Status of the Grafts and the Native Coronary Arteries Proximal and Distal to Coronary Anastomotic Sites of Aortocoronary Bypass Grafts

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SUMMARY The status of the native coronary arteries at necropsy in the vicinity of the coronary anastomoses of saphenous vein aortocoronary bypass grafts in 20 patients with severe coronary heart disease is presented. Of the 37 graft systems (graft plus coronary artery into which graft inserted) analyzed, the lumina of 44% of the native coronary arteries within the first 2 cm distal to the anastomoses were greater than 75% narrowed in cross-sectional area by atherosclerotic plaques, and the native coronary artery at the site of the anastomosis was greater than 50% narrowed in cross-sectional area already by atherosclerotic plaque in 25% of the graft systems. The mean coronary arterial size distal to the site of the coronary graft anastomosis, even after correction for heart weight, was greater in the 13 men than in the seven women. The residual luminal areas squared per gram of heart weight, however, were similar in both men and women. These results suggest that 1) relative coronary vessel size is greater in men than women; 2) the luminal area squared per gram myocardial mass (a relative estimation of flow) is the same in the two groups of patients; and 3) less atherosclerotic plaque is necessary in women than in men to produce similar limitation to coronary flow. Thus, vessel size alone cannot account for the higher reported frequency of unsuccessful aortocoronary bypass procedures in women.

ALTHOUGH SEVERAL REPORTS have described morphologic observations in bypass grafts and in native coronary arteries of patients who had died shortly after aortocoronary bypass procedures, only one focused on the status of the native coronary arteries at, proximal, and distal to the anastomoses of the conduits.

The present report describes the status of the native coronary arteries in the vicinity of the coronary anastomoses in 20 patients (37 grafts) who died shortly after insertion of one or more saphenous vein conduits between ascending aorta and coronary artery.

Materials and Methods

Only patients in whom the major extramural coronary arteries were well preserved were included. Of the 20 patients, 13 were men aged 34 to 59 years (mean, 49) and seven were women, aged 32 to 73 years (mean, 52). All 20 patients preoperatively had severe angina pectoris (stable in five, unstable in 15) and five had histories of acute myocardial infarcts which had healed. By coronary angiography, all 20 patients had severe (judged to be greater than 75% reduction in luminal diameter) narrowing of two or more of the major extramural coronary arteries. Three of the 20 patients also had associated valvular heart disease: one underwent replacement of the mitral valve; one of the aortic valve; and one of both mitral and aortic valves. Clinical evidence of preoperative congestive cardiac failure was present in only three patients, two of the three with associated valvular heart disease (aortic valve, and aortic and mitral valve) and one patient with associated left ventricular aneurysm. By left ventricular angiography, 18 of the 20 patients had well-contracting left ventricles. One patient had localized dyskinesia and one had diffuse hypokinesia and ventricular aneurysm. Of the 20 patients, 15 died within 24 hours and the other five, from four to 56 days after operation. The heart weights ranged from 300 to 700 g, an average of 412 in the women and 447 in the men.

Each specimen was divided for analysis into "graft systems" defined as the vein graft and the entire extramural coronary artery both proximal and distal to the coronary anastomosis. A total of 37 graft systems were available for study: 25 (68%) in men, and 12 (32%) in women. After fixation, each graft system (graft plus coronary artery) was sectioned at 5 mm intervals at right angles to its longitudinal axis. Each 5 mm segment was processed in alcohols and xylene, embedded in paraffin, cut and stained. At least two sections from each 5 mm segment were examined microscopically.

Each graft system was divided into six segments (fig. 1): 1) 2 cm portion of coronary artery immediately distal to the anastomosis (segment 1); 2) the remaining portion of coronary artery distal to segment 1 (segment 2); 3) 2 cm portion of coronary artery immediately proximal to the graft anastomosis (segment 3); 4) the remaining coronary artery proximal to segment 3 (segment 4); 5) the anastomotic site of the graft to the coronary artery (segment 5); and 6) the entire vein graft (segment 6).

