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The Surgical treatment of angina pectoris and coronary throbosis

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THE SURGICAL TREATMENT OF ANGINA PECTORIS AND CORONARY THROMBOSIS

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INTRODUCTION

It might be as well to preface any discussion of the surgical treatment of angina pectoris with a brief consideration of the anginal patients lot and what purely medical measures can do to alleviate it. From Heberden's day "angina pectoris" has been the name given to a symptom-complex, the peculiar feature of which is the possibility of sudden death; modern research has shown that its cause is defective coronary circulation. From the first attack the victim's activity is curtailed, to the particular disgust of the active type of person most prone to angina, and that curtailment is usually progressive. In severe cases fear of the next attack with its agonizing pain weighs heavier than the "angor Animi" which accompanies one. Prognosis is impossible. "The cardinal fact in real angina is its uncertainty" (Osler 1925). Approximately half of the series published by Levine and Eppinger (1934) died suddenly. The disease marches inexorably, for the pathological condition underlying it is defective coronary circulation due to changes in the coronary tree which are irreversible and progressive. Clearly its progress cannot be arrested by physic, and this remark is most true of that catastrophe which awaits every victim of angina--coronary thrombosis. It must not be thought that nothing can be done to alleviate the disease. Much can be achieved by skillful management, which would include avoidance of the factors which precipitate pain (such as emotional stress, undue exertion, heavy meals, or exposure to cold), reduction of the

patient's weight, and the use of nitrites for individual paroxysns. But granted the value of such measures as these, it must be repeated that they can only alleviate angina, and avail not either to attack its underlying cause or to postpone the catastrophe of coronary thrombosis. Medicine, in short, can do much to lighten the lot but little to alter the prognosis of the patient with coronary disease.

The past decade has seen the beginning in this country and in England, of a planned attempt at radical surgical treatment of myocardial ischemia, be it angina pectoris, coronary thrombosis, or coronary arteriosclerosis, or the combination of the three as the case may often be. The classical anginal pain arises in the myocardium and can be regarded as the cry of a distressed heart muscle for more oxygen, for lack of which it cannot beat strongly enough to let its owner walk in comfort or sometimes it cannot beat at all. It has been slowly or suddenly starved of oxygen by the atheromatous or arterio-sclerotic throttling of its own blood-vessels, the coronaries. The medical man has attempted to solve the problem by achieving prevention of this disease process which is better than curing it once it is established. The surgeon has approached it from a different angle--he has tried to correct or improve the condition once it has occured. Until more is known about the exact mechanism and etiology of atheromatous and arteriosclerotic vessel changes and how they can be prevented, then perhaps the newer, more radical, and as yet unproven worth

of surgical treatment should be investigated more carefully.

It is the object of this paper to review the work that has been done on this new concept and to try to arrive at an opinion as to its merit. Since the whole field is yet in its infancy no definite and accurate statement could be made at this time as to the real worth however. Only time will reveal this. The prospect of adding years of active life and comfort for a group of people whose bodies usually have been aging faster than their minds, by some sort of treatment, be it surgical or medical, would indeed be a great achievement.

PRODUCTION OF A COLLATERAL CORONARY CIRCULATION BY OPERATION

The only direct continuity between the heart and the rest of the body is through the structures at its base--the great vessels, fat, lymphatics, and nerves. Because of this anatomical arrangement the heart has been deprived to a great extent of an important compensatory property, namely the ability to develop a collateral compensatory circulation to meet an emergency, to preserve life during the first few months, days and weeks after a serious coronary accident. If life is preserved over a sufficiently long period of time after occlusion of a coronary artery has taken place, a collateral circulation of variable efficiency is produced. However, the appalling incidence of death from coronary occlusion attests to the destructive nature of the disease. It attests also the inadequacy of all compensatory circulations in so far as the preservation of the heart beat is concerned.

