Postoperative Changes in Aortocoronary Saphenous Vein Grafts Revisited

Angiographic Studies at Two Weeks and at One Year in Two Series of Consecutive Patients

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SUMMARY

Comparison of aortocoronary saphenous vein graft status at two weeks and at one year was made in two series of patients. The early postoperative evaluation includes 122 patients of the first 138 operated in our institution (182 grafts) and 83 subjects from a second series of 100 patients operated after modifications of surgical techniques (184 grafts). The one-year follow-up study was obtained in 105 patients of the first series (154 grafts) and in 67 of the second (152 grafts). The patency rate at two weeks was not significantly different between the two groups: 86.3% vs. 91.8%. A marked decrease of stenoses noted early at anastomotic sites was observed: 15% to 5.5% (P < 0.025). The patency rate at one year improved from 67% to 85.5% (P < 0.0005). Grafts having flows at operation of at least 50 ml/min had patency rates of 90% in both series. The patency in grafts with initial flows below 50 ml/min increased from 28% to 73% (P < 0.0005). The incidence of late localized graft stenoses ≥40% decreased from 18.5% to 6% (P < 0.025), and diffuse narrowing ≥40% was found in only 12% of the patent grafts at one year in the second series as compared to 31% in the first (P < 0.001). These improved results do not appear to have been influenced by selection favoring better distal run-off in grafted arteries nor by the introduction of sequential grafts to multiple coronary arteries in the second group. Modified surgical techniques may explain the improved results.

AORTOCoronary Saphenous Vein Graft alterations and high attrition rates noted at two to three weeks and at one year after operation in the first 138 patients operated upon in our institution prompted modifications of surgical techniques.1-3 Comparison of initial results with those obtained in a second series of consecutive patients forms the basis of this presentation. A striking increase in graft patency at one year and a marked reduction in graft alterations now suggest that benefits derived from this operation may last longer than had been previously expected.

Material and Methods

The two prospective series under study are described in table 1. The early angiographic studies were performed 10 to 23 days after surgery, at a mean of 14 days, and the one-year evaluation involved angiographic examinations obtained between 10 to 19 months after surgery, at an average of 12 months. As noted, excluding early deaths only five patients were not studied at two weeks in the first series, and 11 in the second series. In addition to patients who had not been examined at two weeks and requested not to have the one-year postoperative evaluation, 23 of the first series and 15 of the second were not restudied. Nine patients in the first series and one in the second who had all grafts obstructed at two weeks and therefore were not reevaluated are included in the one-year postoperative study. Of the first 138 patients operated on in our institution from September 1969 to October 1970, 124 were evaluated at two weeks and 105 at one year. Of the 100 patients in whom surgery was performed between November 1971 to July 1972, 83 had angiographic control studies at two weeks, and 67 were included in the one-year evaluation. One hundred and twenty-four of the 129 survivors of the first series (96.1%) and 83 of the 94 survivors of the second series (88.1%) were evaluated at two weeks. Of patients who were eligible for study at one year (those with at least one patent graft at two weeks), 105 out of 119 in the first series (88.2%) were included as compared to 67 of the 81 patients in the second series (82.7%).

In both series, the majority of patients were operated for incapacitating stable angina. The age ranged between 37 to 68 years, and the mean age was 48.2 and 50.1 years in the first and second series, respectively. No significant differences were noted between the series associated with sex, lipid abnormalities, associated diseases, or clinical manifestations.

These two series differed however with respect to increased experience of the surgical team, surgical techniques, and probably skill. Modifications of the method of preparation of the saphenous vein and of grafting procedures, as previously described, were introduced in the second series. In brief, during the first series, the vein was removed through multiple skin incisions and tunneling, flushed under pressure with saline to detect leaks, and then kept in saline at room temperature for one to two hours until the recipient coronary arteries were ready to be bypassed. In the subsequent series, a single skin incision was made, avoiding un-
due stretching of the vein and stripping of its adventitia. The vein was left in situ and until grafting was covered by sponges soaked in Ringer’s lactate solution and papaverine hydrochloride. Following removal, it was flushed with heparinized oxygenated blood taken from the arterial line.