Determining the Size of the Coronary Arteries

The size of the coronary artery in segment 1 of each graft system was determined by planimetry. The smallest of the four sections in this 2 cm segment was measured. Each section was stained by Movat's pentachrome method which clearly delineates the artery's internal elastic membrane. The circumferences of both the internal elastic membrane and the lumen were traced after projection at known magnification (fig. 2). Where the internal elastic membrane was artificially indented or in areas of atherosclerotic plaque where the membrane was fragmented, extrapolation to a circular lumen was performed (fig. 2). Planimetry (KE compensating polar planimeter) was carried out on each tracing, yielding the area contained by the internal elastic membrane and the

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area contained by the lumen. The area contained by the internal elastic membrane was considered the artery's normal size, and this measurement was used to compare the original size of one vessel to that of another. Percent luminal narrowing by plaque was determined from these calculations in segment 1. The percent luminal narrowing in segments 2-6 was estimated from study by light microscopy of the section of each segment showing the most cross-sectional luminal narrowing and graded as < 25%, 25-50%, 51-75%, and > 75%. In segment 5, where the graft anastomosis distorted the lumen of the native coronary vessel, percent luminal narrowing was estimated after extrapolation to a closed, circular lumen.

**Results**

The findings of coronary artery narrowings are summarized in table 1.

**Segment 1**

This segment was greater than 75% narrowed in cross-sectional area in 16 (44%) of 36 graft systems analyzed (fig. 3); in 46% of those in men and in 42% of those in women. This segment in another 11 graft systems (10 in men) was narrowed 51-75%. Thus, in 88% of the graft systems in men and in 50% in women, this segment was greater than 50% narrowed (fig. 4). Only two (6%) of the 36 graft systems showed less than 25% narrowing in this segment. In seven of the 16 (44%) graft systems with greater than 75% narrowing
in this segment, less than 75% narrowing was present in the remaining distal coronary artery (segment 2).

Segment 2

This segment was greater than 75% narrowed in eight (24%) of 33 graft systems analyzed; in five (22%) of 23 graft systems in men and in three of ten graft systems in women. In only two patients was this segment 51 to 75% narrowed. Thus, in only 30% (10 of 33) of the graft systems was this segment greater than 50% narrowed.

Table 1. Percent and Location of Narrowings of Native Coronaries Containing a Bypass Graft

<table>
<thead>
<tr>
<th>Segment 1 (first 2 cm distal to anastomosis)</th>
<th>&lt;25%</th>
<th>25-50%</th>
<th>51-75%</th>
<th>&gt;75%</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>1 (4)</td>
<td>2 (8)</td>
<td>10 (42)</td>
<td>11 (46)</td>
<td>24</td>
</tr>
<tr>
<td>Women</td>
<td>1 (8)</td>
<td>5 (42)</td>
<td>1 (8)</td>
<td>5 (42)</td>
<td>12</td>
</tr>
<tr>
<td>Totals</td>
<td>2 (6)</td>
<td>7 (19)</td>
<td>11 (31)</td>
<td>16 (44)</td>
<td>36</td>
</tr>
<tr>
<td>Segment 2 (distal to segment 1)</td>
<td>Men</td>
<td>10 (43)</td>
<td>6 (26)</td>
<td>2 (9)</td>
<td>5 (22)</td>
</tr>
<tr>
<td>Women</td>
<td>5 (50)</td>
<td>2 (20)</td>
<td>0 (0)</td>
<td>3 (30)</td>
<td>10</td>
</tr>
<tr>
<td>Totals</td>
<td>15 (46)</td>
<td>8 (24)</td>
<td>2 (6)</td>
<td>8 (24)</td>
<td>33</td>
</tr>
<tr>
<td>Segment 3 (immediately proximal to anastomosis)</td>
<td>Men</td>
<td>3 (12.5)</td>
<td>3 (12.5)</td>
<td>4 (17)</td>
<td>14 (58)</td>
</tr>
<tr>
<td>Women</td>
<td>2 (17)</td>
<td>1 (8)</td>
<td>2 (17)</td>
<td>7 (58)</td>
<td>12</td>
</tr>
<tr>
<td>Totals</td>
<td>5 (14)</td>
<td>4 (11)</td>
<td>6 (17)</td>
<td>21 (58)</td>
<td>36</td>
</tr>
<tr>
<td>Segment 4 (most proximal portion)</td>
<td>Men</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>7 (28)</td>
<td>18 (72)</td>
</tr>
<tr>
<td>Women</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>3 (25)</td>
<td>9 (75)</td>
<td>12</td>
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<tr>
<td>Totals</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>10 (27)</td>
<td>27 (73)</td>
<td>37</td>
</tr>
<tr>
<td>Segment 5 (at anastomosis)</td>
<td>Men</td>
<td>7 (32)</td>
<td>10 (45)</td>
<td>4 (18)</td>
<td>1 (5)</td>
</tr>
<tr>
<td>Women</td>
<td>6 (55)</td>
<td>2 (18)</td>
<td>3 (27)</td>
<td>0 (0)</td>
<td>21</td>
</tr>
<tr>
<td>Totals</td>
<td>13 (39)</td>
<td>12 (36)</td>
<td>7 (21)</td>
<td>1 (4)</td>
<td>33</td>
</tr>
</tbody>
</table>

