% patency, while fair–poor category vessels had 91% patency. 0: good; 1: fair; 2: poor—small distal vessel; 3: poor—distal lesion; 4: poor—lesion at site of graft; 5: uncertain: vessel filled by collaterals only; 6: uncertain—vessel not visualized; 7: NA (absent).

ing degrees of coronary arterial stenosis or total occlusion. Even in vessels with less than 70% stenosis, the vein graft patency has been excellent (100%), despite the concept that competitive flow predisposes to graft occlusion.

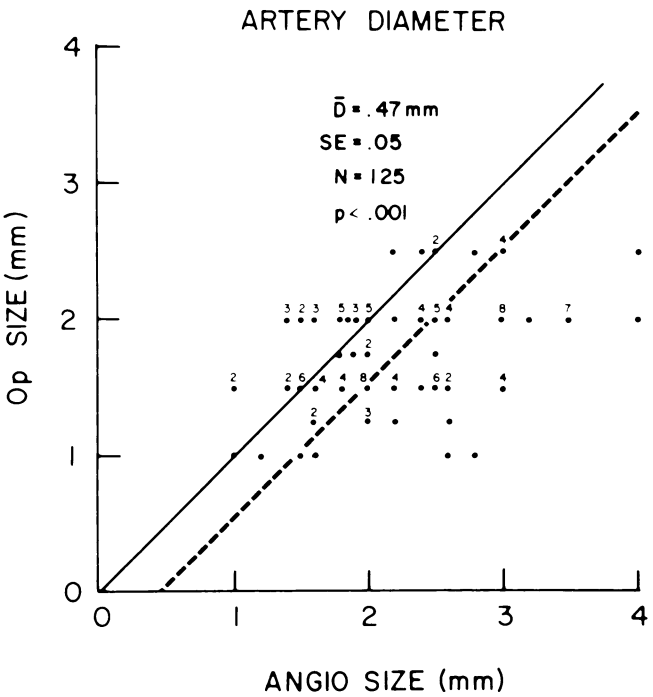

FIG. 6. A significant "magnification factor" is shown when angiographic size is compared with operative size. On average, the angiographic size was 0.47 mm larger (27%) in diameter than the size found at surgery.

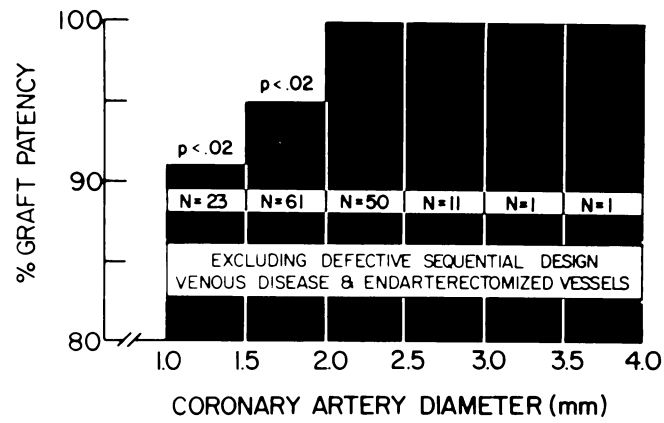

FIG. 7. With increased coronary artery diameter, there is a step-wise increase in patency until the vessel reaches 2 mm in diameter.

Graftability

The graftability rating of all 168 distal vessels grafted was included in categories 0–5 of the graftability code (Table 1). To analyze the predictive value of the graftability rating only, graft occlusion due to venous disease and conceptual errors in sequential graft design were excluded. Figure 5 shows a statistically superior patency in "good" graftability vessels. A surprising finding was the unexpectedly high patency of vessels in the "uncertain" category. These vessels were filled by collaterals only, and an accurate preoperative estimation of their size was impossible. Not only were these vessels usually graftable, but they had a patency of 98.2%. The influence of grafting technique (simple vs sequential) was analyzed along with the graftability ratings, and there was no variation in graft patency in the three graftability categories, whether the simple or the sequential technique was used.

