

1951

Surgical revascularization of the heart in the treatment of coronary arterial disease

Dallas V. Clatanoff
University of Nebraska Medical Center

This manuscript is historical in nature and may not reflect current medical research and practice. Search [PubMed](#) for current research.

Follow this and additional works at: <https://digitalcommons.unmc.edu/mdtheses>

Recommended Citation

Clatanoff, Dallas V., "Surgical revascularization of the heart in the treatment of coronary arterial disease" (1951). *MD Theses*. 1724.

<https://digitalcommons.unmc.edu/mdtheses/1724>

This Thesis is brought to you for free and open access by the Special Collections at DigitalCommons@UNMC. It has been accepted for inclusion in MD Theses by an authorized administrator of DigitalCommons@UNMC. For more information, please contact digitalcommons@unmc.edu.

**SURGICAL REVASCULARIZATION OF THE HEART
IN THE TREATMENT OF CORONARY ARTERIAL DISEASE**

Dallas V. Clatanoff

**Submitted in Partial Fulfillment
for the Degree of Doctor of Medicine
College of Medicine, University of Nebraska**

February 12, 1951

Omaha, Nebraska

CONTENTS

I.	Introduction	1
II.	Coronary Collateral Circulation	3
III.	Vascular Grafts and Adhesions	4
	A. Grafts to the Myocardium	5
	B. Inflammatory Agents Applied to the Heart	11
IV.	Coronary Vein Ligation	16
	A. With Denervation of Coronary Vessels	20
	B. With Arterialization of Coronary Sinus	23
V.	Arterial Transplant into Myocardium	28
VI.	Discussion and Conclusions	29
VII.	Summary	38
VIII.	Bibliography	40

I. INTRODUCTION

Coronary arterial disease is an ever changing process during the development of which the formation of collateral anastomoses opposes the occlusive process. No symptoms occur when the adjustments within the heart are sufficient to compensate for the disease process, but when a discrepancy exists between the myocardial demand and the coronary supply, the resulting myocardial ischemia is responsible for the clinical syndromes of angina pectoris, congestive failure, and myocardial infarction.

Two relatively small arteries supply the most vital muscular structure of the body. This muscular organ is in constant motion, and to make its movements free and frictionless it is enclosed in a moist envelope of mesothelium. The only direct continuity of the heart with the rest of the body is through the walls of the great vessels, the fat, the nerves, and the lymphatics at its base. While the heart is in direct contact with other structures over its entire surface, it has a minimum amount of direct continuity with such adjacent structures. With this anatomic pattern, man is deprived of an important compensatory mechanism, namely, the ability to develop an adequate collateral blood supply to the heart to meet an emergency, to preserve life during the first moments,

hours, days, weeks after a serious coronary accident. If life is preserved over a sufficiently long period of time, the process of coronary occlusion can go on to completion as reported by Leary and Wearn (34) in their two cases of essential closure of both coronary orifices, in which the lesions indicated a slowly progressive process which had probably taken months at least to reach the point of essential complete closure. In other words, complete closure of the coronary ostia at the aorta is compatible with life; however, the appalling incidence of sudden death from heart failure attests to the destructive nature of coronary disease.

The question arises as to whether an impaired myocardial circulation can be improved by operative measures. It is the objective of this paper to review the various surgical procedures performed on the heart for the relief of coronary arterial disease and then to conclude the efficacy of such operations. There are several approaches to the surgical establishment of an increased blood supply to the myocardium and each will be reviewed separately. Total thyroidectomy, since it is not a revascularization procedure but instead reduces the work imposed upon the heart by a general lowering of metabolic requirements, will not be reviewed here.

II. CORONARY COLLATERAL CIRCULATION

Under normal conditions the heart has three sources from which it can receive a supply of blood: the coronary arteries, the Thebesian vessels, and the extracardiac anastomoses between the coronary system and the blood vessels in the fat and other tissues at the base of the heart. The existence of extracardiac anastomoses of the coronary arteries demonstrated by various early workers was reinvestigated in detail by Robertson (50) in 1930 and by Hudson, Moritz, and Wearn (31) in 1932. The latter defined clearly the origin and extent of this widespread and rich potential extracardiac coronary collateral circulation and drew attention to its probable significance in compensating for coronary sclerosis. Although the effective participation of these collaterals in the event of a sudden or rapid coronary occlusion is doubtful, it seems probable that they may, at any rate, operate to diminish and limit the extent of myocardial damage, more especially when the cardiac ischemia is of gradual onset. Many cases have been recorded bearing on this point. Details are given by Robertson of two cases illustrating the important part that may be played by these widespread anastomotic channels in preventing the usual myocardial damage produced by coronary occlusion.

III. VASCULAR GRAFTS AND ADHESIONS

Besides these natural anastomotic channels a further possibility for the revascularization of the heart rests in the formation of cardiopericardial adhesions, establishing connection between the coronary vessels and the pericardial and mediastinal vessels.

In 1903 Thorel (60) reported a case of a man sixty-eight years of age who died of carcinoma and at autopsy both coronary arteries were found to be obliterated in their proximal portions. The obliteration was of a character judged to be of long duration. The existence of extensive pericardial adhesions was thought by him to have provided an adequate collateral circulation through the vessels of the pericardium. Moritz, Hudson, and Orgain (41), in 1932, examined four hearts, with partial or complete obliteration of the pericardial sac by fibrous adhesions, after injection of the coronary arteries with a colloidal suspension of lampblack and showed that the extracardiac anastomoses of the coronary arteries were increased owing to the presence of adhesions. That such blood vessels exist in parietal pericardial adhesions to the human heart was confirmed by observation at operation by Beck (2) in 1932. The adhesion was cut and active bleeding occurred from each end of the transected tissue. This is the first direct observation of the functional

nature of such vessels in man. Beck, Tichy, and Moritz (9,10) reported a series of experiments, in 1935, in dogs in which vascular adhesions were produced between the heart and the parietal pericardium and the pericardial fat after removal of the epicardium and the lining layer of the parietal pericardium. They demonstrated that almost complete occlusion of the right and left coronary arteries was compatible with life if the heart had been provided with a collateral blood supply. Dye was shown to have penetrated the myocardium when injected through the collateral bed. They emphasized the importance of a pressure differential as a stimulus for the formation of collateral channels. Anastomoses between the cardiac and extracardiac circulations were demonstrable as early as two weeks after operation.

A. Grafts to the Myocardium

In subsequent experiments Beck (2) and his coworkers carried out an extensive study of the relief of cardiac ischemia and provided an accessory blood supply to the myocardium by grafting--pedicle grafts of pectoralis muscle and omentum. They found that anastomoses develop readily between the blood vessels of skeletal muscle and of the myocardium, provided that blood supply of the heart has been reduced. In the absence of partial

occlusion of the coronary vessels, the anastomoses, though present, are not so well developed. They concluded that the presence of a collateral vascular bed definitely protected the heart from the ravages of sudden occlusion of a major coronary artery. The graft acts by providing an accessory blood supply and by affording channels of communication between branches of one coronary artery and branches of the other occluded coronary artery. In 1935, Rienhoff (48) stated in a discussion that, after the application of a pedicled omental graft to the heart of the dog, ligation of the descending coronary artery failed to produce an infarct. Further details of his experiments have not been found.