Anastomoses to the aorta and to the recipient arteries were also modified. In the first series, small 5 to 10 mm arteriotomies were performed and interrupted 6-0 silk sutures were used, whereas in the second group, arteriotomies were increased to 10 to 15 mm and running sutures using 6-0 polypropylene were substituted. In the first group, aortic anastomoses were fashioned usually after cessation of cardiopulmonary bypass whereas in the second series they were performed during extracorporeal circulation with a fibrillating heart. Following anastomosis to a 1.5 cm vertical slit in the aorta, the right grafts were made to pass over the right atrial appendage close to the marginal border of the heart without looping or kinking. The left-sided grafts were directed upward along the aorta to pass around the main pulmonary artery and were placed to curve downward along the axis of the recipient artery. Formerly the graft extended out from the aorta at a 45° to 90° angle in a direct path to the coronary artery. The graft frequently joined the diseased artery at a 45° to 90° angle.

Various combinations of sequential grafts to multiple coronary arteries were performed in the second series, for instance, a side-to-side anastomosis to the right coronary and end-to-side to a posterolateral branch of the left circumflex, or a side-to-side to a diagonal with an end-to-side to the anterior descending. Endarterectomy was not carried out in either series, but a larger number of patients in the first series had associated internal mammary artery implantation.

Selective coronary arteriography and graft opacification were performed in most cases with preshaped catheters introduced percutaneously in the femoral artery by techniques previously described. When the graft appeared occluded, selective injections were made into the remaining stumps, or a bolus injection was carried out in the ascending aorta, showing the remaining stump or irregularities of the aortic wall at the graft origin where a metal clip had been sutured at the time of operation.

All bypassed arteries had obstructions that reduced the lumen by at least 60 to 75%. A graft was defined in this study as a segment of saphenous vein between two anastomoses, namely a distal anastomosis at a coronary artery, and a proximal anastomosis which could be (a) at the aorta (single or parallel bypass, main segment of a Y bypass, or the first segment of sequential multiple coronary

Table 1

<table>
<thead>
<tr>
<th>Description of the First and Second Consecutive Series of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>From patient number</td>
</tr>
<tr>
<td>From patient number</td>
</tr>
<tr>
<td>Total number of patients</td>
</tr>
<tr>
<td>early death</td>
</tr>
<tr>
<td>not studied at 2 weeks</td>
</tr>
<tr>
<td>Patients evaluated at 2 weeks</td>
</tr>
<tr>
<td>late death</td>
</tr>
<tr>
<td>not studied at one year</td>
</tr>
<tr>
<td>studied at 2 weeks and one year</td>
</tr>
<tr>
<td>Patients evaluated at one year</td>
</tr>
</tbody>
</table>

*One patient not studied at 2 weeks died within the first year.
†Including 9 patients in the first series and one in the second series who had no patent graft at 2 weeks and therefore were not restudied at one year.

Table 2

Incidence of Graft Occlusion or Attrition Rate Noted at Two Weeks, and Observed at One Year in Grafts Which Were Patent at Two Weeks*

<table>
<thead>
<tr>
<th>Type of graft</th>
<th>First series</th>
<th>Second series</th>
<th>( P ) value (X²–Yates)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Studied</td>
<td>Occluded</td>
<td>Attrition (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Studied at 2 weeks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td>134</td>
<td>18</td>
<td>13.4</td>
</tr>
<tr>
<td>Y</td>
<td>48</td>
<td>7</td>
<td>14.6</td>
</tr>
<tr>
<td>Sequential</td>
<td>0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>(side-to-side)</td>
<td>(32)</td>
<td>(1)</td>
<td>3.1</td>
</tr>
<tr>
<td>(end-to-side)</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>182</td>
<td>25</td>
<td>13.7</td>
</tr>
</tbody>
</table>