Preoperative Coronary Arterial Diameter

Preoperative and operative estimations of coronary arterial size were compared for each vessel grafted. Figure 6 compares the operative and angiographic size, and the aggregation of points below the line of direct relationship shows that for each individual artery, the average angiographic size was 0.47 mm larger than the size found at surgery. This represents an overall "magnification" factor of 27%.

Operative Coronary Artery Diameter

The coronary artery diameter measured at surgery was evaluated as a predictor of graft patency, and Figure 7 outlines a step-wise increase in graft patency with increasing coronary arterial diameter from 1 mm up to 2 mm. From 2 mm to 4 mm, all vessels were patent. There is a statistically significant difference in

the patency of vessels 1.0–1.5 mm in diameter and of vessels 1.5–2.0 mm in diameter, when compared with vessels 2.0 mm or more in diameter. Obviously, in this analysis, grafts that were occluded because of venous disease or defective sequential design and arteries that had been endarterectomized prior to grafting were excluded.

Diameter of Venous Conduit

The external diameter of the vein graft was a significant predictor of graft patency, and Figure 8 shows a step-wise decrease in graft patency with increasing venous conduit diameter. In this analysis, arteries where the defective graft design was used were excluded along with grafts that were occluded because of very limited arterial run-off.

Source of Venous Conduit

In this study, 110 grafts used saphenous vein harvested from the thigh, and 58 grafts were constructed with saphenous vein from the lower leg. The thigh saphenous vein graft patency was 91%, and the leg vein patency was 83%. There is no significant difference in these patency rates. When the source of venous conduit is analyzed in terms of revascularization techniques, as outlined in Figure 9, there appears to be a strikingly significant patency differential between sequential grafts constructed from thigh veins (86%) and sequential grafts from leg veins (67%). However, closer analysis shows that in the thigh vein sequential category, two graft occlusions were due to inadequate run-off; if these are excluded from the analysis, the patency of thigh sequential grafts is 89%. In the leg vein sequential category, there were three graft occlusions due to inadequate run-off; if these are excluded from the analysis, the patency of leg vein sequential grafts is 78%. There is no statistically significant difference between the 89% and the 78%. From these and additional analyses (multivariant discriminate analysis), there is no difference in graft patency whether the vein is harvested from the thigh or the lower leg.

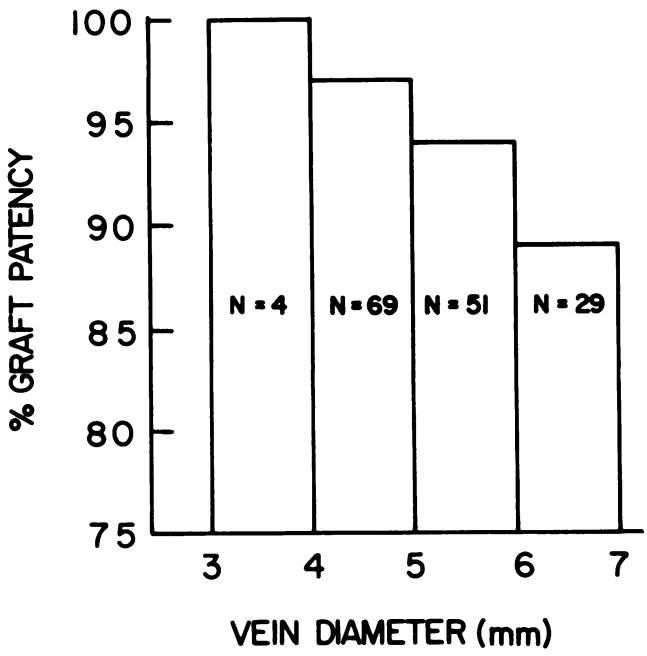

FIG. 8. With increasing diameter of the vein graft, there is progressive diminution in graft patency (excluding defective sequential design and small vessels with distal disease).