Beck first began his experiments in February, 1932. This was the first work done along this line of approach to the subject. Before his experimental study two facts existed that gave some encouragement to proceed with the work. One was the demonstration of small blood vessels in the fat at the base of the heart anastomosing with the coronary system. The other was the presence of blood vessels in cardiopericardial adhesions. It was not known whether these extracardiac anastomoses were of any functional value at the time the experiments were begun. It wasn't known whether anastomotic channels could be produced; and

whether if produced, they could transport sufficient quantities of blood to benefit the myocardium to any appreciable degree.

The surgical approach to the treatment of coronary artery sclerosis was established upon a scientific basis. Beck (1932) compared coronary artery disease to epilepsy. The trigger in the heart "fires" or discharges and produces a state of incoordinated contractions and relaxations of the heart muscle fibers. This is the well known "heart attack" and is fatal. A small amount of blood to the zone of anoxemia can prevent the trigger from "firing". This may be regarded as a blood-bath and can be produced by operative methods.

A brief review of the experimental work done by Beck, Tichy, Moritz, Mautz, and Bright and others will show the great extent to which these men went in order to justify the application of this new concept to the treatment of myocardial ischemia in men. They carried out several thousand experimental operations upon the heart in a period of about ten years.

(1) A collateral vascular bed was produced by the following mechanical method. The mesothelial envelope around the heart was destroyed by roughening the lining of the parietal pericardium. The epicardium was roughened or removed in shreds by means of a metal burr. This was done first on one hundred and three dogs. The surface of the heart was abraded and then the effect was determined

upon the coronary circulation by later ligating one of the three major coronary arteries after a period of from one week to three months. They found it reduced the death rate from seventy per cent in the control group of unprepared dogs to thirty-eight per cent in the prepared group. In terms of recovery this was an increase in survival of from thirty per cent in the control unprepared group to sixty-two per cent in the group of dogs which had the heart surface abraded. Their conclusion was that abrasion exercised a favorable effect and that the infarct was smaller and could be prevented from forming in hearts that were abraded. The development of a common intercornary vascular bed following ligation depends on the existence of a difference in the pressure differential between the open arterial tree and the closed arterial tree. Small anatomic communications were opened up by this pressure. They enlarge till they carry a considerable quantity of blood. Abrasion of the heart protected it in two ways;, (a) provided an extracoronary source of blood supply, and (b) produced a more equitable distribution of blood between the coronary arteries. In some cases total occlusion of a coronary artery could be produced with fibrosis or infarction of

the myocardium. The anastomoses were demonstrated in two ways. A solution of barium sulphate was injected into a coronary artery and then chest roentgenograms were taken. From the heart anastomoses were seen which spread to the chest wall and filled internal mammary, many intercostal, diaphragmatic, and epigastric arteries. In the other method dye was injected into the aorta through one of the carotid arteries. The hearts with a collateral vascular bed showed varying degrees of capillary injection. The normal heart injected in this way showed a little dye in the major coronary arteries, a little in the fat at the base of the heart, but no capillary injection of the myocardium.

(2) The use of various inflammatory agents to produce a collateral vascular bed was also investigated by a number of men and hence a large number of different inflammatory agents have been used. Powdered beef bone was used by Beck at first; aleuronat was used by O'Shaughnessy (1938): talc was used by Thompson (1942): and a mixture of aleuronat, starch, glycerin, commercial gelatin, water and lionite was used by Heinbecker and Barton (1940). A number of other substances such as croton oil, iron filings, tincture of iodine, ether, chlorinated soda, alcohol,

kaolin, formaldehyde, sodium morrhuate, silicon, water class, cotton gauze, skin, and asbestos were used. The most desirable substance appeared to be one that produced a well vascularized type of granulation tissue without producing necrosis of the myocardium, severe exudation and cicatrization. Schildt, Stanton and Beck (1945) reviewed the effect of all of these substances. After a critical analysis they came to the conclusion silicate in the form of powdered asbestos produced the most favorable reaction. The inflammatory process brought about by asbestos was well vascularized. Amounts of about 0.2 grams distributed over the entire surface of the heart produced a more favorable reaction than did a larger quantity. It is slightly exudative in its effect but this is not severe and it does not preclude its use when employed in small quantities. It does not produce compression of the heart due to the formation of scar tissue. The inflammatory effect persisted over a period of several months. They later used it on human patients and the effect was satisfactory. Mortality in animals in which asbestos had been applied to the surface of the heart previous to ligation was thirty-two per cent. Mortality in fifty normal animals following