**Patent grafts at 2 weeks studied at one year**

| Single                              | 95           | 21            | 19                       | 88      | 8        | 9            | \(<0.05\)             |
| Y                                   | 38           | 9             | 23.7                     | 6       | 0        | 0            | NS                    |
| Sequential                          | 0            | —             | —                       | 49      | 2        | 4            | —                     |
| (side-to-side)                      | (26)         | (0)           | 0                       | (23)    | (2)      | 8.7          | —                     |
| (end-to-side)                       |              |               |                         |         |          |              |                      |
| Total                               | 133          | 30            | 22.6                     | 143     | 10       | 7            | \(<0.001\)            |

*Grafts with a single coronary anastomosis (single graft), Y grafts, and sequential grafts are considered separately.
anastomoses bypass), (b) at a saphenous vein (branched segment of a Y bypass), or (c) at another coronary artery (a side-to-side coronary anastomosis of a sequential bypass). A Y bypass was thus considered to have two grafts, and the sequential bypasses had as many grafts as coronary anastomoses. As shown in table 2, single coronary artery bypasses were equally distributed in both series. Few Y bypasses were performed in the second series whereas sequential multiple coronary anastomoses bypasses were used only in the second series. There were 26 bypasses with a side-to-side and end-to-side anastomosis, and six with two side-to-side and end-to-side anastomoses.

At the two week angiographic evaluation, patency or complete obstruction, and stenoses at graft anastomotic sites were identified, as well as complete obstruction of proximal and distal coronary artery segments adjacent to the anastomosis. At the one year study, in addition to the above observations, localized stenosis of the graft itself and diffuse narrowing were recognized, as previously reported.* Localized stenosis was defined as a narrowing over a segment not longer than one third of the graft whereas diffuse narrowing involved more than one third and most frequently the entire length of the graft. Localized and diffuse narrowing reducing the vein lumen by at least 20% were considered significant. Changes in the native circulation other than that of grafted arteries were not considered in this study, although they were reported for the first series.*

The attrition rates at two weeks and at one year were compared in both series and then grafts having flows at operation below 50 ml/min and flows of at least 50 ml/min were studied separately. Flow measurements were carried out in normothermia 10 to 15 min after cessation of cardiopulmonary bypass when the patient's heart rate and blood pressure had stabilized. Electromagnetic flow probes were utilized as previously described.*

Flows were obtained by recording at both limbs of Y grafts and for sequential grafts, by subtracting flows of distal grafts from that measured at the proximal graft. The recording was obtained at sites proximal to each coronary anastomosis whenever feasible. In some cases, particularly for grafts with a side-to-end anastomosis to a circumflex artery, the distal graft was clamped during flow recording of the proximal grafts.

Results

Complete Graft Obstruction at Two Weeks (Early Attrition Rate)

The incidence of complete graft obstruction noted at two weeks did not differ significantly in the two series although a decrease from 13.8% to 8.2% was observed, as shown in table 3. However, early attrition rate had decreased significantly, from 51% to 18.1% (P < 0.01), in grafts having flows below 50 ml/min (fig. 1). In these subsets with flows below 50 ml/min, the average flow in the first series was 34 ± 10, and 32 ± 9 in the second. The attrition rates have remained in the range of 4% to 5.2% in both series for grafts with flows of at least 50 ml/min. Attrition rates were significantly higher in subsets with low flows in both series, 51% versus 4% in the first series (P < 0.005), and 18.1% versus 5.2% in the second (P < 0.025).