From a chiefly pathological study of ninety-four human hearts in which a major coronary artery had been occluded, Moritz and Beck (40) derived data which would indicate that there was a period after the first coronary occlusion in the lives of forty-three of these individuals when the production of extracardiac coronary collateral circulation might have been feasible and beneficial.

With his experimental work as a background, Beck (2) performed the first operation on the human for relief of cardiac ischemia by attaching a pedicle graft of the pectoralis major muscle to the myocardium. He then reported

(3) on eleven operated patients with sclerosis of the coronary arteries and angina pectoris, who were totally disabled and constituted an extremely bad-risk group for any operative procedure. Beck (4) had operated on sixteen patients with coronary disease by October, 1936, and reported a mortality of 50 per cent and realized that the mortality must be reduced if patients with coronary disease were to be given the benefit of this surgical principle. He stated that it could be accomplished in "two ways: (1) by selecting patients for operation who do not have such advanced disease of the coronary arteries, i.e., patients with angina pectoris but with a good myocardium and with sufficient reserve to carry them through an operation, and (2) by reducing the magnitude of the operation." The magnitude of the operation had been reduced. Instead of a bilateral approach to the heart as was made possible by removal of two costal cartilages on each side of the sternum, a unilateral approach was used. The number of costal cartilages removed was reduced to one. In most of the operations the epicardium was removed or roughened mechanically by means of a burr; an attempt to get away from this feature of the operation was made because the removal of the epicardium initiated many extrasystoles.

Mautz and Beck (39) recognized that the ultimate

place of the Beck operation in the treatment of clinical coronary arterial disease would depend upon the comparison of clinical results in comparable groups of operated and unoperated patients. In 1937, they studied collateral circulation in the normal heart, in hearts with chronic obstruction of coronary arteries, and the role of factors introduced by operation in the case of the heart with coronary artery disease. These men concluded that after a sudden occlusion several courses are outlined for intercoronary anastomoses: (1) rapid increase in size of intercoronary anastomoses which compensate to a large extent for the obstruction, (2) an intermediate course, or (3) a poor response. Operation, after complete occlusion of one main branch, might be expected to improve principally the intercoronary anastomoses by dilatation of existing channels and by the establishment of new intercoronary communications which now may gradually enlarge. The only extracardiac anastomoses which would be likely to develop and survive are those in grafts placed directly upon the localized ischemic area and even these might not significantly enlarge, or might regress if the intercoronary adjustments were adequate. After beginning obstruction of the last main coronary artery, operation at this time might be expected to slightly improve intercoronary communications and establish new extracardiac

anastomoses which would be in a position to persist and continue to enlarge as the coronary disease progressed.

A detailed experimental investigation of the methods of augmenting the blood supply to the heart was reported by O'Shaughnessy (42) in 1936. He showed in the greyhound that an omental graft was compatible with the highest degree of physical exertion, and that vascular connections developed rapidly between such a graft and the myocardium. A pedicled omental graft brought up into the chest was used. After three weeks complete injection of the coronary tree could be carried out from the arterial bed of the graft. In these experiments it was shown that the omentum would form vascular attachments when it was applied to normal myocardium, an area of acute ischemia, or an area of chronic ischemia. He emphasized that the blood reaching the heart from the graft was not merely distributed locally but was also available throughout the heart by virtue of the connections between the graft and the branches of the right and left coronary arteries. The application of this experimental work by O'Shaughnessy to the problem of surgical revascularization of the ischemic heart in man was reported (43). He reported six successful cases where cardioomentopexy had been applied in the human heart with apparent benefit; later (15) a total of twenty cases were reported.

Lezius (37,38) studied carefully and in detail the development of a coronary collateral circulation after cardiopneumopexy and reported in 1937 and 1938. In a group of sixteen experiments the lung was sutured to the surface of the heart and a 30 per cent solution of flavine was applied as an additional stimulant to the formation of adhesions. After this operation the left coronary artery could be ligated, and the animals showed a normal exercise tolerance. At autopsy complete filling of the coronary tree could be shown radiologically after the injection of thorotrast into the pulmonary artery. Microscopic preparations demonstrated the absence of infarction in the myocardium and the presence of large new vessels passing from the graft into the myocardium. Lezius emphasizes the importance of cardiac ischemia as a stimulant to the development of collateral circulation; development is slight when the coronary vessels are not ligated and functionally active anastomosis in cardiopneumopexy follows rapidly on ligation of a main coronary vessel.

In 1949, Carter and his associates (13) restudied cardiopneumopexy in dogs using asbestos powder as a means of producing vascular adhesions between the heart and lung. That new vascular channels can be produced between the myocardium and the adherent lung is evident

both grossly and microscopically, but neither the amount of blood flow, the direction of flow, nor the duration of the patency of these channels has been established. Normal hearts revealed much less filling in the myocardium after injection of a suspension of India ink in blood, while in the case of hearts rendered ischemic by coronary artery ligation there was considerably greater filling, not only of the superficial myocardial vessels, but of the deep ones as well. Mortality following ligation of the anterior descending branch of the left coronary artery in animals prepared by cardiopneumopexy was markedly reduced over that in simple ligation in an unprepared animal. Infarction was markedly lessened as well.

B. Inflammatory Agents Applied to the Heart

Stanton, Schildt, and Beck (53), in 1941, showed experimentally that trauma applied to the surface of the heart brought about the development of communications between one coronary artery and another. The type of trauma used in this demonstration was abrasion to the surface of the heart; the epicardium was roughened and torn by means of special burrs. Powdered beef bone had been used by Beck (2) for the purpose of producing an inflammatory (foreign body) reaction on the surface of the heart. Aleuronat (a preparation of aleurone) was

used by O'Shaughnessy in 1939 (44). A mixture of aleuronat, starch, glycerin and water was placed into the pericardial cavity of a cat. Histological and injection studies were presented to show that vascular connections will develop between the vessels of the myocardium and extracardiac vessels.

Thompson (56), in 1939, used hydrous magnesium silicate (talc) powder experimentally inside the pericardial sac of dogs with the development of bread and butter pericarditis. At subsequent operations new blood vessels were demonstrated between the pericardium and epicardium when bleeding was observed from both tissues when the layers were separated. In 1940, he (57) reported ten patients on whom the operation was done, and, in 1942, Thompson and Raisbeck (58) reported thirteen cases in which the procedure had been applied to humans, critically evaluated the results, and concluded that the benefits would warrant further employment of the procedure.

A series of experiments, in which a mixture of gelatin, aleuronat, starch, glycerin, water and lionite was introduced into the pericardial cavity, was performed in 1940 and 1941 by Heinbecker and Barton (30). In some experiments (29) these authors also used sodium morrhuate. After introduction of these substances, the pericardium was closed and the pericardium sutured to the retrosternal tissues.