ligation of the descending ramus of the left coronary artery at its orgina was sixty-eight per cent. In some animals no infarct was produced after ligation in the prepared animals. In all the size of the infarct when it did develop was reduced. They came to the conclusion that many of the inflammatory agents used on the heart may not be without harmful side-effects and thus should not be used indiscriminately. Anastomoses were demonstrated by the use of dye and barium injections.

(3) The production of a new vascular bed by bringing various grafts onto the myocardium was another method by which a new coronary circulation could be produced. The tissues that were used included pericardium, mediastinal fat, pericardial fat, pedicle grafts of skeletal muscle from the chest wall, omentom brought up through an opening in the diaghragm, lung, stomach, and spleen. Anastomoses between the grafts and the heart could be demonstrated in three weeks after the grafts were placed. Anastomoses increased after a physiological need for blood was established in the myocardium. The physiological need for blood is a pressure-differential between the vascular bed of the grafted tissues and the vascular bed of the myocardium. Beck was again the instigator of original research in

this new method of producing a new vascular bed to the heart. He was soon followed by O'Shaughnessy (1936) in England, who in his work used omentum for his grafts and brought it though an opening in the diaphragm and applied it to the apical region of the ventricles. After performing experiments upon animals he applied the procedure to patients, beginning in January 1936. Although O'Shaughnessy claimed originality for the idea of cardio-omentopexy, Beck and Tichy had first used it in 1932. This procedure was dropped by Beck because of the development of herniations in some of his experiments. O'Shaughnessy however states "diaphragmatic hernia was naturally considered as a possible complication of cardio-omentopexy, but we have not seen it in man, it has not occurred in the grey-hounds which were subjected to great physical strain after their operation, and we do not now believe it to be a serious danger." In his earlier experiments and operations the omental graft was always sutured to the heart; this was later modified by suturing the graft to the pericardium only and applying aleuronat paste between the graft and the heart to cause intrapericardial adhesions. Cardio-omentopexy was thought to reinforce the new vessels formed in the

adhesions while the dange of placing sutures in a friable and degenerate heart was thereby avoided (O'Shaughnessy, 1938).

After the heart had been given a collateral vascular bed by the use of muscle grafts, Beck (1934-1935) then later ligated the right coronary artery and found that the survival rate was seventy-five per cent in these dogs. In the unprepared group the mortality rate after ligation of the coronary artery was seventy per cent, or the survival rate only thirty per cent. Beck stated that the grafted tissues did not seem to interfere with the movements of the heart and that cardiac adhesions were usually silent and incidental. He said this after observations of about five hundred experiments in which grafts were placed upon the heart.

Lately Weinstein and Shafiroff (1946) have done some work on grafts of free muscle upon the myocardium. They used seperate free grafts of skeletal muscle from the internal abdominal oblique and the vastus lateralis. They placed the graft around the heart and sutured it by cotton sutures. They obtained over fifty per cent takes and demonstrated on re-operation that the graft was not absorbed but was well fixed. There was no shrinkage with a definite rich vascular network present between the myocardium and the free muscle graft. They concluded that free muscle grafts could be successfully transplanted upon the myocardium.

