CARDIAC REVASCULARIZATION IN CORONARY ARTERY DISEASE

DENNIS M. L. ROSENBERG, M.B., B.Ch. (Rand), M.D., F.A.C.S.

Assistant Professor of Clinical Surgery, Tulane University, School of Medicine, New Orleans, Louisiana

Coronary arteriosclerosis, with its resulting myocardial ischemia,* was first recognized by Morgagni in 1707 and was vividly described by him in 1761.[19] Today, coronary insufficiency is responsible for more than 75% of all heart disease, and in the United States alone approximately 800,000 new cases of myocardial infarction occur annually. Of these, about 320,000 patients die. Affecting man in his prime, coronary insufficiency has become the number-one problem of disability in the population as a whole and in the medical profession in particular. Until recently, its solution remained entirely in the hands of the internist, who continues to maintain a deeply entrenched attitude similar to that he held toward the the problem of mitral stenosis some 10 years ago. Since, however, medical treatment has been of little avail, a new approach seems warranted. It is possible that surgical intervention may provide some hope for victims of this disease. Obviously, prevention is to be desired, but when this has failed, the direct approach to the study of coronary artery disease is the most effective. Toward this end, established experimental facts should be applied to the clinical problem.

A thorough knowledge of the anatomic, pathologic, and physiologic phenomena associated with the coronary arteries is essential. The coronary arteries arise from the anterolateral sinuses of Valsalva of the aorta, the right coronary artery passing laterally in the sulcus between the right auricle and ventricle. It divides into a posterior descending branch, which supplies the major portion of the posterior surface of the heart and the interventricular septum, and a smaller branch, which anastomoses with the circumflex branch of the left coronary artery. The left coronary artery passes behind the pulmonary artery to reach the anterior surface of the heart; immediately below the left auricle, it divides into the circumflex and anterior descending arteries. The anterior descending branch passes downward in the interventricular sulcus to the apex, whereas the circumflex branch swings around the base of the left atrium almost as far as the posterior sulcus to reach the apex of the heart. The coronary veins course parallel to the branches of the coronary arteries, returning the blood to the right atrium by way of the coronary sinus. The tributaries of the veins, however, consist of a far richer interlocking system than the arteries; they are far more numerous and have more communications. This anatomic arrangement is of utmost importance in the consideration of some operative technics designed to improve the supply of blood to the myocardium. The myocardium is richly supplied with vascular channels, the capillaries coursing along the cardiac muscle fibers.

One peculiarity of the circulation that deserves particular mention is that the coronary arteries behave as end arteries, with little or no intercoronary communication in about 90% of hearts. Minute anastomoses exist, however, which are capable of gradual enlargement and development. Other peculiarities of this circulation are the presence of direct channels from the arterioles, from the capillary bed, and from the coronary veins directly into the cardiac lumen—the Thebesian veins and arterioluminal vessels. Deep in the myocardium, in addition to the capillary bed, are thin-walled irregular channels known as myocardial sinusoids.

Mechanisms of myocardial nutrition exist other than through the coronary arterial system; for example, an extensive system of vascular communication between the lumina of the cardiac chambers and the myocardial capillary bed forms an important nutritional route in fishes and some amphibia, in which coronary arteries may be small or absent. Although it does not contribute significantly to adult human myocardial nutrition, it must be helpful in maintaining life in the presence of complete coronary occlusion. Another source of myocardial nourishment is the myriad of minute vessels at the junction of the visceral and parietal pericardial reflection. These vessels, arising from intercostal, mediastinal, esophageal, and bronchial arteries, are largely responsible for the new capillary vascularity that develops

*American spelling retained throughout.

in the presence of adhesions secondary to pericardial and epicardial irritation. Anastomoses between these capillary beds and the myocardial capillary bed have been demonstrated.

Actual obstruction to coronary arterial flow consists in atherosclerotic thickening or formation of a plaque within the first few centimetres of the coronary arteries. The end result of this sclerosis is modified by a number of factors: anatomic structure of the coronary vascular system, arterial head pressure, venous back pressure, collateral circulation, and natural response to gradual occlusion of the coronary flow of blood.

CARDIAC REVASCULARIZATION

Pre-eminent in the development of a surgical approach to sclerosis is Claude Beck,[5-8] who, in his many years of animal experimentation in more than 6,000 dogs, has classified death from coronary disease into two types, both related to blood supply, but otherwise different. In the first type, the heart is electrically unstable, associated with trigger zones in localized areas of ischemia, with little destruction of muscle. A deficiency of oxygen in the dry area often produces arrythmia and fatal ventricular fibrillation. Increased flow of oxygenated blood to such an area will result in a more stable heart. In the second type of death from coronary disease, an appreciable amount of muscle has been destroyed in an electrically stable heart. Nothing can be done to revive destroyed muscle and replace it extensively by fibrous connective tissue. The myocardium largely gives way, and heart failure ensues.