Fourteen animals were prepared and four to twelve weeks later a second operation with ligation of the descending ramus and circumflex ramus of the left coronary near the aorta was done. Six of the fourteen animals survived; infarcts were not demonstrable at autopsy.

Schildt, Stanton, and Beck (52), in 1943, studied this subject realizing that the most desirable substance would be one producing a well vascularized type of granulation tissue without producing necrosis of the myocardium, severe exudation, and cicatrization. Beck had previously carried out experiments which he never fully reported. Powdered beef bone (2) had produced the most favorable reaction; chlorinated soda (1,6) produced compression scars. Kaolin, iron filings, tincture of iodine, ether, alcohol, saturated solution of sodium chloride, solution of glucose, horse serum, acids, and alkalies had been found unsatisfactory. In this experiment it appeared that silicate in the form of powdered asbestos produced the most favorable results; there was slight exudation, the inflammatory process was well vascularized, no compression of the heart by scar tissue was caused, and the inflammatory effect persisted over a period of several months. Ligation of the descending ramus of the left coronary artery at its origin was performed after asbestos was applied to the heart and mor-

tality was reduced by half, and size of infarcts also was smaller. Other substances used at this time produced various reactions and were found unsatisfactory; they critically used aleuronat, previously reported by O'Shaughnessy, and found that it produced a severe exudative reaction with an early increase in vascularity but later no increase in vascularity was found. Thompson had reported favorably on the use of talc, but Schildt, Stanton, and Beck failed to confirm his highly beneficial results. Also the Heinbecker and Barton mixture reaction was not as satisfactory as that produced by powdered asbestos.

In 1940 Burchell (11) carried out experiments in which grafts were placed upon the heart and the coronary arteries were occluded. Following is a quotation from his work: "So far as these studies on coronary occlusion in dogs are concerned, the role played by vascular channels in pericardial adhesions in supplying blood to the myocardium has been minimal or non-existent. The possibility that the small vascular connections, between a graft and the heart, might develop to a functioning value cannot be denied, but in the experiments seemingly favorable to such a result it has not occurred." Thus, a controversy exists not only concerning the most favorable agent for production of adhesions but also about the value

of such adhesions.

Rakov (47) reported, in 1942, that a solution of 5 per cent sodium morrhuate plus iodochlor was injected without exposure into the pericardial cavity of two patients suffering with arteriosclerotic heart disease and chronic coronary insufficiency with production of a clinical pericarditis without interference of the heart action and with apparent beneficial results. Further experimental work concerning this has not been found.

Gorelik and Krell (24), in 1950, reported one case of cardiopericardiopexy using the talcum powder method of Thompson. They believe an ischemic myocardium can be converted into a hyperemic myocardium by the introduction of sterile talcum powder inside the pericardial sac. The newly formed vessels between the pericardium and the myocardium are of various sizes, some of which can be distinguished by the naked eye. The foreign body inflammation or the pericarditis persists for a very long time without interfering with the patient's daily activities. Since the procedure is simple and the need for an effective treatment admittedly great, they believe that this operation merits a much wider application.

Feil and Rossman (23) reported electrocardiographic observations during cardiac surgery in 1939. The predominant electrocardiographic abnormalities found were

isolated ventricular beats, ventricular tachycardia, and deviations of the S-T segment from the isoelectric line. Ventricular premature beats and ventricular tachycardias are directly related to the manipulation of the heart by the surgeon. Most of the T-wave variations during cardiac surgery are transient; many are associated with S-T changes which take place postoperatively due to an acute pericarditis. The effectiveness of quinidine in preventing prefibrillation arrhythmias could not be conclusively demonstrated; however, procaine hydrochloride, as a local anesthetic applied to the surface of the heart during cardiac operations, may be of some use in preventing prefibrillation arrhythmias.

There is a general feeling (3,58) that grafts and adhesions do not interfere with cardiac activity. Thompson (58) has measured venous pressures preoperatively and postoperatively on his patients to determine if there is any development of constrictive pericarditis--no increase in pressure has been shown.

IV. CORONARY VEIN LIGATION

In 1937, Gross, Blum, and Silverman (28) applied the idea of vein ligation to the heart and reported an important research on the coronary sinus in dogs. Partial occlusion of the sinus by itself had a lower operative

mortality and also lowered the mortality rate when ligation of the descending coronary artery was done subsequently. The infarcts obtained in the dogs with partial occlusion of the sinus were smaller than those obtained without any obstruction of the sinus but they were not as small as those obtained after complete obstruction of the sinus. Gross and his coworkers concluded that "complete or even partial occlusion of the coronary sinus, whether this be permanent or transient, affords a definite method of anatomically and functionally enriching the coronary bed to such an extent that infarction may be completely prevented or minimized." Thus, they base their enthusiastic conclusions of the beneficial effects of sinus ligation on the presence and size of infarcts, stating that the mortality rate was unaffected except in partial sinus occlusion.

Katz, Jochim, and Bohning (33) found that occlusion of the coronary sinus resulted in a decrease in the total coronary artery inflow. These authors concluded that there was no rationale to ligation of the coronary sinus as a method to increase the coronary arterial bed. During physiologic studies after ligation of coronary vessels, in 1938, Gregg and Dewald (25,26,27) found that the pressure in the coronary sinus rose to the level of aortic pressure after the sinus was ligated, that the contour

and time relations of the venous pressure curves resembled closely the curves obtained from the coronary artery, that the pressure in the peripheral coronary arterial bed was increased by ligation of the coronary sinus. When the artery was ligated and cut, the retrograde flow was about 1 c.c. per minute. After ligation of the coronary sinus, the retrograde flow from the artery was as high as 39 c.c. per minute. This value of 39 c.c. per minute approaches or equals the volume of blood which might be expected to flow into the central non-occluded coronary artery. The retrograde blood was highly unsaturated, containing only 3 to 4 volumes per cent oxygen; the oxygen content of blood drawn from the coronary sinus under normal conditions was 8 volumes per cent. The myocardium failed to contract over the area supplied by the ligated artery, and occlusion of the sinus had practically no effect on the circulation in the right side of the heart. Gregg and Dewald do not believe that venous ligation is a method of "choice" for encouraging the blood supply to a potentially infarcted area of the myocardium.

Thornton and Gregg (62) studied the problem after the coronary sinus had been occluded for thirty days. They found the measurements obtained by Gregg and Dewald had practically returned to normal levels. The altera-

tions in the circulation produced by occlusion of the coronary sinus were transient in their duration.

Thornton, Gregg, and Mautz (61) studied the magnitude, adequacy and source of collateral blood flow and pressure in chronically occluded coronary arteries in 1939. On the basis of their observations the authors concluded that a considerable collateral circulation develops following chronic occlusion of the coronary arteries. Furthermore, the retrograde blood could not be differentiated from arterial blood on the basis of its oxygen and carbon dioxide content. They further stated that such volume flows of retrograde blood were sufficient for the metabolic needs of the potentially infarcted myocardium, since the myocardial region exhibited normal contractions except in areas of scarring.