Vineberg and Jewett (1947) have attempted to develop

communication between a transplanted internal mammary artery and the coronary vessels in a series of experiments on dogs. This was done in three ways; (a) bringing the cut free end of the internal mammary artery into a prepared tunnel in the wall of the left ventricle and then fixing it there (b) freeing the artery from its bed and suturing it into a slit made in the walls of the left ventricle (c) ligating the vena magna cordis and the anterior descending branch of the left coronary artery and then suturing the internal mammary artery into the wall of the ventricle as in the second method. Results in the last two methods were poor but in the first method they found a definite communication between the left coronary artery and the transplanted in twenty per cent of the dogs, in eighty per cent the internal mammary artery remained patent, and in ninety per cent the transplanted artery revascularized the surrounding structures. The reason for the failure in most cases was due to the formation of scar tissue around the transplanted internal mammary artery. Work is now being done to diminish the frequency of the scar formation, and in the event that this can be done it is possible that the procedure might be attempted on human subjects.

Thus we see after a brief review of the experimental work done on the subject, the rationale of trying the procedure on human patients. Beck (1935) began operating upon patients with coronary artery disease and in the following eight years completed a series of thirty-seven cases. Except for O'Shaughnessy's

similar work on a much smaller series of patients only Beck and his associates have attempted this type of operation on human subjects.

CLINICAL APPRAISAL OF THE BECK OPERATION

Beck began to operate on patients in 1935 after a period of four years of experimental work on dogs as reviewed before. In the following eight years he operated on a total of thirty-seven patients. As regards to the type of patients operated upon, the first of the series were ones who were suffering angina on slight exertion. They included patients with serious coronary disease (arteriosclerotic heart disease, severe angina pectoris, hypertension, coronary occulusion) and complicating factors such as generalized arteriosclerosis, diabetes, thromboangiitis, rheumatic heart disease, and others. Later in the series patients were selected with less severe coronary disease and without complicating factors. The diagnosis of coronary artery disease was definitely established and other pathologic conditions simulating the symptoms of angina were ruled out. Diabetes, if controlled, was not a contraindication, nor was hypertension alone. Pulmonary disease, such as bronchiectasis, chronic bronchitis, and severe emphysema, was a contraindication. The patients ages ranged from thirty-five to seventy years.

OPERATIVE TECHNIC

The operative technic changed slightly during its development during the years. Beck (1935, 1936, 1941, 1944) first used a

pedicle graft of the inferior portion of both the right and left pectoralis major muscles and used a bilateral approach. Later he used only a unilateral approach with pedicle grafts from the left pectoral muscle. Beck's (1943) method of operation is as follows: through a curved incision along the left sternal border over the fourth, fifth and sixth costal cartilages, these cartilages are completely removed and a small portion of the same ribs removed also. The pleural cavity is then entered. The internal mammary artery is left intact. Next the pericardium is then sutured to the precordium in such a way that the heart will not be rotated from its normal position. The lining of the parietal pericardium everywhere is roughened by special burs. Powdered asbestos, 0.2 Gm., is then applied to the heart. Some of this is rubbed into the parietal pericardium with a bur and some, mixed with saline, is dripped upon the heart and along the mammary artery and vein. Mediastinal fat is brought in through openings in the parietal pericardium so that it comes into contact with the heart. Fat, according to Beck, is one of the best tissues for vascularization. The parietal pericardium is then sutured to the chest wall so that the heart and the precordium are in contact. The internal mammary artery and the intercostal arteries are in close proximity to the heart. Closure is then carried out and the pectoral muscle is sutured where it was incised. No drains were used.

CLINICAL RESULTS OF OPERATION

As to the deaths occurring as a result of the operative procedure Feil (1941, 1943) reported a total of fourteen or thirty-seven and eight tenths per cent of the series of thirty-seven patients. The operative mortality in the first seventeen patients was forty-seven per cent but this was reduced in the second seventeen cases to thirty-five and three tenths per cent. He thought that the mortality would be much lower if patients selected would have been operated earlier in the course of their disease.

