Direct and Indirect Coronary Surgery

By René Favaloro, M.D.

DRAMATIC developments have marked the progress of operative technics devised to treat coronary artery disease since the first selective cinearteriographic study was performed in October, 1958, by Sones at the Cardiac Laboratory of the Cleveland Clinic.1

Selective coronary cineangiography can precisely demonstrate the degree of obstruction, the exact location and distribution, and also the presence of collateral circulation within a lumen diameter of 100 μ or larger. The data obtained with this method are the basis on which the surgeon selects not only the patient for whom surgical revascularization is appropriate, but also the specific surgical technic. Another advantage of coronary cineangiography is that it is the basis for evaluating the results of revascularization surgery, even though there is some correlation between the clinical postoperative evaluation and the angiographic findings.

Surgical treatment of coronary artery disease can be classified into three different groups: (a) direct myocardial revascularization, (b) indirect myocardial revascularization, and (c) resection of scar tissue or ventricular aneurysm on the left ventricle

Direct Myocardial Revascularization

Early in 1962, the Cleveland Clinic team attempted to perform true endarterectomies. Nevertheless, the mortality rate was extremely high, due mainly to dissection of the distal portion of the coronary circulation or occlusion of important side branches, and the procedure was abandoned.

The next method used was the pericardial patch-graft reconstruction. A longitudinal incision was made at the site of the obstruction precisely located by reviewing carefully the preoperative coronary cineangiography. A patch was sewn with fine 6-0 silk, generally with running sutures at both sides and interrupted sutures at the proximal and distal ends. There was low operative mortality among patients who underwent operation on the right coronary artery. On the other hand, among patients who submitted to operation on the left coronary artery, mainly because of the anatomic position of the artery, the mortality was extremely high (65%). Of the 163 patients who were operated upon, approximately 60% benefited and showed no obstruction anywhere in the reconstruction. In about 20% of cases the results were poor because of undue diminution of the lumen, and approximately 20% of the patches were closed.

In May, 1967, the saphenous vein graft technic in direct coronary artery reconstruction was introduced at the Cleveland Clinic.2, 3 Careful analysis of patients who previously underwent pericardial patch-graft reconstruction led us to consider the possibility of utilizing the saphenous vein graft technic, predicated on its successful use for several years in peripheral vascular and renal artery reconstruction.

Initially we started with an interposed graft technic. The segment of the coronary vessel was resected and was replaced by two end-to-end anastomoses, with a segment of the saphenous vein obtained from the same patient when the femoral artery was exposed for cannulation. In patients with proximal obstruction it was realized that it was impossible to apply this technic, and the bypass approach was utilized early. Among the first 15 patients operated upon two were bypasses from the anterolateral wall of the aorta. At present, only bypasses are performed, and rarely are interpositions used in localized segmental obstruction in the right coronary artery.

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Operative Technic

The vein is obtained from the patient's groin through the same incision used to expose the femoral artery for cannulation. The incision is extended to the uppermost segment of the thigh so that an adequate length can be excised. When the diameter of the saphenous vein is too large, another small incision can be made in mid-thigh, and even below the knee, to obtain a segment of lesser diameter. At present we are using the distal segment of the saphenous vein more and more. The dissection should be done very carefully in order to avoid injury to the vein. The segment of the vein must always be reversed when grafted to avoid impairment of blood flow by valves that may be present. The distal anastomosis may be performed end-to-end or end-to-side. The end-to-end anastomosis is very seldom used at present, and is only used on the right coronary artery when the artery is totally occluded.

The end-to-side anastomosis is most commonly used at the present time. We do not generally dissect the artery from the surrounding epicardium and subepicardial fat in the left coronary artery distribution (anterior descending and circumflex branches). This has been a significant improvement of the technic. After the lumen has been entered on the coronary artery, the incision is elongated and the anastomosis is performed utilizing interrupted 6-0 silk sutures placed at the arteriotomy site and kept in place in the operative field by individual mosquito clamps. Then, after the saphenous vein stump has been prepared, the anastomosis always starts at the proximal segment of the arteriotomy, and the sutures are passed one by one on the venous stump. In recent work with small arteries, I have found that most anastomoses are in arteries about 2 mm in diameter, and I am quite convinced that the interrupted suture offers the best result. Nevertheless, when the lumen is appropriate, running sutures can be used. All the distal anastomoses are performed first with the patients on total cardiopulmonary bypass, induced electrical fibrillation, and intermittent cross clamping of the aorta. To accomplish the proximal anastomosis a partial aortic clamp is applied to the lower portion of the ascending aorta. An opening is made by a triangular resection, with the base on the bottom for grafting to the right coronary artery, or facing the pulmonary artery for grafting to the left coronary artery. The anastomosis is made with 6-0 Ethiflex running sutures. As previously mentioned, the proximal anastomosis is done at the end of the operation, with the heart beating on partial bypass, or with the bypass circulation already stopped.