However, Fauteux (17,20), in 1940 and 1941, found that if he ligated the great cardiac vein and then ligated the descending ramus of the left coronary artery that the mortality in dogs was very much less than if he ligated only the artery. He was eager to ligate this vein in human patients with coronary sclerosis and soon carried out this operation.

In 1941 Beck and Mako (7) repeated the experiments of Gross, Blum, and Silverman and found that in the ex-

periments in which the artery was completely occluded there was no definite difference in the size of the infarct whether the vein was or was not occluded. This did not appear to be the case when the artery was only partially instead of completely occluded; it appeared that ligation of the vein did reduce the size of the infarct as compared to the infarct following partial occlusion of the artery alone. They concluded that the beneficial effect following vein ligation was probably not great enough to justify application to patients.

A. With Denervation of Coronary Vessels

Leriche (36), in 1917, advanced the idea that partial arteriectomy could have value in the treatment of some forms of arteritis. In his opinion, the resection of a major diseased arterial trunk interrupts vasoconstrictive pathways and invariably brings about an active vasodilation. His experimental studies and results seem to substantiate his views. So impressed was he with the beneficial and permanent results of partial arteriectomy in the extremities that he went so far as to suggest it as a worthwhile procedure in coronary disease. In 1928 Otto (45) showed that if the sympathetic nerves were intact the heart fibrillated after coronary occlusion, while if they had been cut an hour previous to the occlusion

the heart dilated and stopped in diastole. A decrease in immediate mortality following ligation of coronary arteries after stellate ganglionectomy has been noted by Cox and Robertson (14) and Schauer, Gross, and Blum (51). Yodice (67), in 1941, repeated experiments on sympathectomy and experimental occlusion of a coronary artery to ascertain whether the effect of sympathectomy was sufficiently beneficial to apply the procedure in the treatment of coronary sclerosis. He reported that sympathectomy cannot be considered an effective method of reducing mortality or size of infarcts in dogs result- from acute coronary occlusion. It may have a slightly beneficial effect, but this effect, if present, is tran- sient.

Fauteux has stated that the objective of all his experimental studies has been to develop a procedure which would eradicate sensory disturbances, vasomotor reactions, and mechanical circulatory disorders. He reported the results of his studies on the effects of arteriectomy (16) and venous ligation (17) on the dog's heart. Partial coronary arteriectomy was found incom- patible with life in dogs with normal coronaries. How- ever, when this procedure was combined with coronary venous ligation, the mortality rate was considerably lower. It was concluded that ligation of the great car-

diac vein after occlusion of the anterior descending branch of the left coronary artery of the dog helps to maintain adequate coronary circulation after partial coronary arteriectomy.

"Pericoronary neurectomy", the term applied to the destruction of most of the nerve branches reaching or leaving the left and right coronary arteries, was described by Fauteux (18) in 1945. Nerve resection of this sort interrupts sympathetic, vagal, and sensory branches. Experimental studies by this author briefly were as follows: In one group of dogs used as a control series, the circumflex artery was ligated at its origin. Twenty per cent of these dogs survived. In the second group, which was prepared in advance by coronary venous ligation, the circumflex artery was ligated as in group one. Forty per cent of this group lived. In the third group, prepared in advance by pericoronary neurectomy, ligation of the circumflex was done as in the previous groups. Sixty per cent survived. In the fourth group, prepared in advance by pericoronary neurectomy and coronary venous ligation, the circumflex was again ligated as in the previous groups. The survival rate rose to eighty-six per cent. He reported one case of coronary disease with angina on whom pericoronary neurectomy combined with ligation of the great cardiac vein was carried out. Fauteux (19) feels that it is

fundamental to act simultaneously against both mechanical and vasomotor disorders in coronary disease to achieve better results through operation, and that coronary venous ligation combined with pericoronary neurectomy should be tried and carefully studied in correctly selected cases of coronary disease.

B. With Arterialization of Coronary Sinus

Arterialization of the coronary sinus was suggested by Pratt (46) in 1898. Concerning the possibility of the formation of an arteriovenous fistula for vascularization of an ischemic heart, Roberts, Browne, and Roberts (49) reported on fourteen dogs in which arterial blood was brought to the myocardium by a glass cannula connecting the coronary sinus with the brachiocephalic, subclavian, or innominate artery. After ligation of coronary arteries and branches, the heart beat was preserved for variable periods of time. Later dye was injected under pressure into the coronary sinus and a complete injection of the myocardium was revealed. These authors suggested that an ischemic myocardium might be revascularized by anastomosis of a large artery with the coronary sinus and coronary veins.

In 1946 Beck began a series of experiments which seemed to be more effective in supplying the heart with

oxygenated blood. Careful consideration of the coronary circulation presented several possibilities. Wearn and his associates (66) had shown that an appreciable amount of the coronary arterial blood (up to 30 per cent) does not leave the heart by its major venous channels. This blood presumably leaves the myocardium by way of the Thebesian channels or by other exits. Gross and Fauteux had already shown that the heart could tolerate and derive some measure of benefit from ligation of the coronary sinus. Beck postulated that the venous system of the heart could be converted into an accessory arterial system by perfusing the venous system with arterial blood, allowing it to find its exit through other channels. In 1948 Beck, Stanton, Batiuchok, and Leiter (8) reported the difficulty, progress, and degree of benefit in revascularization of the myocardium by graft of a systemic artery into the coronary sinus. During the two years prior, seven hundred operations were done on three hundred and fifty dogs. There was difficulty in securing a patent anastomosis and many anastomoses later on became occluded by thrombus. They feel that left ventricular ecchymosis consequent upon the complete sinus occlusion plus arterIALIZATION is due to malnutrition and disease in the dogs, and that in healthy dogs the coronary sinus and its tributaries can tolerate arterial pressure. The coronary

sinus was ligated first, and ten to fourteen days later the left common carotid artery was anastomosed to the sinus. Measurements of benefit were made by complete ligation of the descending ramus of the left coronary artery at its origin and then determination of the results. Mortality was markedly reduced in the group of dogs with a patent anastomosis; destruction of the myocardium was also slight or absent in the group of dogs with patent anastomoses. Retrograde flow through the coronary artery was determined. Prior to anastomosis it was 9 c.c. per minute, and after anastomosis 22 c.c. per minute. On the basis of these experiments it appeared that blood could enter the arterial bed from the venous bed.. No experiments were done on oxygen-exchange of the arterial blood in a venous system, or whether any of the arterial blood from the venous side by-passes the capillary bed and escapes into the chambers of the heart without giving up its oxygen.

Beck (5) reported on a patient with severe coronary artery disease on whom this operation was performed. A free graft of the brachial artery was placed between the aorta and coronary sinus. Death occurred after twenty-four hours. A fresh infarct developed in the interventricle septum probably at the time of operation; however, the anastomosis was patent at the time of death.