As shown in table 2, the early attrition rate for grafts having a single coronary anastomosis was significantly improved in the second series, 6.1% to 13.4% (P < 0.05). The attrition rate of all sequential grafts with side-to-side and end-to-end coronary anastomoses was 9.8%, and it did not differ significantly

![Figure 1](http://circ.ahajournals.org/lookup/suppl/doi:10.1161/01.CIR.32.3.712/-/DC1/fig_1.jpg)

The attrition rate at 2 weeks in grafts with flows of at least 50 ml per min at operation was similar in both series, 3/75 or 4% and 6/115 or 5.2%. It was markedly less in grafts of the second series with flows below 50 ml per min, 8/44 or 18.2% versus 16/31 or 51.6%. Attrition rates were significantly higher in subsets with low flows in both series, 52% versus 4% in the first series, and 18.2% versus 5.2% in the second.

Table 3

<table>
<thead>
<tr>
<th>Type of bypass</th>
<th>Number of grafts</th>
<th>Patency Rate (%)</th>
<th>Number of grafts</th>
<th>Patency Rate (%)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First series</td>
<td></td>
<td>Second series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td>Studied</td>
<td>74</td>
<td>67.3</td>
<td>91</td>
<td>81</td>
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<tr>
<td></td>
<td>Patent</td>
<td>44</td>
<td>65.9</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequential</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(side-to-side)</td>
<td>0</td>
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<td></td>
<td>55</td>
<td>47</td>
</tr>
<tr>
<td>(end-to-side)</td>
<td>0</td>
<td></td>
<td></td>
<td>(26)</td>
<td>(19)</td>
</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>103</td>
<td>66.9</td>
<td>152</td>
<td>133</td>
</tr>
</tbody>
</table>

*Includes grafts of patients who were not reevaluated at one year because all their grafts were obstructed at two weeks (nine in first series, one in second series).

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from that of single grafts ($\chi^2$ [chi square analysis, corrected by Yates' method] = 0.477). Only one graft with a side-to-side anastomosis (belonging to a bypass having two side-to-side coronary links) occluded whereas five grafts with a side-to-end anastomosis failed. It is to be noted also that the attrition rate of Y grafts, which was similar to that of single grafts in the first series, did not significantly change in the second series ($\chi^2 = 0.048$).

Stenoses at Sites of Graft Anastomoses

As shown in figure 2, a stenosis at one of the anastomotic sites was observed in 20 instances in the first series as compared to eight instances in the second, 15% versus 5.5% of patent grafts at two weeks ($P < 0.025$). However, the incidence of stenoses at aortic and coronary sites considered separately was not significantly different in the two series. In grafts with such stenoses in the first series, ten became completely occluded and three severely narrowed (≥90%) at one year whereas only one became occluded in the second series ($P < 0.025$). The degree of narrowing became significantly greater at one year in the first series (Student's paired t-test: $P < 0.001$), but in the second series it remained unchanged in most instances, or it diminished. The decrease or disappearance of the stenosis at anastomotic sites in four cases was due to subsequent narrowing of the graft segment adjacent to the anastomosis resulting in lesser degrees of lumen size differences of graft and anastomosis at one year.

Complete Graft Obstruction at One Year (Late Attrition Rate)

The incidence of complete obstruction occurring sometime between two weeks and one year was markedly less in the second series. As shown in table 2, the late attrition rate dropped from 22.6% to 7% ($P < 0.001$). Late attrition rates in these two series did not differ in grafts having flows of at least 50 ml/min, 8.3% versus 5.3%, but the attrition rate was significantly lower in the second series in grafts with flows below 50 ml/min, 12.9% versus 42.3% ($P < 0.025$). As also shown in figure 3, late attrition in the first series was significantly greater in grafts having a low flow as compared to those with a flow of at least 50 ml/min (42.3% versus 8.3%; $P < 0.001$), but the closure rate did not differ significantly in grafts of the second series with respect to flows (12.9% versus 5.2%). In the low flow group in each series, the average flow was 35.6 ± 7.9 in the first series and 32.6 ± 7.7 in the second. Results were not significantly different in either series with respect to graft flows when stenoses at anastomotic sites were excluded.