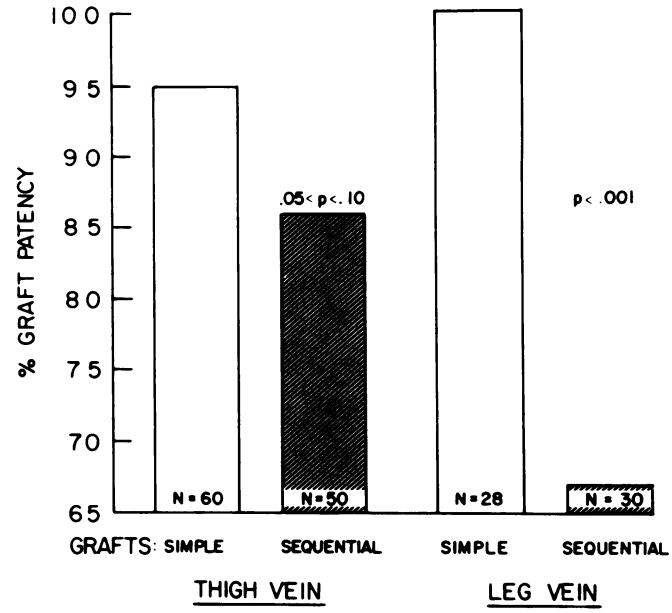

FIG. 9. Thigh vein patency vs leg vein patency: when the 110 thigh vein grafts and 58 leg vein grafts were divided into simple and sequential categories, there seemed a significant difference between the leg vein sequential graft patency and the thigh vein sequential graft patency (67% vs 86%). However, when graft occlusions due to inadequate run-off are excluded, the leg sequential patency is 78% and thigh sequential patency is 89%, and the difference is insignificant.

Vein–Artery Ratio

Attempts were generally made at surgery to match the diameter of the vein to the diameter of the artery grafted, within the limits of the venous conduit available. However, on many occasions the vein diameter was larger than desired. This external diameter of the venous conduit was compared to the internal diameter of the grafted vessel (V:A ratio), and the influence of the V:A ratio on graft patency was analyzed. With increasing V:A ratio there is a step-wise deterioration in graft patency until the ratio becomes 4.5:1 (Fig. 10). At this level the graft patency rate is 71%. However, there were six grafts (all sequential) with a ratio between 4.5:1 and 6:1 that were patent. When the V:A

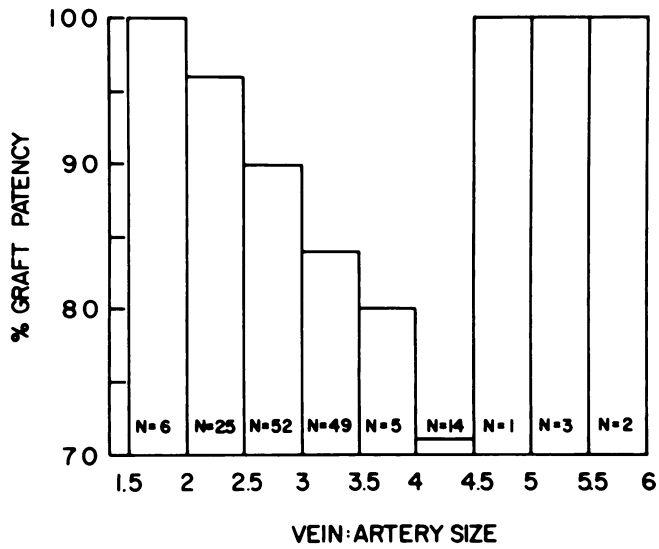

FIG. 10. As the vein-to-artery ratio increases, there is progressive deterioration in overall graft patency from 100% down to 71%. Despite this trend, there were six sequential grafts (all patent) with V:A ratios greater than 4.5:1.

ratio for simple grafts was analyzed, there was no step-wise deterioration in graft patency with increasing V:A ratio, but then the overall patency of simple grafts was 96%. With sequential grafts with an overall anastomosis patency of 80%, there seemed to be step-wise deterioration in graft patency with increasing V:A ratio until the ratio became 5:1. However, when graft occlusion due to design errors was excluded, the sequential anastomosis patency was 88%, and there was no significant difference in graft patency with increasing V:A ratio. The number of grafts in each V:A ratio category is small, and in grafting small arteries there was an operator bias towards using sequential revascularization techniques, as there was no simple V:A ratio greater than 5:1. Although in this study there is no statistical validity in the concept that graft patency deteriorates with increasing V:A ratio, the trend seems clear. The success of the sequential technique in achieving graft patency in the small number of vessels with V:A ratio greater than 5:1 justifies continued utilization of this technique in this setting.