In a discussion of this latest type of operation by Beck, Leiter (35) states that physiologic experiments are being performed to determine the amount of flow which can be tolerated in the venous graft and in the coronary venous system. It had not been determined whether ligation of the sinus should be done prior to or at the time of anastomosis. After ligation the pressure in the coronary sinus reaches levels of arterial pressure but returns to near normal in about three weeks. He further states that there is some vascular damage with hemorrhage and perivascular fibrosis, and with the prolonged arterial pressures of a patent anastomosis these changes may progress to total fibrosis in long term experiments. Postoperative stasis in the veins has been a serious complication; apparently there is a variable time element involved before widening of the Thebesian channel takes place. He feels that perhaps the greatest problem is whether a diseased heart will be able to tolerate the extensive surgery involved.

Stenstrom (54) reported three hundred and fifty-six operations on two hundred and forty dogs. The operations consisted of anastomosis between a systemic artery and the coronary sinus plus coronary artery ligation. He concluded that occasionally arterial blood could be delivered to the myocardial capillary

bed through the veins. The frequency of acute left ventricular hemorrhage and anastomotic occlusion was stressed. In a more recent report (55), Stenstrom carried out additional operations consisting of partial and complete coronary sinus occlusion, anastomosis between the carotid artery and the open and closed sinus plus coronary artery ligation. Coronary sinus occlusion in the normal dog heart frequently produced hemorrhage, degeneration, and necrosis in the myocardium. Acute arterialization of the closed coronary sinus with reversal of circulation with survival was not produced. Death was not prevented by simultaneous arterialization of the closed sinus plus ligation of the main left coronary artery. An arterio-sinus-right atrium fistula was produced a number of times, apparently without early ill effect. He felt that gradual reversal of circulation in the cardiac veins would be more successful.

Johns, Sanford, and Blalock (32) reported a series of experiments in 1950 in which artificial shunts between the coronary sinus and either the carotid artery or the pulmonary artery were established. The results were in agreement with Stenstrom and others in showing that an arterial anastomosis to the sinus which has been occluded at its ostium results in damage to the superficial myocardium of the left ventricle. The creation of an anas-

tomosis between a systemic artery and the ligated coronary sinus results usually in death of the animal or thrombosis of the anastomosis, while such an anastomosis to the patent coronary sinus is more often followed by survival and an open anastomosis but probably with little or no back flow of blood into the coronary venous system. The authors believe that the results demonstrate the difficulty of the procedure itself, the seriousness of the damaging changes it produces in the myocardium, and the uncertainty and inconsistency of the benefits which may follow. In the occasional case in which a successful operation leads to prolonged arterialization, there appears to be some protection against coronary artery occlusion and the development of myocardial infarction.

V. ARTERIAL TRANSPLANT INTO MYOCARDIUM

In 1946, Vineberg (63) published experimental evidence in dogs that the internal mammary artery when transplanted into the left ventricle of the heart developed anastomotic channels with the left coronary circulation after an adequate period of time. This was demonstrated by the free flow of injection fluid from the cannulated internal mammary artery into the branches of the left coronary artery after four months. The following year Vineberg and Jewett (64) reported on dogs in which

the left internal mammary artery was transplanted into the wall of the left ventricle. Scar tissue formed about the transplanted internal mammary artery frequently and in only fifty per cent of the animals was the artery patent throughout. In ninety per cent the internal mammary artery after transplantation revascularized the surrounding structures; twenty per cent showed a definite communication and anastomosis with the left coronary artery.

More experiments of the same type were reported by Vineberg (65) in 1949. Of the total number of operations only sixteen per cent of the animals showed proven anastomoses with the left coronary artery. Vineberg relates technical difficulties found in the dog which are not present in the human, and because of these differences believes transplantation of the internal mammary artery into the wall of the left ventricle, in human cases of coronary artery disease, would have a better chance of forming a new vascular bed.

VI. DISCUSSION AND CONCLUSIONS

Thousands of experiments on dog's hearts have been carried out by the investigators doing the experimental work on surgical revascularization of the heart. In nearly all of the papers reviewed the authors had pre-

viously investigated their ideas in the laboratory before application to the human heart. This is very definitely as it should be and one can only be critical of the surgeon going ahead with operations on the human heart in the hope that the patient would be helped and that science would come later.

During the past twenty years many attempts have been made to augment impaired coronary circulation. Four main procedures have been described. The first of these is dependent upon the grafting of a vascular structure to the ventricular wall such as the pectoral muscle of Beck or the great omental graft of O'Shaughnessy. The second procedure employs the parietal pericardium as a source of fresh blood. Talc powder or asbestos fibers are introduced into the pericardial sac. The reaction caused by the foreign body particle stimulates the formation of granulation tissue between the visceral and parietal pericardium. The third procedure, described by Fauteux, depends upon ligation of the great cardiac vein to increase ventricular circulation. This procedure has been modified, or added to, recently combining it in one instance with pericoronary neurectomy by Fauteux and in another instance with arterialization of the coronary sinus by Beck and Stenstrom. More recently, for the fourth procedure, Vineberg and Jewett have suggested transplanta-

tion of the internal mammary artery into the wall of the left ventricle for the purpose of improving its nutrition.

With exception of the fourth, all procedures have been carried out upon human cases of coronary artery disease. The first two methods bring a fresh supply of arterial blood to the ventricle through a layer of granulation tissue. Although actual direction of flow and amount of flow in extracoronary communications in grafts or adhesions was not determined, postmortem injections of the vessels demonstrate that these vessels do communicate with the vessels in the myocardium, and the investigators accepted the decrease in mortality and size of infarcts after ligation of a major coronary artery as indication of additional myocardial blood supply through the grafts and adhesions. The scientific controversy which exists about the value of such communicating vessels, particularly whether an adequate amount of blood is able to pass through the vessels to the ischemic myocardium, and also whether the blood really flows toward the heart or actually away from the heart, seems to be of academic interest, particularly when the clinical result is obvious. With the third method, coronary vein ligation appeared highly controversial but several investigators, in face of the un-

favorable evidence of the physiologists, continued their research. Ligation of the coronary sinus is not an entirely innocuous operation. It is true that the mortality rate is low, but hemorrhage and congestion occur in the superficial myocardium of the left ventricle and the local appearance is an alarming one. However, this procedure now has developed into a very integral part of some of the most recent research--coronary vein ligation and pericoronary neurectomy or coronary sinus arterialization. The procedure partially relies upon venous occlusion to open anastomoses between partially thrombosed coronary arteries, arterial sinusoidal vessels, and coronary veins. Carried over into clinical experience the results with pericoronary neurectomy have been promising; but a much wider application of the method will be required to establish its place in practice. Concerning arterialization of the cardiac veins, coronary sinus obstruction appears to be necessary in order to reverse the circulation in the left ventricle. While such obstruction carries a low mortality rate, the venous stasis produced causes myocardial lesions in a great number of hearts. It is not known whether the same myocardial effects would be produced with acute sinus occlusion in a heart with a chronically deficient arterial supply, as the work done has reference to the dog heart with a pre-

sumably normal coronary artery outflow. It is advisable to point out that the hypothesis that tissues may be nourished effectively by the backward flow of blood through the capillary bed remains unproved this far. Vineberg's and Jewett's experimental studies have not yet been supported by clinical trial, but new vascular channels have appeared in the myocardium of dogs after the transplant.