Of the 30 grafts occluded at one year in the first series, ten were found at the two week angiographic

The incidence at two weeks and the fate at one year of grafts having a stenosis at anastomotic sites are illustrated. The symbols indicate the anastomotic site, namely the aortic (○), coronary (□), and veins of Y grafts (△). The percentage on the vertical scale indicates the reduction of the lumen. The incidence of stenosis at anastomotic sites decreased from 15% (20/133) to 5.5% (8/143) between the two series. Ten of the 20 grafts of the first series became occluded and three severely narrowed at one year, whereas only one of the eight grafts in the second series showed significant progression ($P < 0.025$).

The attrition rate during the first year in patent grafts at two weeks with flows of at least 50 ml per min did not differ in the two series (8.3% versus 5.3%). It was significantly lower in grafts of the second series with flows below 50 ml per min, 12.9% versus 42.3%. In the first series, late attrition was significantly greater in grafts having a low flow, 42.3% versus 8.3%. The failure rates of low-flow and high-flow grafts did not differ significantly in the second series.

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study to have a stenosis at an anastomotic site whereas only one of the ten completely obstructed grafts in the second series was associated with this early defect. This difference however is not statistically significant ($\chi^2 = 1.04$).

The attrition rate significantly improved in single coronary artery grafts, as shown in table 2, 9% versus 19% ($P < 0.05$). The incidence of complete obstruction at one year in grafts of the second series which were patent at two weeks was 9% for grafts to a single coronary artery (eight out of 88), as compared to 4% (two out of 49) for the sequential grafts to multiple coronary arteries (difference not significant, $\chi^2 = 2.038$). None of the six Y grafts of the second series occluded, whereas a 23.7% attrition rate was noted in the first series, but the difference is not statistically significant ($\chi^2 = 1.799$).

Narrowing of Patent Grafts Noted at One Year

The incidence of localized or segmental stenoses reducing the lumen by at least 20% (excluding stenoses at anastomotic sites) dropped from 34.9% in the first series to 8.4% in the second ($P < 0.0005$). Diffuse narrowing by at least 40% was observed in 31% of grafts in the first series as compared to 12.7% in the second ($P < 0.001$). The frequency distribution of these narrowings is shown in figures 4 and 5. Only three grafts of the first series and one of the second had segmental narrowing reducing the lumen by at least 60%, whereas three in each series had diffuse narrowing of such severity.

At one year, a few grafts showed anastomotic narrowings which were not present at two weeks. This unusual finding cannot be explained; stenoses at anastomotic sites are thought to be related to surgical techniques, and thus, should be observed in the early postoperative period. A 90% stenosis at the coronary anastomosis in a graft of the first series and stenoses of 50% and 90% were observed at the coronary anastomosis of two grafts in the second series at one year. These cases were not included in the above group of grafts having localized stenosis, but they were considered as unsatisfactory grafts.

Complete Obstruction of Grafted Coronary Arteries

Complete obstruction of a grafted artery adjacent to the anastomosis in the presence of a patent graft was observed at two weeks in seven cases of the first series and in nine of the second. The majority of these occlusions involved the distal coronary artery segment: five out of seven in the first series and seven out of nine in the second. These grafts had remained patent and the other segment of the grafted artery was occluded. In one case of the first series and in two cases of the second, grafts to these arteries were occluded by one year. Diffuse graft narrowing reducing the lumen by more than 60% was observed in three cases of the first series and in one case of the second. Grafts to arteries with distal occlusion had remained patent and without severe narrowing ($\geq 60\%$) in two cases of the first series and in four of the second, but they were considered unsatisfactory.

Figure 4

Graft stenoses reducing the lumen between 20% to 40% have decreased from 17% to 2%. The incidence of stenoses $\geq 40\%$ passed from 16.5% to 6%.

Figure 5

The incidence of diffuse narrowing of grafts $\geq 40\%$ decreased from 31% to 12.7%. A shift to the left is noted, with a greater incidence in the second series of grafts having a narrowing $< 40\%$. 

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The only graft to an artery having a proximal segment occlusion (belonging to the first series) was judged adequate.