Ejection Fraction

Segmental wall motion and global ejection fraction were taken from the right anterior oblique cineventriculogram both pre- and postoperatively for each individual patient (Fig. 11). The mean preoperatively was 63%, and postoperatively it was 65%, but there is no significant difference between these two. Comparison of ejection fractions of patients with patent grafts and occluded grafts shows no significant difference either. Thus, ejection fractions cannot be used as a predictor or marker of graft patency.

Discussion

Degree of Arterial Stenosis and Arterial Size

This study suggests that there is no *in vivo* validity in the theoretical concept that a bypass around a 50% stenosis sets up competitive flow and predisposes towards graft occlusion. There was complete patency in all of these grafts, but whether such grafting precipitates deterioration in the proximal native circulation needs additional clarification. In stenotic vessels, graftability is a valuable predictor of patency; however, it has no value as a predictor of patency in totally occluded vessels. The high patency rate (98.2%) of vessels in the "uncertain" category encourages an aggressive attempt at revascularization for all totally occluded vessels.

Several reports have discussed the degree of stenosis found at autopsy and compared that with the angiographic stenosis.[1,9,18] There is a consistent angiographic underestimation of the severity of the stenosis (5–33%) as compared with autopsy findings. However, the authors were unable to find a report of the comparison of the angiographic and operative arterial diameters, and the overall magnification factor (27%) is not unexpected. At angiography, the coronary artery is distended by physiological blood pressures; in the ar-

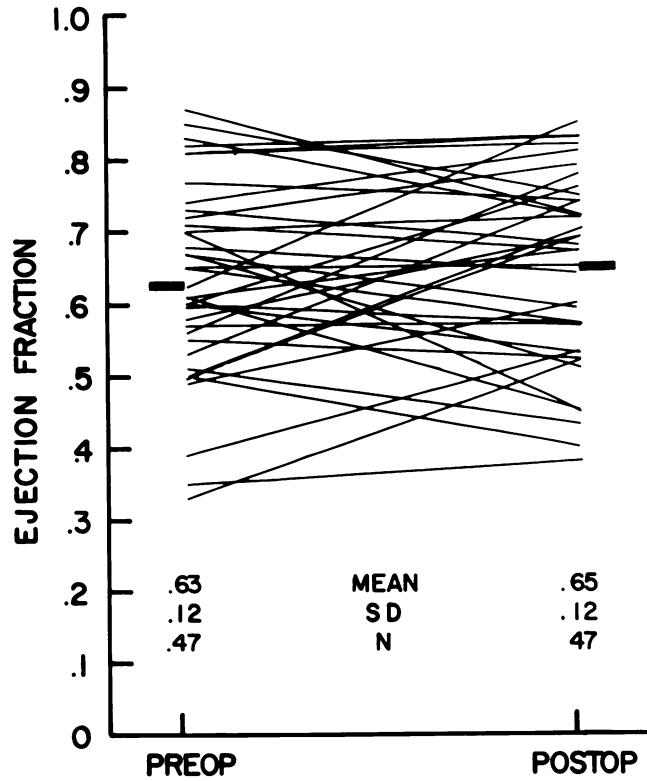

FIG. 11. The average ejection fraction went from 63% preoperatively to 65% postoperatively. There was no difference in ejection fractions in patients with patent or occluded grafts.