Operations are performed through a midline transsternal thoracotomy for all the varieties, with the patient heparinized, cannulated, and attached to the heart-lung machine.

Elective cardiac arrest is accomplished with the AC fibrillator, and cross clamping of the aorta for 15–20 min (ample time to perform the anastomosis) is done in most patients. A left ventricular vent is routinely used when bypasses are performed in the left circumflex coronary artery distribution. Full decompression of the left ventricle and induced fibrillation allow us to expose any area in the circumflex coronary artery.

Indications for Saphenous Vein Graft

Direct myocardial revascularization by the saphenous vein graft is primarily indicated in patients with severe segmental occlusion or totally occluded vessels, with good distal runoff (obstruction less than 50%) that is visualized directly or indirectly by collateral circulation. At present, grafts can be performed anywhere in the coronary circulation: right coronary artery, diaphragmatic portion of the right coronary artery, bifurcation of the right coronary, atrioventricular branch of the right coronary artery, posterior descending branch of the right coronary artery, main left coronary artery, diagonal branches of the anterior descending coronary artery, main circumflex coronary artery, lateral branches of the circumflex coronary artery, and diaphragmatic distribution of the circumflex coronary artery (figs. 1–4).

The ideal patient shows severe coronary artery disease, yet the left ventricular muscle is intact. A routine left ventriculogram will show good contraction of the entire left ventricle. However, this occurs in approximately 50–60% of the patients; the rest will show changes that range from small areas of localized scar tissue to totally impaired left ventricular contraction.

Operations in this last category involve an increased operative risk. Nevertheless, significant improvements can be demonstrated in a very important percentage of cases by a repeated left ventriculogram and hemodynamic studies. Another indication for the saphenous vein graft operation is evidence of acute coronary insufficiency. Acute coronary insufficiency can be classified into: (1) impending...
myocardial infarction, (2) myocardial infarction without cardiogenic shock, and (3) myocardial infarction with cardiogenic shock. Patients in the first category should be immediately studied by means of selective coronary cineangiography, and the saphenous vein graft should be performed as an emergency operation in order to prevent myocardial infarction. Following this idea, we have been able to operate on 65 patients with severe, prolonged chest pain in whom emergency coronary cineangiography was performed and was immediately followed by operation. All of the patients except four tolerated the operation without complications and were discharged from the hospital in excellent condition.

In the second group it was possible to demonstrate that emergency cinecoronary angiography could be performed in the middle of an acute myocardial infarction without increasing the risk. The visualization of the coronary artery tree allows us to carefully evaluate the possibility of direct operation to increase myocardial perfusion. If the operation can be performed within 6 hours of the acute episode, the majority of the infarcted area can be recuperated. Nevertheless, we do not as yet have a significant clinical experience to obtain a definite conclusion, and this is a subject open to discussion.

Patients in the last category account for approximately one third of the deaths from acute coronary insufficiency which occur annually in the United States. The actual medical treatment in acute myocardial infarction with cardiogenic shock presents a mortality rate between 80 and 100%. In such patients assisted circulatory support by any of the presently available methods should be applied in order to improve myocardial function and allow better generalized perfusion. Emergency cinecoronary angiography can be performed immediately after the patient has been stabilized by assisted circulation. After careful examination of the cinecoronary angiogram some patients will be candidates for resection of the infarcted area and immediate revascularization with the saphenous vein graft technique.
The experience already accumulated at the Massachusetts General Hospital demonstrates that the combined medical and surgical treatment with the utilization of assisted circulation can ameliorate the devastating results among patients with myocardial infarction and cardiogenic shock.