The cause of death in these cases is listed as follows:

Case	Age	Days Lived	Cause of death
2	53	6	Thrombosis of abdominal aorta
5	58	2	Mediastinitis (Cl. welchiiinfection)
7	57	4	Cerebral hemorrhage; broncho pneumonia
8	53	1	Coronary thrombosis
10	56	2	Coronary insufficiency, acute
12	54	9	Broncho pneumonia
14	53	5	Broncho pneumonia
16	57	1	Coronary insufficiency, acute
29	50	2	Broncho pneumonia
30	54	0	Coronary insufficiency, acute
32	58	0	Coronary insufficiency, acute
33	44	12	Coronary insufficiency, acute
34	56	2	Broncho pneumonia
35	64	2	Coronary insufficiency, acute

There were an additional nine patients who survived the operation but who died from four months to six years later. The results in these patients were classified as: Excellent--five; little or no improvement--four. Postmortem studies revealed severe coronary disease in all cases, as seen below:

Case	Age	Survival Period Years	Months	Cause of Death
3	53	2	6	Coronary insufficiency
6	61	6	1	Myocardial failure
9	51	5	8	Acute myocardial infarction
13	58	0	6	Myocardial failure
15	54	6	0	Coronary insufficiency
18	53	5	1	Coronary insufficiency
20	70	2	3	Cerebral hemorrhage
24	47	1	3	Acute myocardial infarction
31	54	0	4	Coronary insufficiency

Thus of the twenty-three patients who survived the operation, fourteen were still living in 1944. Of these nine were definitely improved and five showed an increase in exercise tolerance and a diminution in their symptoms.

Of the twenty-three patients who survived the operation, the results were classified as follows:

Excellent----fourteen, or sixty and nine tenths per cent.

Good---------five, or twenty-one and seven tenths per cent.

Little or no improvement---four, or seventeen and four tenths per cent.

It can be surmised that patients with severe coronary artery disease either usually did not survive the operation or if they did survive they did not improve much. Beck (1941, 1943) stated that there must be a sufficiently good myocardium to maintain

life or the improved coronary artery circulation produced by operation would be ineffectual.

An example of a case operated (Beck's first case) will be cited to show what striking benefits were obtained in some of the cases. Feil (1943)

> Case #1. -- Arteriosclerotic heart disease and agnina pectoris of nine years' duration; severe for five years; moderate generalized arteriosclerosis with hypertension; arterial pressure 169/92. Moderate chronic pulmonary emphysema. A 48 year old farmer, with gradually diminishing exercise tolerance, finally became incapacitated for any work because of retrosternal pain, fatigue and dyspnea. Operation was performed Feb. 13, 1935. Four months later he began to do light work around the hospital as a gardener and made 82 trips on the steps without pain, stopping because of dyspnea. It is now eight years and five months since the operation (1943) and he is able to work 12 hours daily as a farmer. He feels no more than the usual fatigue at the end of the day. The result in this patient is classified as exellent.

There have been no more patients operated on since the original series of thirty seven patients, as further investigation was interupted by the war. A recent follow-up of the patients who survived the operation and are still living has not been published as yet. This new method of treatment has been introduced too recently to allow proper evaluation as to its practicablilty. Until more cases are done and followed for longer periods of time, the actual worth of such a procedure cannot be established with any certainty.

PARAVERTEBRAL ALCOHOL INJECTIONS and SYMPATHECTOMY FOR THE RELIEF of CARDIAC PAIN

Another type of surgical approach that has been used is cutting or destroying the nerves carrying impulses from the heart to the spinal cord, thus severing the reflex arc for the referred pain. This has been by three methods, (1) thoracic and cervical sympathectomy, and (2) paravertebral injections of alcohol and procaine into the dorsal roots, (3) Laminectomy and division of the upper four thoracic sonsory nerve roots (posterior rhizotomy).