It is readily noted that this field of surgery is largely experimental, there having been very little therapeutic trial in human patients. The review of the literature only briefly cited the various operations and number of patients operated upon; therefore, a table has been compiled from the facts available (and indeed these facts have turned out to be meager) to summarize as briefly and informatively as possible the procedures applied to and the results derived from the experimental therapeutic trials. A summary of clinical data (see Table I) shows that 119 human patients have undergone some type of surgery for the revascularization of the heart as a treatment for their coronary arterial disease. Only in a few of these are the patients very adequately described both preoperatively and postoperatively. None are critically analyzed as to results achieved over a long period of time, only mention as to survival is made

Observer	No. of Cases	Av. Age	Operative Procedure	Opera. Mortal.
1. Beck (22)	37	54	Inflammation of surface of heart and implanting grafts.	14 (3)
2. Thompson (59)	36	?	Cardiopericardiopexy using talc.	6 (1)
3. O'Shaughnessy (15,43)	14 6	59 56	Cardioomentopexy. Cardiopericardiopexy using aleuronat.	1 (7) 0
4. Rakov (47)	2	74	Cardiopericardiopexy using sodium morrhuate without pericardotomy.	0
5. Fauteux (18,19,21)	10 1 9	? ? ?	Coronary venous ligation. Pericoronary neurectomy. Coronary venous ligation with pericoronary neurectomy.	1 (1) 1 (1) 1 (1)
6. Beck (5)	1	45	Coronary sinus ligation with arterialization of coronary sinus.	0
7. Carter (12)	2	?	Cardiopneumopexy.	0
8. Gorelik (24)	1	54	Cardiopericardiopexy using talc method of Thompson.	0
TOTAL	119	?	ALL PROCEDURES	24 (2)

* Ex

† Go

** St

TABLE I

SUMMARY OF CLINICAL DATA IN HUMAN PATIENTS

Survival Period	Postmortem		Condition after Operation				Still Living
	Survival Period	Cases - %	Excellent*	Good†	Little or no Improvement	Not Followed	
4 mos to 6 yrs	9 (24.5%)	14	5	4	0	14 (3	
3 wks to 6.9 yrs	5 (14%)	19	4	4	2	23 (6	
7 das to 3 mos	4 (28.5%)	0	9	2	0	9 (6	
2 mos	1 (16%)	0	2	4	0	5 (8	
?	?	?	?	?	2	2 (1	
3 mos to 2.5 yrs	2 (20%)	5	3	1	0	7 (7	
- - -	0	0	0	0	0	0	
2.5 yrs	1 (11%)	?	?	?	9	?	
24 hours	1 (100%)	0	0	0	0	0	
36 hours	1 (50%)	1	0	0	0	1 (50	
- - -	0	1	0	0	0	1 (10	
24 hrs to 6.9 yrs	24 (20.2%)	40	23	15	13	62 (52	

Excellent: Sufficient improvement to permit patient to return to his former occupation with no or minimal symptoms.

Good: An increase in exercise tolerance and diminution in symptoms.

Still Living: At time of report of various publications.

Still Living**	Av. Duration of Life Following Operation of Pats. Still Living	Remarks
14 (37.8%)	6.9 yrs	Long term autopsy findings not available.
23 (64%)	Unknown	Long term autopsy findings not available. 4 additional cases since report with "no deaths and marked improvement."
9 (64%) 5 (84%)	Unknown Unknown	Long term autopsy findings not available.
2 (100%)	Unknown	Very brief mention made in report of condition of pats. ("apparent beneficial results") and follow-up.
7 (70%) 0 ?	4.9 yrs - - - Unknown	Follow-up reports not found on operations of past 5-6 years.
0	- - -	Circulatory failure was cause of death; postmortem showed recent infarction of myocardium.
1 (50%)	1 yr	Postmortem showed overwhelming infection in the one case.
1 (100%) 62 (52%)	3 mos	5 additional cases operated upon since report with "excellent results" and to be reported later.

in some instances. The overall operative mortality was 20.2 per cent and an additional 20.2 per cent came to autopsy over a period of time from 24 hours to 6.9 years following operation. 52 per cent of the patients were still living at the time of the various reports, varying from a duration of 3 months to 6.9 years. From the number of clinical cases reported, it is impossible to evaluate the results of the various methods and determine the procedure of choice. Certainly in these few human patients the clinical results have been encouraging but the amount of autopsy material available to give definite evidence as to the state of the revascularization and the amount of effective collateral circulation is still meager.

The medical problems (59) which arise in connection with the surgical treatment of coronary artery disease include the following: (1) the establishment of criteria for the selection of patients, (2) preoperative study and preparation, (3) postoperative management, and (4) the evaluation of results.

Haphazard selection of patients with "severe coronary disease" should be deplored. Criteria upon which selection is based have been extremely rigorous. The subjective criterion of a clearly defined anginal syndrome, pain of characteristic nature and distribution,

and with a definite relationship to exertion is basic. Objective evidence of coronary and myocardial disease in the form of physical, electrocardial, and roentgenological findings is of equal importance. The absence of improvement under fairly prolonged medical management and an extreme degree of disability necessitating greatly limited physical activities are additional criteria. A previous coronary occlusion is not considered a contraindication, but any active myocardial process should be ruled out. Congestive heart failure is a contraindication if there are any clinical evidences of passive congestion.

Preoperative study should begin with a complete history and physical examination, serial electrocardiography, chest x-ray and fluoroscopy. Later circulation time and venous pressure may be determined. Complete blood count and sedimentation rate are essential.

Postoperative management must be individualized--physical and x-ray findings may substantiate pneumonitis, mediastinitis, pericardial effusion. On the whole the complications have been minimal, but specific therapy is indicated in any of the complications.

Actual selection of cases at one time or another by the surgeons has been guided by the principle that

operation is justified if the patient has nothing to lose and possibly something to gain. Thus, many of these groups of cases represents cardiac derelicts with advanced coronary disease and under ordinary circumstances a hopeless prognosis. However, most of the patients have tolerated the operations well and the postoperative course has gone on rather smoothly. Nevertheless, simplicity of the operation must be stressed. In the evaluation of results most authors have felt gratified. The exact degree of relief or improvement is difficult to measure. The nearest approach to an objective test is the exercise tolerance test as done under basal conditions. Also the degree of relief by the subjective test, namely, relief of the patient's symptoms, can be calculated; this is certainly far from an accurate method, but in so far as the patient is concerned it is paramount.

Attempts to transfer the prospects of any operative procedure from the experimental animal to the human subject with coronary disease must always take into account the usual widespread vascular handicap in the latter. It must be borne in mind that until it is possible to duplicate this condition in animals and from that baseline to induce coronary occlusion, the clinical projection and application of experimental studies may

be presumptive and the results relatively fortuitous.