**Mortality: Follow-up**

From May, 1967, to October 30, 1970, 1697 saphenous vein grafts were performed at the Cleveland Clinic Hospital. The overall hospital mortality rate was 3.5%. It is interesting to note that the operation has been combined in approximately 20% of the cases with single and double internal mammary implantations, and also with aortic and mitral valve replacements. In approximately 15% of the cases reconstruction of the left ventricle has been done due to the presence of significant scar tissue, either on the anterolateral or diaphragmatic wall of the left ventricle. The late follow-up, as seen in table 1, has shown that approximately 81% of the grafts remained open. The great majority of the studies have been done within 6 months and 4 years after the operation. To date no dilatation of the saphenous vein graft has been seen, and there have been only a few cases of late thrombosis among patients who initially had vein grafts angiographically visible.

**Indirect Myocardial Revascularization**

This technic began at the Cleveland Clinic in January, 1962, following Vineberg's technic.

| Table 1

<table>
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<tr>
<th>Grafts</th>
<th>Pt (no.)</th>
<th>Grafts (no.)</th>
<th>Open (no.)</th>
<th>Occlusions (no.)</th>
<th>Open (%)</th>
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<td>440</td>
<td>354</td>
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<td>Ant desc</td>
<td>267</td>
<td>270</td>
<td>222</td>
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<td>109</td>
<td>86</td>
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<td>79</td>
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<td>Total</td>
<td>656</td>
<td>819</td>
<td>662</td>
<td>157</td>
<td>81</td>
</tr>
</tbody>
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Abbreviations: RA = right artery; Ant desc = anterior descending artery.

*819 grafts in 656 patients until January 9, 1971: 523 patients with single graft; 133 patients with multiple graft.
CORONARY SURGERY

Figure 3
Saphenous vein graft (arrow) to the circumflex coronary artery.

It was limited to patients with left anterior descending involvement and no history of myocardial infarctions. In July, 1966, I was able to expose and implant both mammary arteries through a midline incision. Post-operatively, the angiographic studies showed for the first time that entire revascularization of the left ventricle was accomplished.

Technic

The initial cases were done through a left thoracotomy, and the artery was dissected according to Vineberg's technic. Since 1963 the operation has been done following the Sewell pedicle procedure. The advantages of this technic were the shorter time it took to accomplish the dissection and the high percentage of patent arteries. However, since the tunnel was made with a bistoury blade there was an increased risk of myocardial damage. Early in 1966 I combined both technics by dissecting the artery as a pedicle and trimming the distal end for implantation; I was able to make a small tunnel and to get better results.

Today we perform this operation through a midline incision, which gives us better exposure, and by using the self-retaining retractor designed for this purpose. The tunnel itself is made with a special tunneling instrument with the proper angulation. When the implantation is to be performed for the anterior descending branch of the left coronary artery, a tunnel is made parallel to the main anterior descending coronary artery, across and beneath lateral and diagonal branches of the anterior descending coronary artery. The mammary implant is seldom placed underneath the main anterior descending coronary artery for fear of entering the right ventricle. When the implantation is indicated for the circumflex coronary artery a long tunnel is made across and beneath its lateral and posterior diaphragmatic branches. Occasionally, and when necessary, two tunnels in tandem can be created underneath the distal distribution of both right coronary and circumflex arteries.

Indications

At present the implantation surgery is indicated when: (1) diffuse and severe disease (over 90% obstruction) has been visualized with cinecoronary angiogram with poor runoff (obstruction more than 50%); (2) left ventricular muscle is within normal level or there is minimal fibrosis; (3) collateral circulation is present. In general, the indirect approach is utilized as a complement of the
direct approach with the saphenous vein graft bypass. In the last 2 years I have only performed five operations of double internal mammary implant alone.

**Follow-up**

Postoperative coronary cineangiographic evaluations were performed in more than 900 patients who had undergone single or double internal mammary artery implantations. Between 92 and 95% of the implants were patent, and about 70% had definite communication with the coronary circulation, and showed good filling of the coronary system and additional demonstration of the coronary sinus (fig. 5). Approximately 25–30% of the implants were open but showed no connection with the coronary circulation. Many of them demonstrated good myocardial blush with visualization of the coronary sinus, evidence of some myocardial perfusion. Some patients in this situation were recatheterized 3 and 6 years after the first catheterization, showing that mammary implants were then connected to the coronary circulation due to progression of the coronary disease.

We believe we have gathered sufficient data to prove that the internal mammary artery implant does perfuse the myocardium: (1) Angiographic evidence: Injection of contrast medium into the internal mammary artery implant with visualization of the coronary artery and coronary sinus indicates normal myocardial perfusion. (2) Electrocardiographic evidence: In a significant group of patients, typical anginal pain will be experienced when a catheter is introduced into the lumen of the internal mammary artery implant; the electrocardiogram will show typical patterns of myocardial anoxia. On five occasions patients have experienced episodes of ventricular fibrillation, which were easily converted by direct-current external cardioversion. (3) Protection against further occlusion: Subsequent coronary cineangiographic studies performed within 1 year after the operation have shown progress of the disease in approximately 20% of the patients.