At one year, complete obstruction of the proximal coronary artery segment adjacent to the anastomosis was observed in one case in each series in the presence of a patent graft. Late occlusion of the distal segment adjacent to the anastomosis was not found in either series when the graft had remained patent.

Occlusion at the site of preoperative stenosis on the proximal coronary artery segment occurred frequently in both series in both patients with occluded grafts and those with patent grafts. It was noted in 31.8% (4/13) of arteries having closed grafts in the first series and in 20% (2/10) of the second. At one year progression to complete obstruction was observed in 35.7% (10/28) of arteries with occluded grafts of the first series, and in 23.1% (3/13) of the second. A similarly high incidence of occlusion at the site of proximal coronary artery stenosis was noted in grafts having patent grafts at one year, 57.7% (34/59) in the first series, and 56% (28/50) in the second. These differences however were not statistically significant.

Of the 25 occluded grafts of the second series at one year, as shown in table 4, occlusion of the distal segment near the anastomosis was present in nine instances. In three of these instances, the stenosis at the proximal segment which existed before surgery had progressed to complete obstruction. Occlusion of the proximal segment near the anastomosis was observed in only one instance. Of the 18 instances in which the status of the grafted artery was known at one year, it had remained unchanged in only eight, 44.4%. (Proximal occlusion or progression to complete obstruction in a pre-existing stenosis may not always have been recognized since visualization of the artery depends on collateral circulation.)

**Status of Grafts at One Year**

The one-year patency rate improved from 66.9% in the first series to 87.5% for the second series (table 3). It should be noted however that 21 of the 25 grafts (84%) which were occluded at two weeks are included in the one-year figures in the first series whereas only nine of the 15 grafts having early occlusion (60%) were restudied in the second series. The cumulative patency, as derived from the patency rates at two weeks and at one year (which is felt more representative), shows a patency rate of 66.8% for the first series and of 85.4% for the second (fig. 6). Grafts having flows of at least 50 ml/min had patency rates of approximately 90% in both series (89.2% and 89.8%). The patency rate rose from 27.8% to 72.9% in grafts having flows below 50 ml/min ($P < 0.0005$).

The status of grafts evaluated at one year, including those of patients who were known to have all their grafts occluded at two weeks and therefore not restudied, is shown in figure 7. Grafts having a narrowing and those with a stenosis at an anastomotic site, reducing the lumen of the anastomosis by at least 60%, were considered unsatisfactory, as were patent grafts associated with an occlusion of distal segment at the site of anastomosis. There were only two instances of these occlusions, which were considered to be related to the surgery, in the first series and four in the second. (Obstructions which appeared in the coronary artery at a distance from the anastomosis were not considered since they were thought to be related to the natural progression of atherosclerosis.) Several of the grafts with either severe stenosis at the anastomotic sites or associated with an occlusion of the distal segment of the grafted coronary artery had

![Figure 6](http://circ.ahajournals.org/)

The cumulative patency rates at one year show an improvement from 66.8% to 85.4% when all grafts are considered. Grafts having flows of at least 50 ml per min had patency rates close to 90% in both series. The patency rate rose from 27.8% to 72.9% in grafts having flows below 50 ml per min.

**Table 4**

<table>
<thead>
<tr>
<th>Prox CA</th>
<th>Unknown</th>
<th>Distal</th>
<th>Prox</th>
<th>Sten-Occl</th>
<th>Unchanged</th>
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<tr>
<td>Ocel(N = 9)</td>
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<td>2</td>
<td>1</td>
<td>--</td>
<td>2</td>
</tr>
<tr>
<td>Sten(N = 16)</td>
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<td>7</td>
<td>0</td>
<td>3*</td>
<td>6</td>
</tr>
<tr>
<td>Total(N = 25)</td>
<td>7</td>
<td>9</td>
<td>1</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

*All 3 with occlusion of distal segment as well.