Figure 3. Severe obstruction of coronary artery distal to the site of insertion of a vein bypass graft in a 40-year-old woman (A74-212) who could not be weaned from cardiopulmonary bypass after 3-vessel vein grafting. a) Anterior view of heart showing anastomosis of vein graft to the left anterior descending coronary artery (LAD). b) LAD at approximate area shown by arrow in a. Severe narrowing of the vessel (segment 1) is seen. b) Movat stain X 22.

Figure 4. Narrowing of coronary artery distal to insertion of vein graft in a 50-year-old man (MHCMH — 4961) who died less than 24 hours after triple vessel bypass grafting. a) Section of the anastomosis of the vein graft to the left anterior descending coronary artery (c.a.) at the site of considerable narrowing by atherosclerotic plaque (p). b) Coronary artery section distal to the anastomosis showing significant narrowing by plaque. Movat stains, X 11 (a and b).
FIGURE 5. Insertion of vein graft at site of plaque in a 46-year-old man (NA75–107) who died 24 hours after insertion of three grafts. a) The vein graft to the right coronary artery is large in relation to the coronary artery into which it inserts. A large atherosclerotic plaque is present at the anastomosis. Postmortem clot present in lumen was eliminated by retouching. b) Right coronary artery just proximal to the anastomosis in a showing hemorrhage into the plaque and fibrin deposition on its luminal surface. c) High power view of lumen of b, showing fibrin deposition on the luminal surface. Movat stains × 22.6 (a), × 40 (b), × 184 (c).

Segment 3
This segment was greater than 75% narrowed in 21 (58%) of 36 systems analyzed, 51 to 75% narrowed in six (17%), and less than 50% narrowed in nine (25%). The degree of narrowing of this segment was similar in both men and women.

Segment 4
This segment was greater than 75% narrowed in 27 (73%) and 51–75% narrowed in 10 (27%) of 37 graft systems analyzed. The degree of narrowing was similar in both men and women.

FIGURE 6. Anastomosis of vein graft at plaque (segment 5). a) Anastomosis of vein graft to the proximal right coronary artery in a man (A75–279) who died shortly after operation. Significant narrowing of the coronary artery by plaque (p) at the site of insertion of the graft is seen. b) Dissection of atherosclerotic plaque from coronary wall at the anastomosis of the vein graft to the posterior descending coronary artery in the same patient. The dissection extended for 2 cm proximal to the anastomosis. Movat stains: × 11 (a), × 16 (b).
Coronary Bypass Grafts/Spray, Roberts

Figure 7. Graft thrombosis and intimal fibrous proliferation (IFP) extending into the coronary artery at the site of vein graft anastomosis in a man (PHWT A73-28) who died suddenly 34 days after bypass grafting to the right coronary artery. a) Anastomosis of vein graft to aortic wall, showing intimal proliferation of the vein and adventitial fibrosis extending from the aorta over the exterior of the graft. b) Section taken at the venocoronary anastomosis (Segment 5) showing antemortem thrombosis of the vein graft extending into the coronary artery (CA). c) Higher power view of area enclosed by box in b showing moderate IFP of the vein with extension across the suture line (s) into the coronary artery. d) Section of the coronary artery distal to the anastomosis of the graft showing marked narrowing by plaque and fibrous tissue. Movat stains; ×13 (a), ×11 (b), ×31 (c) ×12 (d).