*Figure 4*

*Multiple saphenous vein grafts (arrows) to the anterior descending, diagonal, and circumflex coronary artery.*
Some of them advanced from partial to total occlusion without experiencing a myocardial infarction because the distal portion is now being perfused by the systemic artery, implanted alongside a major branch of the coronary circulation. (4) Evidence from the flow studies showing that the flow of blood occurred during the diastolic phase of the cardiac cycle as normally occurs in the coronary circulation; the systemic artery actually functions as a third coronary artery. (5) Response to drugs such as nitroglycerin, norepinephrine, or isoproterenol has shown similar reaction as the coronary circulation; (6) Krypton gas studies have been performed at Harvard University, in which krypton-tagged saline solution was injected. The clearance rate of this gas proved not only that true myocardial perfusion was occurring but also that the possibility of arteriovenous shunting from the implant directly into the venous system was excluded. (7) Tissue lactic acid determination and lactate level in the coronary sinus before and after implantation show definite change from anaerobic to aerobic metabolism.

At present we have definite evidence that patients with functional implant obtained significant protection for the future. A postoperative investigation among patients with widely patent internal mammary artery connected to the coronary circulation and a similar series treated medically has shown in the first group a mortality rate of less than 2% per year in comparison with a 50% mortality within 5 years in the second group.

It must be emphasized that data of both series have been tabulated and based on coronary cineangiographic evidence, which is the only way medical and surgical series can be compared without introducing significant errors.

**Ventricular Aneurysmectomy or Left Ventricular Scarctectomy**

Ventricular aneurysmectomy or resection of scar tissue on the left ventricle has been performed in 301 patients up to September 30,
1970. Ventricular aneurysms can be defined as thick scar-tissue replacement of a large segment of the left ventricular wall. A clear-cut line of demarcation demonstrates the viable muscle of the left ventricle, which is easily palpable after the aneurysm has been incised.

Such true ventricular aneurysms have been encountered in 252 patients. In 49 of the patients, the entire anterolateral wall of the left ventricle was replaced by scar tissue with mild-to-moderate enlargement and sometimes slight paradoxic motion. The absence of a frank bulging mass does not exclude a surgical diagnosis of ventricular aneurysm. Resection of the noncontractile wall, in most cases, results in disappearance of the elevated end-diastolic pressure and significant clinical improvement. Hopefully, the resection precludes further enlargement of the affected segment and continued deterioration of the left ventricle.

The location of each aneurysm in this series of patients was on the anterolateral wall and apex of the left ventricle, except in 10 patients in whom involvement was on the diaphragmatic surface of the left ventricle. Large posterior ventricular aneurysms are very uncommon because massive infarction of the posterior wall of the left ventricle will affect the papillary muscle and chordae tendineae of the mitral valve, with concomitant mitral insufficiency. This additional burden, on a nearly catastrophic situation, is too great for the heart to bear, and the patient seldom survives.

Most of the patients showed clinical symptoms of coronary insufficiency with various degrees of angina pectoris. Manifestations of congestive heart failure associated with impaired left ventricular contraction occurred in approximately 70% of all cases. Severe arrhythmias ranging from atrial fibrillation to ventricular tachycardia were present in approximately 12% of the cases. A large thrombus was found in each of 117 patients; nevertheless, peripheral embolization occurred in only a small number of patients.

Operative Technic

At present, all operations are performed through a midline transsternal thoracotomy, since this provides obvious advantages. Large ventricular aneurysms can be easily approached and dissected.

The aneurysm is approached by a direct incision in the midportion of the ventricle and, when a clot is present, the aorta is kept totally clamped until the aneurysm and the clot have been entirely removed. The aortic clamp should be opened after careful inspection of the left ventricular atrial chambers in a dry, operative field to avoid systemic embolization.

A complete excision of the aneurysm should be performed, leaving only a rim of scar tissue at the edges of the resection for support of the suture (figs. 6, 7).