Abbreviations: Prox CA = proximal coronary artery; Distal = occlusion of distal segment; Prox = occlusion of proximal segment; Sten-Occl = progression of stenosis to occlusion.
Comparison of the status of grafts at one year in both series shows a significant improvement in graft patency, and in relatively intact grafts, i.e., patent grafts without narrowing ≥80% or complete obstruction of the distal segment of grafted arteries adjacent to the anastomotic site.

also developed marked narrowing or had occluded at one year and were included only in these latter categories. Thus, 58.4% of the grafts in the first series were considered satisfactory as compared to 80.2% of the grafts in the second series (P < 0.0005).

Discussion

Aortocoronary saphenous vein graft patency rate has been reported in the range of 64% to 96%. Attrition rates of 5% to 15% were observed during the first months following surgery, and additional 5% to 20% failure rates were noted by the first 12 to 18 months. These wide variations in attrition rates were thought related to case selection for surgery as well as for postoperative follow-up studies. It was accepted that early patency depended primarily on the existence of coronary arteries suitable for grafting, i.e., having a diameter of at least 1.5 mm, being free of significant distal atherosclerosis, and leading to a relatively large vascular bed. Since most of the reported studies were not carried out in consecutive patients, high failure rates have been attributed to the preponderance of patients studied because of recurrent symptoms. In patients evaluated as part of a routine follow-up the patency rate would be expected to be higher. Some workers felt that patency rate reflected the quality of the surgical techniques.

Following our initial studies, we recognized that occlusion appearing early was observed almost exclusively in grafts to arteries having a poor distal runoff, but only one third of the late failures could be explained on that basis. At least half of the grafts which occluded during the first year had shown early alterations at two weeks which appeared related to surgical techniques, such as stenosis at anastomotic sites, kink, or a meeting with the coronary artery at a 45° to 90° angle. Furthermore, the high incidence of segmental and diffuse graft narrowing which did not appear related to a poor coronary artery distal run-off, and which had not been observed frequently in some centers, suggested that surgical techniques might be involved. These alterations appeared to represent an excessive appearance of an expected phenomenon in autogenous vein grafts, namely medial fibrosis and intimal proliferation. This phenomenon had been first described in animals by Carrel in 1906, was subsequently found in saphenous vein femoropopliteal bypasses, and in aortocoronary SVG. It was thought that such a severe hyperplasia could have been related to injury to the vein during its excision and manipulations, or to abnormal pressure-flow conditions in badly designed bypasses. It was recognized that a certain degree of intimal proliferation was inevitable, an "arterialization" phenomenon which was considered an accepted response of a vein subjected to hydraulic and hemodynamic conditions of an arterial system. Occasionally a vein might respond in a hyperactive manner possibly related to characteristics of the vein itself, thus causing severe hyperplasia of the graft.

These considerations prompted modifications of the surgical techniques. Whether the marked improvement which followed was related to these new techniques or simply to improved skill of the surgical team remains an unanswered question. Furthermore, it is not possible to identify which modifications influenced the results obtained in the second series since many variables were introduced in differing combinations. Statistical analysis was often not definitive since the groups compared, particularly the occluded grafts in the second series, were very small.

The significantly lower incidence of stenoses at anastomotic sites in the second series may have led to a lower late attrition rate. As suggested by Sheldon and Grinfeld, contraction of anastomoses, which are most likely due to inadequate surgical techniques, may cause late failure. This association could not be demonstrated clearly in our series. Late occlusion of grafts having anastomotic stenoses at two weeks was found in 50% in the first series, as compared to 10% in the second, but the difference is not significant (χ² = 1.04).