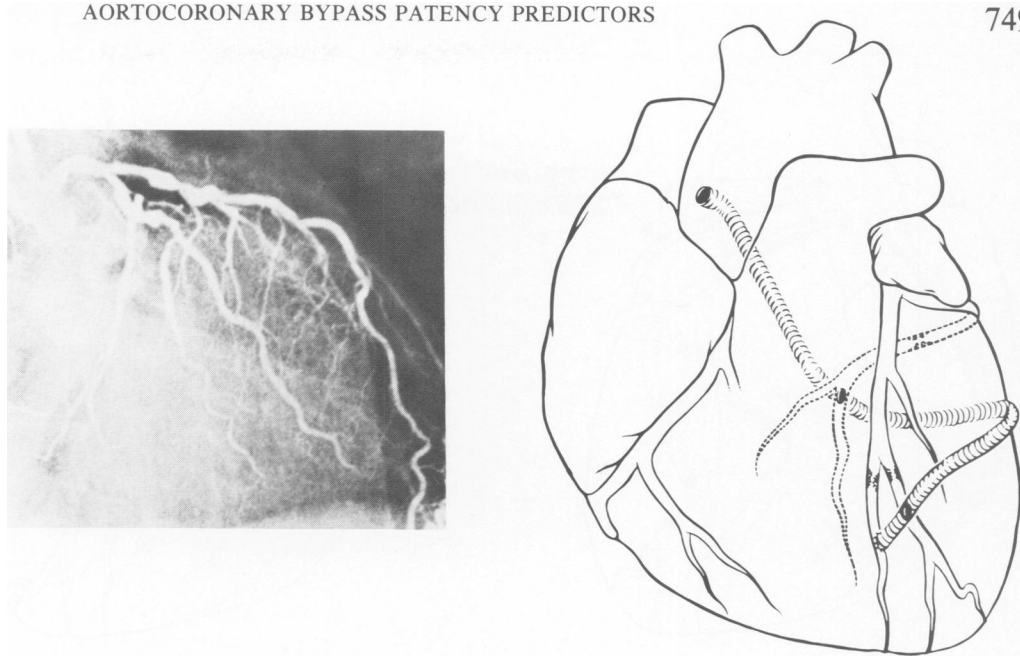

FIG. 12. The transverse sinus sequential graft allows revascularization of small circumflex branches and termination of the conduit in the larger LAD run-off.

rested, cooled, flaccid heart with the artery collapsed, this distending pressure is absent. Additionally, hypothermic vasoconstriction will play some role in the reduction of the diameter of the distal vessels.

If one grafts coronary arteries with a diameter of 2 mm or more only, the patency will be exceptional. However, this standard would preclude revascularization of the many people (*e.g.*, diabetic females) whose coronary artery size is no greater than 1.25 mm. Incorporating a large number of these latter patients in any series will result in a lower overall graft patency (Fig. 8). The size of the distal artery and the diameter of the vein graft are more important in terms of graft patency than whether the venous conduit comes from the thigh or the leg area.

Graft Patency

In the years since the preliminary publication of the results of the Veterans Administration Randomized Cooperative Study,[14,15] many authors have reported vein-graft patency rates considerably higher than the 69% overall patency rate in that study.[7,10–12,17] However, patency rates of venous coronary bypasses have traditionally been lower than the 96–100% early patency of the internal mammary graft to the anterior descending artery.[7,11,17] While the overall simple graft patency rate in this series was 96%, simple grafts to the anterior descending artery had a patency rate of 97%. It is encouraging to see that the LAD vein graft patency now approximates the good patency level of the internal mammary artery graft. Although there will be deterioration in the venous conduit, it will be interesting to see if the late vein graft patency approximates the late patency rates (92–96%) at one year for the internal mammary artery reported by other authors.[11,17]