It must be recognized that no surgical procedure can replace the diseased myocardium or stop the progressive changes occurring within the coronary arteries. It has been shown, however, that it is feasible to add sufficient blood to the ischemic areas of the myocardium to relieve anginal pain and to prevent or limit the extent of subsequent episodes of infarction. There must be sufficient good myocardium to maintain life or the improved coronary circulation will be ineffectual. Therefore, if the operative mortality is to be kept within reasonable limits in this group of patients, the candidates for the operation should be carefully selected, both as to extent and degree of coronary artery sclerosis and as to associated pathologic conditions. Details of preoperative and postoperative care must be carefully observed and the surgical procedure must be as technically simple as possible.

VII. SUMMARY

1. The literature concerning surgical revascularization of the heart has been reviewed.

2. Four procedures for revascularization were studied: (1) grafts to the myocardium, (2) pericardial adhesions, (3) coronary vein ligation with either (a) peri-

coronary neurectomy or (b) arterialization of the coronary sinus, and (4) arterial transplant to the myocardium.

3. A table is presented summarizing 119 human cases in which the various operative procedures have been applied. The operative mortality for all the various operations was 20.2% and an additional 20.2% came to autopsy within a 6.9 year period. 52% of the patients were still living at the time of the various reports, ranging up to a 6.9 year period.

4. Although the clinical results have been encouraging, it is impossible to determine at this time which operative procedure can be best applied to surgical revascularization of the heart because of the inadequate postoperative follow-ups and the meagerness of autopsy material, chiefly of patients long after surgery with apparent clinical improvement.

VIII. BIBLIOGRAPHY

1. Beck, C.S.: The Effect of Surgical Solution of Chlorinated Soda (Dakin's Solution) in the Pericardial Cavity, Arch. Surg. 18:1659, 1929.
2. Beck, C.S.: The Development of a New Blood Supply to the Heart by Operation, Ann. Surg. 102: 801, 1935.
3. Beck, C.S.: Further Data on the Establishment of a New Blood Supply to the Heart by Operation, J. Thoracic Surg. 5:604, 1936.
4. Beck, C.S.: Coronary Sclerosis and Angina Pectoris: Treatment by Grafting New Blood Supply upon Myocardium, Surg. Gynec. Obstet. 64:270, 1937.
5. Beck, C.S.: Revascularization of the Heart, Ann. Surg. 128:854, 1948.
6. Beck, C.S., and Griswold, R.A.: Pericardiectomy in the Treatment of the Pick Syndrome: Experimental and Clinical Observations, Arch. Surg. 21:1064, 1930.
7. Beck, C.S., and Mako, A.E.: Venous Stasis in the Coronary Circulation; Experimental Study, Am. Heart J. 21:767, 1941.
8. Beck, C.S., Stanton, E., Batiuchok, W., and Leiter, E.: Revascularization of Heart by Graft of Systemic Artery into Coronary Sinus, JAMA 137: 436, 1948.
9. Beck, C.S., and Tichy, V.L.: Production of Collateral Circulation to the Heart; Experimental Study, Am. Heart J. 10:849, 1935.
10. Beck, C.S., Tichy, V.L., and Moritz, A.R.: Production of a Collateral Circulation to the Heart, Proc. Soc. Exper. Biol. & Med. 32:759, 1935.
11. Burchell, H.B.: Adjustments in Coronary Circulation after Experimental Coronary Occlusion: With Particular Reference to Vascularization of Pericardial Adhesions, Arch. Int. Med. 65:240, 1940.

12. Carter, B.N.: Discussion of Paper by Beck, Ann. Surg. 128:862, 1948.
13. Carter, B.N., Gall, E.A., and Wadsworth, C.L.: An Experimental Study of Collateral Coronary Circulation Produced by Cardiopneumopexy, Surg. 25:489, 1949.
14. Cox, W.V., and Robertson, H.F.: Effect of Stellate Ganglionectomy on the Cardiac Function of Intact Dogs and Its Effect on the Extent of Myocardial Infarction and on Cardiac Function Following Coronary Artery Occlusion, Am. Heart J. 12:285, 1936.
15. Davies, D.T., Wales, M.D., Mansell, H.E., Oxon, B.M., and O'Shaughnessy, L.: Surgical Treatment of Angina Pectoris, Lancet 1:1, 1938.
16. Fauteux, M.: A New Method for Developing a Better Collateral Blood Supply to the Heart, Canad. M. A.J. 38:186, 1938.
17. Fauteux, M.: Experimental Study of the Surgical Treatment of Coronary Disease, Surg. Gynec. Obstet. 71:151, 1940.
18. Fauteux, M.: Treatment of Coronary Disease with Angina by Pericoronary Neurectomy Combined with Ligation of Great Cardiac Vein; Case, Am. Heart J. 31:260, 1946.
19. Fauteux, M.: Surgical Treatment of Angina Pectoris; Experience with Ligation of the Great Cardiac Veins and Pericoronary Neurectomy, Ann. Surg. 124:1041, 1946.
20. Fauteux, M., and Palmer, J.H.: Treatment of Angina Pectoris of Atheromatous Origin by Ligation of the Great Cardiac Vein, Canad. M.A.J. 45:295, 1941.
21. Fauteux, M., and Swenson, O.: Pericoronary Neurectomy in Abolishing Anginal Pain in Coronary Disease, Arch. Surg. 53:169, 1946.
22. Feil, H.: Clinical Appraisal of the Beck Operation, Ann. Surg. 118:807, 1943.

23. Feil, H., and Rossman, P.L.: Electrocardiographic Observations in Cardiac Surgery, *Ann. Int. Med.* 13:402, 1939.
24. Gorelik, A.N., and Krell, S.: Cardiopericardiopexy for the Treatment of Coronary Artery Disease, *N.Y. St. J.M.* 50:2201, 1950.
25. Gregg, D.E., and Dewald, D.: Immediate Effects of the Occlusion of the Coronary Veins on Collateral Blood Flow in the Coronary Arteries, *Am. J. Physiol.* 124:435, 1938.
26. Gregg, D.E., and Dewald, D.: Immediate Effect of the Occlusion of the Coronary Arteries, *Am. J. Physiol.* 123:84, 1938.
27. Gregg, D.E., and Dewald, D.: Immediate Effects of Coronary Sinus Ligation on Dynamics of Coronary Circulation, *Proc. Soc. Exper. Biol. & Med.* 39:202, 1938.
28. Gross, L., Blum, L., and Silverman, G.: Experimental Attempts to Increase Blood Supply to the Dog's Heart by Means of Coronary Sinus Occlusion, *J. Exper. Med.* 65:91, 1937.
29. Heinbecker, P., and Barton, W.A.: Operation for the Development of Collateral Circulation to the Heart, *J. Thoracic Surg.* 9:431, 1940.
30. Heinbecker, P., and Barton, W.A.: An Effective Method for the Development of Collateral Circulation to the Myocardium, *Ann. Surg.* 114:186, 1941.
31. Hudson, C.L., Moritz, A.R., and Wearn, J.T.: The Extracardiac Anastomoses of the Coronary Arteries, *J. Exper. Med.* 56:919, 1932.
32. Johns, T.N.P., Sanford, M.C., and Blalock, A.: An Experimental Study of the Anastomosis of Arteries to the Coronary Sinus of the Heart of the Dog, *Bull. Johns Hopkins Hosp.* 87:1, 1950.
33. Katz, L.W., Jochim, K., and Bohning, A.: Effect of Extravascular Support of Ventricles on Flow in Coronary Vessels, *Am. J. Physiol.* 122:236, 1938.