The types of graft did not appear to have influenced the one-year patency rate. As shown in table 3, sequential side-to-side grafts had a 96.5% patency rate at one year, but the difference is not significant when compared with that of single grafts (χ² = 2.484). However no single side-to-side anastomoses occluded; the only side-to-side graft that closed was in a triple bypass procedure, two of which were side-to-side
anastomoses. The other seven instances of sequential graft closure were observed in grafts with end-to-end anastomosis (six with one side-to-side and one with two side-to-side). The patency rate at one year for all sequential grafts, including both side-to-side and end-to-side anastomoses, did not differ significantly from that of single grafts, 85.5% versus 89% ($\chi^2 = 0.798$). No difference is observed in patency rates of Y grafts and single grafts, although the number of Y grafts may be too small for reliable statistical analysis. Y grafts have been found to occlude more frequently by Walker et al.15 The smaller number of Y grafts and the introduction of sequential grafts in the second series do not seem to explain the improved graft patency. Indeed, the patency rate at one year was significantly improved in grafts with a single coronary anastomosis, 67.3% to 89% ($P < 0.0005$), suggesting that factors other than the types of graft were involved. This improvement reflects lower early and late attrition rates in the second series for these single grafts.

The use of saphenous veins having a smaller diameter may also prevent some graft failures since it is known that velocity is inversely proportional to the cross-section of the conduit.28

The decreased early and late attrition rates in grafts with low flows measured at surgery suggests that a possible selection bias toward cases with better distal coronary artery run-off was not a significant factor in the improved graft patency in the second series. It is recognized however that graft flow reflects the integrity of the graft, its anastomoses, as well as the distal run-off. Indeed, inadequate grafts and contracted anastomoses related to technical faults may not have been recognized in occluded grafts at two weeks and these factors rather than poor distal runoff documented prior to surgery may have caused early graft failure. Among patent grafts at two weeks, a significant improvement in late attrition was observed in grafts with low flows, even when low flows due to poor distal run-off were analyzed alone, eliminating grafts in which anastomotic stenosis might have caused low flow. As shown in figure 6, the one-year patency rate was approximately 90% in both series for grafts having flows of at least 50 ml/min, suggesting that the fate of technically sound grafts to arteries having adequate distal run-off has been satisfactory from the onset of our experience and has not been changed by modifications of surgical techniques. It is apparent that the marked improvement in patency in the second series was due to the lower failure rate of grafts having flows below 50 ml/min, and improvement in this group may well be related to better surgical techniques. This raises the likelihood that grafts to arteries with a poor distal run-off may remain patent in a high percentage of instances, provided surgical techniques are optimal, as previously suggested by Walker et al.15 The failure rate in such cases remains relatively high, however, and grafting arteries with inadequate distal segments is still questionable.

The improved attrition rate in grafts with low flows, the lack of progression to stenosis at anastomotic sites, and the lower incidence of graft narrowing all suggest decreased endothelial hyperplasia which may have been related to modifications of surgical techniques involving the excision and manipulation of the vein, although changes in flow-pressure characteristics related to the designs of the bypasses cannot be disregarded.4, 6

Deleterious changes in the native circulation which appear to result from this surgery, such as occlusion of proximal and distal segments, are frequently observed in arteries with occluded grafts. Indeed, only 44% of such arteries in the second series have not deteriorated. Complete obstruction at the site of a pre-existing stenosis in the proximal segment, a change most likely related to surgery, is observed in approximately one-third of arteries having closed grafts at one year. These changes, which may have serious pathological repercussions, suggest that only arteries having a good distal run-off and therefore the lowest risk of graft closure4 should be considered for saphenous vein bypass. In arteries having patent grafts, occlusion of the distal segment has not been observed frequently in either series. Progression of proximal coronary artery stenosis to occlusion, which was found to occur in over 50% of arteries having patent grafts at one year, appears however to have no clinical consequence.7, 29-31 In view of these considerations, a high graft patency rate is desirable in order to minimize the harmful side effects of this surgery in addition to favor its success. Graft patency at one year of 85% appears satisfactory, and previous reports have shown that it tends to remain at that level or decrease slightly over the subsequent three to four years.11, 16, 32 It is gratifying to note that 95.5% of patients of this second series (64/67) had at least one patent and satisfactory graft at one year.

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