Circumflex Grafts

Simple grafts to the circumflex system had an overall patency of 95% in this series. However, circumflex side-to-side grafts had a 67% patency rate, and end-to-side circumflex sequential grafts had a 61% patency rate. When the circumflex grafts are excluded from the sequential series, the side-to-side patency rate in the overall experience is 92%, and the end-to-side patency rate is 86%. In terms of global graft patency, another way to look at the results in this study group is that right coronary grafts had 100% patency, anterior descending diagonal grafts had 93% patency rate, and circumflex grafts had 75% patency. While this circumflex patency is similar to that reported by Bigelow and Bartley,[4] the results are somewhat unsatisfactory. Sewell reported a 97% side-to-side anastomosis patency rate, and an 87% end-to-side anastomosis patency rate, along with an 88% simple graft patency rate.[16] While Sewell's sequential anastomosis patencies appear remarkably good, when one analyzes these data further, end-to-side anastomoses to the circumflex marginal vessels (20 grafts) had only a 75% patency rate. Grondin[10] made an important feature of his sequential grafting technique the termination of all grafts on the left anterior descending artery (a large run-off bed!). He felt that diamond-shaped side-to-side anastomoses were preferable and that alignment of the graft to avoid

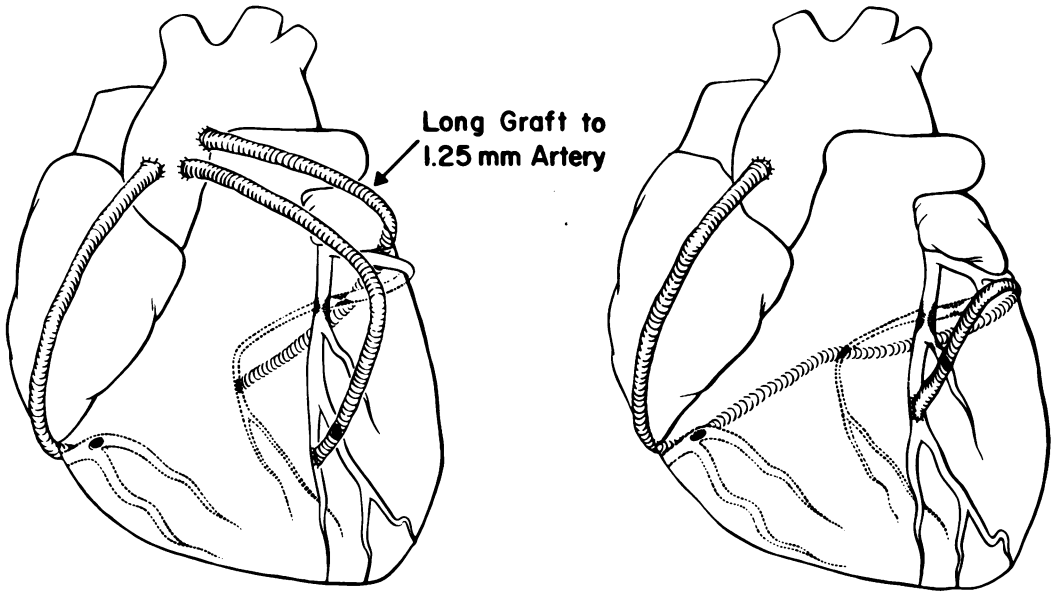

FIG. 13. In patients with small arteries (1.0–1.5 mm in diameter), rather than the conventional triple venous conduit reconstruction technique, the long-sequential graft allows total revascularization with a higher chance of patency in the smaller circumflex arteries.

kinking was an important feature of early graft patency (95.7%).

When the circumflex vessels are small (1.25 mm in diameter), a modification of the sequential technique should be considered. Using a transverse sinus conduit, a side-to-side anastomosis to the small circumflex artery is performed. Then anastomosis to the diagonal, and finally the anterior, descending artery gives complete revascularization with the graft ending in a large run-off bed and this predisposing to sequential graft patency (Fig. 12). Similarly, a small (1.25 mm) distal circumflex vessel, that would require a long simple graft in the conventional triple-vessel reconstruction, would have a lower chance of long-term patency; from the analysis of the predictors of graft patency in this study, consideration should be given in this situation to incorporating the revascularization of this circumflex vessel as part of a circular graft utilizing sequential techniques (Fig. 13).