Most deaths from coronary disease fall into the first of these groups, in which unequal oxygenation of the myocardium exists. These trigger zones, or ischemic dry areas of myocardium, become ectopic centers for impulses and, in turn, disrupt the co-ordinated mechanism of the heart beat. The destructive property of a trigger zone can be reduced by as small a quantity of blood as 1-5 cc. Beck[7] has pointed out, after the observations of Zoll and associates,[25, 26] that normal intercoronary arterial communications exist in only about 9% of normal human hearts; if the coronary arteries become occluded slowly, about 58% of these hearts will exhibit some intercoronary communication, When occlusion is complete, the incidence rises to 89% for acute closures and 100% for insidious closures. The presence of these intercoronary anastomoses makes maintenance of life possible despite the presence of almost complete or even complete occlusive disease. 90% of all deaths from coronary disease are caused by lack of natural intercoronary communication.

Methods of overdevelopment of these intercoronary vascular channels, artificially or naturally, may prevent necrosis of the myocardium when the supply of blood from the main source has been curtailed. Expansion of intercoronary communications, with increasing flow of oxygenated blood, can impede the development of electrical instability.

Increase of Supply of Blood

Methods of increasing the supply of blood to the myocardium have followed various patterns, largely as a result of the efforts of the pioneers, Claude Beck[5-8] and Lawrence O'Shaughnessy and associates.[21, 22] They have, in general, been directed toward (1) more complete and more uniform distribution of blood in the coronary system, (2) increase in supply of blood from external sources, and (3) resection or correction of occluded segments of the arteries with restoration of the channel. Like many of the significant developments in vascular surgery, revascularization of the myocardium originated in the laboratories of the Frenchmen, Leriche and Fontaine,[17] in 1932. These investigators implanted the pectoralis muscle into the myocardium and significantly reduced the fatality rate in dogs on ligating the descending branch of the left coronary artery. Lezius[18] modified this approach somewhat by attaching the lung to the myocardium; his animals were also able to survive ligation of the left coronary artery. Beck,[5] in 1932, promoted vascular adhesions by suturing the pectoralis minor muscle to the myocardium, and O'Shaughnessy,[21] who used the great omentum for the same purpose, established a collateral extracardiac circulation, with significant relief of pain, in about 30 patients. His project was terminated by his death at Dunkirk, and little further clinical work in this field was published for many years. Heinbecker and Boston,[15] in 1939, produced irritative pericarditis by intrapericardial injection of carborundum sand and sodium morrhuate. In 1940, Fauteaux[12] ligated the great cardiac vein in dogs on the premise that mechanical distention of the direct arteriovenous communication improved survival of tissue after arterial occlusion. Thompson and Raisbeck,[23] in 1942, applied Heinbecker's method in human patients but substituted talc and asbestos for the sand and were successful in promoting collateral extracardiac circulation.

In 1955, an entirely new approach was demonstrated by Vineberg and associates,[24] who implanted the internal mammary artery into a myocardial tunnel. Experimentally, at least, some branching and budding from the terminal end of an open intercostal branch ensued in the ischemic heart. These new branches, joining with existing myocardial arterial channels, assured flow from the extracardiac source. Lung, pedicled skin graft, and pedicled jejunal graft[16] have all been used to increase the supply of blood to the myocardium from external sources. Most of these, however, provide only superficial revascularization. Recently, again largely as a result of Beck's vast experience, efforts to increase the effective flow of blood through the myocardial bed have been focussed on stimulating overdevelopment of the intercoronary collateral circulation. Flow of blood from the descending aorta, by way of a vascular graft, to the coronary sinus, which is later incompletely ligated, is the essence of the Beck II procedure. Although studies by Bakst and associates[3] have demonstrated gradual occlusion of the graft, with abolishment of flow, within 3-6 months after implantation, tremendous overdevelopment of the intercoronary collateral circulation has been stimulated before the cessation of flow within the graft. Ligation of the coronary sinus alters the venous back pressure, and this chronic passive congestion, in itself, leads to some overdevelopment of the intercoronary system.

The Beck I procedure, simpler and apparently just as effective, consists in replacing the more complicated aorta-coronary sinus graft. This operation has 4 component manoeuvres, viz. (1) mechanical abrasion of the lining of the parietal pericardium and surface of the heart, (2) application of 0.2 g. of powdered asbestos, (3) partial occlusion of the coronary sinus to a diameter of about 3 mm., and (4) grafting of the parietal pericardium and mediastinal fat to the surface of the abraded heart. Each part achieves some beneficial effect. Intercoronary channels are stimulated and developed,

the oxygen differential is reduced, and some additional extracardiac blood is brought to the heart.

An important question concerns the quantity of extra blood needed by an ischemic heart. Only a few cubic centimeters per minute may be needed in the presence of an occluded coronary artery. 5 c.c. per minute, or approximately 300 c.c. per hour, will carry a dog through the crisis of occlusion of the descending coronary artery. Even if an infarct occurs, life will be maintained. The Beck operation permits the coronary artery to be perfused with at least 280 c.c. of blood per hour; this reduces oxygen differential and preserves viability of cardiac muscle. Since death from coronary occlusion results from iniquities in supply of blood to contiguous areas of the myocardium, which lead to oxygen differential, electrical instability and ventricular fibrillation, redistribution of a few c.c. of available blood to the appropriate site by this operative procedure can prevent the catastrophic sequelae of coronary artery disease.