Segment 5

This segment was greater than 75% narrowed in one (3%), 51–75% narrowed in seven (21%), and less than 50% narrowed in 25 (76%) of 33 graft systems analyzed (figs. 5 and 6).

Segment 6

Of the 37 grafts, 2 (5%) were totally occluded by thrombus (fig. 7); 10 others had mural fibrin deposits (figs. 8 and 9). In 9 of these 12 graft systems, fibrin thrombus also was present in the coronary artery at the anastomosis (table 2), and in 4, the coronary arteries proximal to the graft anastomoses contained fibrin thrombi (fig. 10).

Dissection of Native Coronary Artery at or Near Graft Anastomosis

Dissection occurred in five (14%) of the 37 graft systems. The dissection was confined to the artery within 2 cm of the anastomosis in four graft systems (fig. 6), and in the fifth, it was 8 cm long (fig. 11). In two additional graft systems, the atherosclerotic plaque opposite the site of vein anastomosis was separated from the medial wall (fig. 12). If these two graft systems are included, then disruption of the coronary artery at the anastomosis due to technical factors occurred in seven (19%) of 37 graft systems.

Table 2. Fibrin Present on Walls

<table>
<thead>
<tr>
<th></th>
<th>Graft No. (%)</th>
<th>Coronary No. (%)</th>
<th>Total Grafts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>6 (24)</td>
<td>8 (32)</td>
<td>25</td>
</tr>
<tr>
<td>Females</td>
<td>4 (33)</td>
<td>1 (8)</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>10 (27)</td>
<td>9 (24)</td>
<td>37</td>
</tr>
</tbody>
</table>
FIGURE 8. Muralt fibrin deposition in a 4-day-old vein graft to the left anterior descending coronary artery (cor. art.) in a woman (A75-109). a) Thick fibrin layers are present on the vein wall at the coronary anastomosis. b) Higher power view of area enclosed by box in a. Deposits of fibrin line the lumen of the vein graft. Movat stain: × 16 (a) × 54 (b). Retouched to eliminate artifactual postmortem clot in lumen.

Size of Coronary Artery Distal to the Anastomosis

Comparison of the areas contained by the internal elastic membrane in the smallest section of the coronary artery

within 2 cm distal to the vein graft anastomosis in the 22 graft systems in men and in the 12 graft systems in women is plotted in figure 13. Three graft systems (all in men) were excluded from these comparisons because the grafts were anastomosed to the proximal portions of the coronary arteries and could not be compared with the other 34 grafts which were inserted at, or distal to, the middle portion of the

FIGURE 9. Subendothelial fibrin in a 56-day-old vein bypass graft (male patient). Marked intimal fibrous proliferation (IFP) is present and the smooth muscle in the media is diminished. Phosphotungstic acid-hematoxylin stain; × 54.

FIGURE 10. Thrombosis of the coronary artery proximal (segment 3) to the site of insertion of a vein bypass graft in a man. Left) Diagram showing appearance of histologic sections taken below (A.), above (C.) and at (B.) the level of the venocoronary anastomosis. Right) Section of coronary artery (cor.) and thrombosed vein graft taken at level shown in C on left. Large amounts of atherosclerotic plaque (p) are present in the proximal artery, and the residual lumen is filled with thrombus. Movat stain, × 11.
CORONARY BYPASS GRAFTS/Spray, Roberts

Mean cross-sectional area of the arteries in men was \(202 \times 10^{-4} \text{ cm}^2\), and in women, \(124 \times 10^{-4} \text{ cm}^2\); mean area of the residual lumens was \(63 \times 10^{-4} \text{ cm}^2\) in men and \(55 \times 10^{-4} \text{ cm}^2\) in women (fig. 13). This difference in mean arterial size between men and women cannot be explained by differences in mean heart weights. When the original arterial areas are divided by the cardiac weights for each graft system, the mean values (all \(\times 10^{-4} \text{ cm}^2/\text{g}\)) were 0.417 in men and 0.316 in women. Luminal size, however, was almost identical in men and women, 0.133 vs 0.131 (\(\times 10^{-2} \text{ cm}^2/\text{g}\)).