Summary

The predictors of aortocoronary bypass patency in a prospective study–operation–restudy protocol of 50 consecutive patients at the University of Virginia were subjected to multivariant discriminate analysis. The degree of arterial stenosis and the source of the venous conduit (thigh vs lower leg saphenous vein) had no influence on graft patency. Large distal arteries and narrow venous conduits were predictors of excellent graft patency. Simple graft patency (96%) was superior to sequential anastomosis patency (80% overall). Careful attention to sequential graft design allowing side-to-side anastomoses to smaller circumflex vessels and termination of the conduits in larger anterior descending or right coronary vessels should result in superior patency.

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Discussion

Dr. Richard E. Clark (St. Louis, Missouri): The authors have reinforced findings that have been noted before; namely, that if you have a coronary artery of 2 mm or larger, you have an excellent chance for immediate and long-term patency. Secondly, a poorly visualized vessel on angiography requires surgical exploration, because, in most cases, one can find an area of that artery which is suitable for anastomosis. This is illustrated by the fact that the authors had a 94% immediate patency rate with this type of vessel.

This study is somewhat at odds with the findings of others concerning the importance of matching the diameter of the vein graft with the size of the artery. Dr. Crosby found diameter matching to have no statistically significant influence on patency. However, the studies of Green in 1972 and Gott in 1977 emphasized the importance of velocity on patency and the influence of anastomotic area on velocity suggesting improved patency with vascular diameter matching. The authors found, as had Grondin, that sequential grafts should probably terminate in the vessel of larger size.

I'd like to ask Dr. Crosby several questions; first, were graft flows measured, and if so, could these data be correlated to any of the other variables considered in this study?

Second, since the last patient was entered into the protocol on the 28th of January, 1980, has any patient had a second cine angiographic study to provide more information concerning the long outcome, particularly concerning the sequential grafts?

Third, I'd like to know his opinion about bridging separate vascular beds with sequential grafts, particularly where each of these separate beds may have separate resistances.

Finally, does he still recommend more than two anastomoses per sequential graft?

Dr. Ivan K. Crosby (Closing discussion): We feel that the vein/artery ratio is important, and obviously, in all cases, we try to tailor the diameter of the vein graft to the size of the artery being grafted. However, you can't change the size and quality of the venous conduit in most patients and in many cases, the diameter of the graft was larger than what we would consider optimal; and that's why we looked at the ratio of the venous diameter to arterial diameter.

Even though we tried to look at this in several ways, we were limited by the fact that in these 50 patients, there were only 168 distal anastomoses and that the number of grafts in each vein diameter category was quite small, and we were thus unable to demonstrate statistic validity with this analysis. In this regard, and this is in answer to one of your other questions, an additional 50 patients will be restudied after coronary revascularization (I think we are up to 48 at present) and these 50 will be added to this analysis.

In terms of longitudinal studies, we haven't, at present, any additional data on these initial 50 patients. We are contemplating bringing them back a year after operation for further analysis.

We have, traditionally, done sequential grafts in the same coronary bed; for example, the anterior descending diagonal bed, the circumflex bed, or the right coronary and posterior descending bed. However, in attempts to revascularize distal vessels of small diameter, we have compromised some of these principles to achieve more optimal flow characteristics and better graft design.

(slide) This represents the average length of an anterior descending graft, 13 cm. A right coronary graft is about 16 cm. A graft to the circumflex through the transverse sinus is just under 12 cm, and a circular graft, revascularizing everything, is about 36 cm.

In an attempt to shorten the length of the graft, which was one variable we didn't analyze, and also in an attempt to give side-to-side anastomoses to small vessels, we do at times cross beds and go from the circumflex system to the anterior descending, or occasionally from the right system over to a very dominant atrioventricular groove branch of the circumflex. I don't have any long-term follow-up data on these patients at this time.

We didn't measure graft flows in this study. We have two flow meters and we have been disappointed with the quality and consistency of the measurements with both instruments, and thus, flow measurement wasn't included in this study.