The reconstruction of the left ventricle is done in a linear fashion from base to apex by a continuous running suture. The initial closure is reinforced by interrupted horizontal sutures, which can be placed over Teflon pledgets. Interrupted figure-of-eight sutures are placed more superficially at the edges of the previous closure. Since I have been using this three-way closure, I have not had a single case of postoperative bleeding originating from the reconstruction of the left ventricle. When combined concomitant revascularization procedures are performed, the aneurysm can be resected first and a left ventricular vent left close to the apex of the heart. With the heart fibrillating and totally decompressed, bypasses to the distal distribution of the circumflex coronary artery or right coronary artery can be performed.

It must be borne in mind that the surgical treatment for ventricular aneurysms is not curative, since the underlying disease process remains. The cardiac rehabilitation associated with increased efficiency of left ventricular function would be affected by the condition of the residual myocardium and the severity of obstruction in the rest of the coronary circulation. This is the main reason why, at present, we are performing increasingly more ventricular aneurysmectomies and resection of scar tissue, mainly with the saphenous vein graft technic. For example, among the last 110 patients operated upon between January, 1969, and September, 1970, concomitant direct and indirect revascularization procedures were performed in 64 patients.

Conclusions

Until 1966 only one-stage operations were performed in patients with severe diffuse coronary artery disease, even when it was...
apparent that more than one type of revascularization would be necessary to overcome existing perfusion deficit.

The subsequent development of an operative technique permitting dissection of the internal mammary artery through a midline incision has reduced the need for multiple operative procedures. The present availability of the saphenous vein graft technique is an important advancement in the surgical treatment of coronary arteriosclerosis. At present, all three procedures can be combined simultaneously in a great number of patients in a single operation. Operations involving several procedures can be performed with a low operative mortality rate, attributed to several factors: (1) high-quality coronary cineangiography provides the basis for precise evaluation and selection of the best operation for each patient; (2) the exact location for the distal anastomosis is carefully determined; and (3) the selection of the best operative approach for the individual patient can be discussed and made before opening of the chest.

Additional reasons for the low operative mortality rate include: (1) the excellent anesthesia obtained with the utilization of methoxyflurane with minimal depression of the cardiovascular system; (2) total cardiopulmonary bypass performed at normothermia with hemodilution and the generous administration of nitroglycerin during the operation, allowing excellent myocardial and tissue perfusion; and (3) standardization of the operative technique, which enables the team to perform the operation in the simplest manner and in minimal time. (Our present operative technic allows us to perform bypasses even in arteries between 1 and 2 mm in diameter.)

Another step lowering operative mortality rate is careful determination of the blood volume at the end of the procedure and in the immediate postoperative period by the evaluation of the left atrial pressure in patients with abnormal ventricles. This is undoubtedly one of the most important reasons for the low hospital mortality rate in our series of patients with abnormal ventricles. In patients with
end-stage coronary arteriosclerosis and poor ventricular function, it takes approximately 24 hours for left ventricular contraction to improve. If, during this critical period, the patient’s circulation is overloaded, the left ventricle will become distended and myocardial insufficiency will lead primarily to severe pulmonary congestion with subsequent pulmonary edema and possible systemic hypotension. Continuous nasotracheal intubation and controlled ventilation for the first 24 hours ensures optimum oxygenation with consequent controllable homeostasis of blood gases. The liberal use of coronary vasodilators and sedation for the first 24 hours not only ensures satisfactory ventilation but also prevents spasms in the coronary circulation. Another important step is the prevention and correction of hypokalemia, the most common cause of ventricular arrhythmia, by serum potassium determination before, during, and after surgery. There should be rapid intravenous administration when the level is below 4 mg. Serum potassium levels are determined more frequently when digitalis is administered. In the past, the incidence of postoperative myocardial infarctions was as high as 18% in patients who underwent double internal mammary artery implantation. At present it is less than 5%, even though we have combined the various approaches in most patients.

Significant achievements have marked the development of operative procedures for the treatment of coronary artery disease in the last decade. Coronary artery disease, as we know, is the principal cause of death throughout the world, and the amelioration of the devastating effect of coronary arteriosclerosis is an important and urgent need. The surgeon is obligated to accept this challenge. Many problems remain but the various operations currently feasible provide a favorable outlook. I do not have any doubt that the long follow-up will prove that prolongation of the cardiac patient’s life, improvement in his health, and a return to productive living are now realistic results of surgical procedures.

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Nevertheless, it should be borne in mind that surgical treatment does not preclude medical treatment. Both work together for the benefit of the patient, before, during, and after the operation.

References
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