In order to compare the data in men and women on the basis of coronary flow rather than cross-sectional area, the areas of the internal elastic membranes and lumens were squared. This calculation expresses the data in terms of radius to the fourth power (Poiseuille's equation for flow of a

**FIGURE 11.** Coronary artery dissection in the left circumflex coronary artery after bypass grafting in a woman who died shortly after operation (A72-209). a) Anastomosis of the vein graft to the coronary artery showing entrance site of the dissection. The media of the coronary artery and the associated atherosclerotic plaque (p) are separated from the adventitia by the false lumen (D). b) Circumflex coronary artery distal to insertion of the vein graft. The dissection has progressed distally, causing some narrowing of the lumen. Movat stains; \(\times 38\) (a), \(\times 44\) (b).

**FIGURE 12.** Minimal dissection of the coronary artery immediately beneath the anastomosis in a 4-day-old bypass graft in a woman (A75-109). Incision of the posterior wall of the artery at the time of arteriotomy is the most likely cause of this localized dissection. Fibrin deposition on the vein wall is present. S = suture. Phosphotungstic acid = hematoxylin stain, \(\times 39\). Retouched to eliminate luminal postmortem artifact.

**FIGURE 13.** Plot of the area contained by the internal elastic membrane and lumen in the most narrowed section of coronary artery within 2 cm distal to the aortocoronary anastomosis in men and women. The mean area of the internal elastic membrane in the men is larger than that in the women.
Newtonian fluid through a nondistensible cylinder) rather than radius squared (area); results were then divided by heart weights and are listed in table 3. The relative arterial sizes (expressed as area²) between men and women remained significantly different after correction for differences in heart weight, but the luminal sizes (area²) were similar, suggesting similar limitation to coronary flow in the two groups.

**Comments**

A high (44%) frequency of significant (> 75%) coronary arterial luminal narrowing by atherosclerotic plaque was found distal to the site of graft insertion in the 37 graft systems studied histologically in our 20 patients. The distal obstructions were due solely to atherosclerotic plaques. Thus, in nearly one-half of the graft systems studied, the bypass grafts failed to bypass significant obstructions. This result suggests that either the grafts were not placed far enough distally or that angiography failed to demonstrate the more distal narrowings or both. Since 44% of the native coronaries which were greater than 75% narrowed within 2 cm distal to the graft anastomosis were less than 75%

narrowed in the remaining coronary artery, placement of the graft more distally would have bypassed significant obstructions in these patients, assuming that such anastomoses had been technically feasible. Comparison of men to women in this study disclosed similar degrees of maximal cross-sectional luminal narrowing by atherosclerotic plaques in all segments studied in each group. The mean coronary arterial size, however, was smaller in the women than in the men. This difference was not explained entirely on the basis of differences in heart weights between the sexes. Residual coronary arterial luminal area squared (which can be taken as a measure of outflow of the graft system), however, was almost identical in men and women after correction for heart weight. Thus, less atherosclerotic narrowing is required to produce a given limitation to blood flow in women than in men

![Figure 14. Diagrammatic comparison of heart weight and coronary arterial parameters in normal adult men and women (above) and in men and women with atherosclerotic coronary heart disease (below) who died soon after aortocoronary bypass surgery.](http://circ.ahajournals.org/)

**TABLE 3. Coronary Size Expressed As Area²/Heart Weight**

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal elastic membrane</td>
<td>106.7 ± 22.2</td>
<td>47.1 ± 12.1</td>
</tr>
<tr>
<td>Lumen</td>
<td>11.6 ± 3.1</td>
<td>9.2 ± 2.7</td>
</tr>
</tbody>
</table>

*Mean ± SEM X 10⁴ cm²/g.
**Student's t-test.
anastomosis was created at a site of moderately severe atherosclerotic narrowing. The presence of such plaque at the site of anastomosis was common: greater than 50% narrowing at this location occurred in about 25% of the graft systems studied.

The presence of fibrin deposits on the walls of both grafts and adjacent coronary arteries in many patients may be related to injury to the vessel walls by high flow or “jet” lesions or to relative stasis of blood in these graft systems. If similar deposits occur in successful grafts, organization of the fibrin deposits may result in luminal narrowing of the graft, or increases in the degree of narrowing of the coronary artery at or distal to the anastomoses.

Thrombosis in our patients was occasionally present in the portion of the coronary artery proximal to the graft. In this location, it presumably is the result of relative stasis caused by competitive blood flow due to stenosis in the upstream coronary artery.

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