Harken and associates[14] used a simple procedure in at least 20 patients, in whom areas of the epicardium had been removed chemically with a 95% solution of phenol. The lingula pulmonis was then attached to the denuded myocardium. An irritative effect was added to the procedure by application of powdered asbestos and talc. Whereas this method is yet another of primary superficial revascularization, it emphasizes the importance of removal of the epicardial barrier in permitting the development of anastomosis from the coronary collateral to the extrinsic collateral circulation. Other new surgical possibilities have included (1) replacement of diseased segment of coronary arteries by a graft, (2) endarterectomy of coronary vessels,[1, 2] and (3) grafting from a systemic vessel to a coronary artery beyond the point of occlusion. Since the basic problem is, obviously, one of diminished supply of blood to the functioning myocardium, successful removal of the occluding plaques or replacement of the occluded area is a more direct and appealing approach. Experimental work along these lines is in progress throughout this country and with utilization of the cardiac bypass, may perhaps lead to clinical application. Murray,[20] a few years ago, reported perfusion of the distal portion of an occluded segment of the anterior descending artery during its resection and replacement by a graft.

The most recent approach to the problem of myocardial revascularization has been devised by Glover,[13] who, following the teaching of some Italian surgeons, has advocated simple ligation of the internal mammary arteries. This permits shunting of blood into the pericardiacophrenic artery, with increased flow of blood to the pericardium and epicardium and, consequently, to the myocardium. This simple procedure, frequently possible under local anesthesia in patients who are extremely ill soon after myocardial infarction, has resulted in dramatic relief of pain in over 90% of 100 patients operated upon by Glover. Sixty-six of 70 patients originally operated upon by the Italian workers, Battezzati, Tagliaferro, and De Marchi,[4] of Genoa and Parma, became free of pain. This relatively innocuous procedure may hold great promise, but basic experimental work has yet to be published, and further experimental and clinical reports may be expected in the near future.

Criteria for Selection of Patients

In Beck's opinion, the most desirable patient is one who has had disease of the coronary artery for one or more years, has had one or more infarcts, is still ambulatory and can do some work, is lean rather than obese, and has coronary pain.[7] If an infarct has occurred, 6 months must elapse before operation is undertaken, to allow some natural development of intercoronary channels. Contrary to expectation, the risk is greater in young persons, in whom the process is much more rapid and malignant. The large failing heart constitutes an unequivocal contra-indication to operation, and patients with extensive destruction of muscle obviously cannot be benefited by surgical intervention. Also hazardous is the presence of progressively severe angina without demonstrable infarction, since in such patients areas of ischemia may develop during or immediately after operation.

Operation should never be considered as a salvage procedure to be applied when medical treatment has failed. In persons of about 50 years of age who have mild to moderate anginal pain on effort and one or more infarcts, the operative fatality rate is about 3%. In those who have more advanced disease, with moderate to severe angina pectoris and one or more infarcts, the operative fatality rate is about 5%. In patients with severe coronary disease, or 'salvage' cases, it rises above 25%. Effective treatment of coronary arterial insufficiency must (1) prolong life, (2) reduce invalidism and disability, (3) maintain productivity and well-being, (4) relieve pain and discomfort, and (5) be accompanied by a non-prohibitive operative risk.

Results and Evaluation of Operation: Beck Procedure

On the basis of collective reports of over 200 patients evaluated 6-12 months after operation, Beck has reported that 45% obtain complete relief from pain and 45% experience diminution of pain; 35% are able to return to work without limitation of activity, whereas 55% can return to work with some restriction of duties. In Brofman's series of 75 patients,[10, 11] 44 have been followed up 10-30 months after operation. Only 2 have died of the disease; 27, including coal miners, laborers and medical practitioners, have returned to full-time work; 10 are working more than before operation, and 4 are still unable to work at all. The safety and effectiveness of the procedure in producing more adequate distribution of coronary blood flow seems beyond question. Occlusion will undoubtedly continue to occur, since no means of preventing this disease has yet been found, but the operation appears to lessen the effects of occlusion when it does occur. It cannot, however, revive degenerated myocardium, and if the occlusive disease progresses very rapidly, it may overtake the benefit derived from the operation.

SUMMARY AND CONCLUSIONS

Recently, increasing interest has been directed toward the surgical treatment of coronary insufficiency, one of the most important medical problems confronting us today. Various methods have been proposed for increasing the diminished supply of blood to the myocardium in coronary sclerosis, all aimed at greater and more uniform distribution of blood to the myocardium and resection of occluded arterial segments with re-establishment of the channel. Effective surgical treatment must prolong life, reduce disability, maintain well-being, relieve pain, and involve a non-prohibitive risk. The Beck II operation appears to be safe and effective. Other procedures for cardiac revascularization have been advocated, and additional ones are being continually devised. Most recent of these is ligation of the internal mammary

artery, but sufficient time has not yet elapsed for definitive evaluation. Experimental and clinical evidences warrant more widespread use of surgical treatment in selected patients with coronary artery disease.

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