34. Leary, T., and Wearn, J.T.: Two Cases of Complete Occlusion of Both Coronary Orifices, *Am. Heart J.* 5:412, 1930.
35. Leiter, E.: Revascularization of the Heart, *J. of Ia. St. Med. Soc.* 40:252, 1950.
36. Leriche, R., and Heitz, J.: De la reaction vasodilatatrice consecutive a la resection d'un segment arteriel oblitere, *Compt. rend Soc. de biol.* 30:160, 1917. (from Fauteux, *Am. Heart J.* 31:260, 1946)
37. Lezius, A.: Die kunstliche Blutversorgung des Herzmuskels, *Arch. klin. Chir.* 189:342, 1937.
38. Lezius, A.: Die anatomischen und funktionellen Grundlagen der kunstlichen Blutversorgung des Herzmuskels durch die Lunge bei Coronararterienverschluss, *Arch. klin. Chir.* 191:101, 1938.
39. Mautz, F.R., and Beck, C.S.: The Augmentation of Collateral Coronary Circulation by Operation, *J. Thoracic Surg.* 7:113, 1937.
40. Moritz, A.R., and Beck, C.S.: The Production of a Collateral Circulation to the Heart. II. Pathological-Anatomical Study, *Am. Heart J.* 10: 874, 1935.
41. Moritz, A.R., Hudson, C.L., and Orgain, E.S.: Augmentation of the Extracardiac Anastomoses of the Coronary Arteries Through Pericardial Adhesions, *J. Exper. Med.* 56:927, 1932.
42. O'Shaughnessy, L.: An Experimental Method for Providing a Collateral Circulation to the Heart, *Brit. J. Surg.* 23:665, 1936.
43. O'Shaughnessy, L.: Surgical Treatment of Cardiac Ischemia, *Lancet*, 1:185, 1937a.
44. O'Shaughnessy, L., Slome, D., and Watson, F.: Surgical Revascularization of the Heart: The Experimental Basis, *Lancet*, 1:617, 1939.
45. Otto, H.L.: The Extracardiac Nerves: IV. An Experimental Study of Coronary Obstruction, *Am. Heart J.* 4:64, 1928.

46. Pratt, F.H.: The Nutrition of the Heart Through the Vessels of Thebesius and the Coronary Veins, Am. J. Physiol. 1:86, 1898.
47. Rakov, H.L., and Kingston, N.Y.: Therapeutic Pericarditis by Intrapericardial Injection in Chronic Coronary Insufficiency, Preliminary Report, Am. Heart J. 23:803, 1942.
48. Rienhoff, W.F., Jr.: Discussion of Paper by Beck: The Development of a New Blood Supply to the Heart by Operation, Ann. Surg. 102:811, 1935.
49. Roberts, J.T., Browne, R.S., and Roberts, G.: Nourishment of the Myocardium by Way of the Coronary Veins, Federation Proc. 2:90, 1943.
50. Robertson, H.F.: The Vascularization of Epicardial and Periaortic Fat Pads, Am. J. Path. 6:209, 1930.
51. Schauer, G., Gross, L., and Blum, L.: Hemodynamic Studies in Experimental Coronary Occlusion: Stellate Ganglion Experiments, Am. Heart J. 14:669, 1937.
52. Schildt, P., Stanton, E., and Beck, C.S.: Communications Between the Coronary Arteries Produced by the Application of Inflammatory Agents to the Surface of the Heart, Ann. Surg. 118:34, 1943.
53. Stanton, E.J., Schildt, P., and Beck, C.S.: The Effect of Abrasion of the Surface of the Heart Upon Intercoronary Communications, Am. Heart J. 22:529, 1941.
54. Stenstrom, J.D.: Vascularization of the Myocardial Capillary Bed by Arterialization of the Cardiac Veins: An Experimental Study, Canad. M.A.J. 59:520, 1948.
55. Stenstrom, J.D.: Vascularization of the Myocardial Capillary Bed by Arterialization of the Cardiac Veins: An Experimental Study, J. Internat. Coll. Surgeons, 12:417, 1949.
56. Thompson, S.A.: Development of Cardiopericardial Adhesions Following the Use of Talc, Proc. Soc. Exper. Biol. & Med. 40:260, 1939.

57. Thompson, S.A.: An Operation for the Relief of Coronary Artery Disease: A Preliminary Report, Quart. Bull. Sea View Hosp. 5:175, 1940.
58. Thompson, S.A., and Raisbeck, M.J.: Cardioperi-cardiopexy: The Surgical Treatment of Coronary Artery Disease by the Establishment of Adhesive Pericarditis, Ann. Int. Med. 16:495, 1942.
59. Thompson, S.A., and Raisbeck, M.J.: The Surgical Rehabilitation of the Coronary Cripple, Ann. Int. Med. 31:1010, 1949.
60. Thorel, C.H.: Pathologie der Kreislauforgane, Ergebn. allg. Path. u. path. Anat. 9:559, 1903. (from Moritz, Hudson, & Orgain, J. Exper. Med. 56:927, 1932)
61. Thornton, J.J., Gregg, D.E., and Mautz, F.R.: Magnitude, Adequacy and Source of Collateral Blood Flow and Pressure in Chronically Occluded Coronary Arteries, Am. J. Physiol. 127:161, 1939.
62. Thornton, J.J., and Gregg, D.E.: Effect of Chronic Cardiac Venous Occlusion on Coronary Arterial and Cardiac Venous Hemodynamics, Am. J. Physiol. 128:179, 1939.
63. Vineberg, A.M.: Development of an Anastomosis Between the Coronary Vessels and a Transplanted Internal Mammary Artery, Canad. M.A.J. 55:117, 1946.
64. Vineberg, A.M., and Jewett, B.L.: Development of Anastomosis Between Coronary Vessels and Transplanted Internal Mammary Artery, Canad. M.A.J. 56:609, 1947.
65. Vineberg, A.M.: Development of Anastomosis Between the Coronary Vessels and a Transplanted Internal Mammary Artery, J. Thoracic Surg. 18:839, 1949.
66. Wearn, J.T., Mettier, S.R., Klumppe, T.G., and Zschiesche, L.J.: Nature of Vascular Communications Between Coronary Arteries and Chambers of Heart, Am. Heart J. 9:143, 1933.
67. Yodice, A.: Sympathectomy and Experimental Occlusion of an Artery, Am. Heart J. 22:545, 1941.