Before either of these methods can be discussed, an understanding of the nerve pathways involved must be had. This has come about only through the work of numerous investigators throughout the past thirty-one years. A brief review of the numerous operations on the cervical and thoracic sympathectic nervous system will best show this natural evolution of the present day concept of the innervation of the heart. Jonnesco (1916) introduced cervical sympathectomy for the relief of angina pectoris. This was the first of the procedures introduced to separate the sympathetic nerve connections to the heart and thus relieve cardiac pain from myocardial ischemia. Statistical comparison of his results compared to others later showed that his results were fairly satisfactory. Jonnesco (1928) later recommended extirpation of the stellate ganglia with its chief

effect being the removal of "centrifugal impulses which force the heart to do unphysiologic work". He felt removing the stellate ganglia did not damage the heart function, since the nervi. card. thorac. still provided the heart with accelerative impulses to a sufficient amount. Cutler (1927) summarized the work done up to this time which included the following types of operations:

1. Complete Jonnesco operation--both sides or one side
2. Cervical Sympathetic chain-
   (a) superior cervical ganglion resection and division
   (b) middle cervical ganglion resection and division
   (c) inferior cervical ganglion resection and division
3. Operations on the depressor nerve
4. Combined operations, atypical, upon both the vagus and sympathetic elements

He came to the conclusion that any single procedure had no marked success in alleviating cardiac pain, yet no single procedure failed to alleviate pain in some cases. The many varied procedures gave relief in some cases and none in others, and therefore the exact pathway of pain fibers was not known. Some investigators had good results however from resection of the cervical superior ganglion alone; Coffey and Brown (1923), and Kerr (1925), which only seemed to confuse things. This was in contradiction to the work of Ranson and Billingsley (1918) who stated that there were no afferent neurones found in the upper portion of the cervical sympathetic trunk. Swetlow (1925-1926) was of the opinion that pain fibers from the heart pass through the rami communicantes and ganglia of the eighth cervical to the seventh thoracic spinal

segments. He got poor operative results from cervical sympathectomy. Heinbecker (1933) stated that pain fibers from the human heart and the first portion of the aorta were found in all sympathetic nerve trunks supplying efferent fibers to these structures, and that these fibers entered the central nervous system via the fifth cervical nerve and via the rami communicantes, and by the dorsal roots of the eighth cervical to the sixth or seventh thoracic spinal nerves. He thought it probable that pain fibers from the heart in small numbers might also asecend in the vagus nerve trunk, since complete removal of the cervical sympathetic chain or alcohol injection of nerve roots from the eighth cervical to the seventh thoracic levels would not in his cases eliminate all pain pathways. White (1933) however felt that the vagus carried no important pain fibers from the heart, and that operations on the cervical sympathetic trunk, even if they included the stellate ganglia, could not interrupt all the pathways of cardiac pain. Thus it can be seen that Jonnesco procedure of stellate ganglionectomy or complete cervical sympathectomy might result in an interruption of the major portion of the afferent pathways from the heart in a large percentage of cases. But the cervical operation was bound to fail when the accessory pathway through the thoracic cardiac nerves was well developed. White (1932, 1933, 1934, 1944) who has done extensive work on this problem probably best expresses our present knowledge of the pathways of cardiac pain. It is that

since the great majority of impulses entering the cervical chain must descend to the upper thoracic levels before entering the spinal cord, operations on the sympathetic ganglia or posterior spinal roots in the upper thorax serve to block all stimuli causing a sensation of pain from the heart, and that cervical sympathectomy does not interrupt the direct cardiac nerves in the thorax, which carry important accessory sensory fibers. He has supported this in his operative results which will be reviewed later.

In evaluating neurosurgical procedures for the control of angina pectoris, White (1935) considered three possible points of attack:

1. Vasomotor nerves: Prevention of spasm in the coronary arteries and in the aortic arch.
2. Motor accelerator nerves: Interruption of cardiopressor reflexes.
3. Sensory nerves: Interruption of pathways carrying impulses causing pain.

He did not consider the first of these methods to be practicable, but recent investigations have shown that some of the benefit of paravetebral block as a method of relieving pain in angina pectoris may be due to an actual improvement in the coronary circulation. Braun (1946) studied the effect of paravertebral block on the electrocardiogram in angina pectoris. He found that out of eleven cases with cardiographic abnormalities before the block, eight showed an improvement of the cardiogram. The T waves which before the block were flat, diphasic, iso-electric, or negative

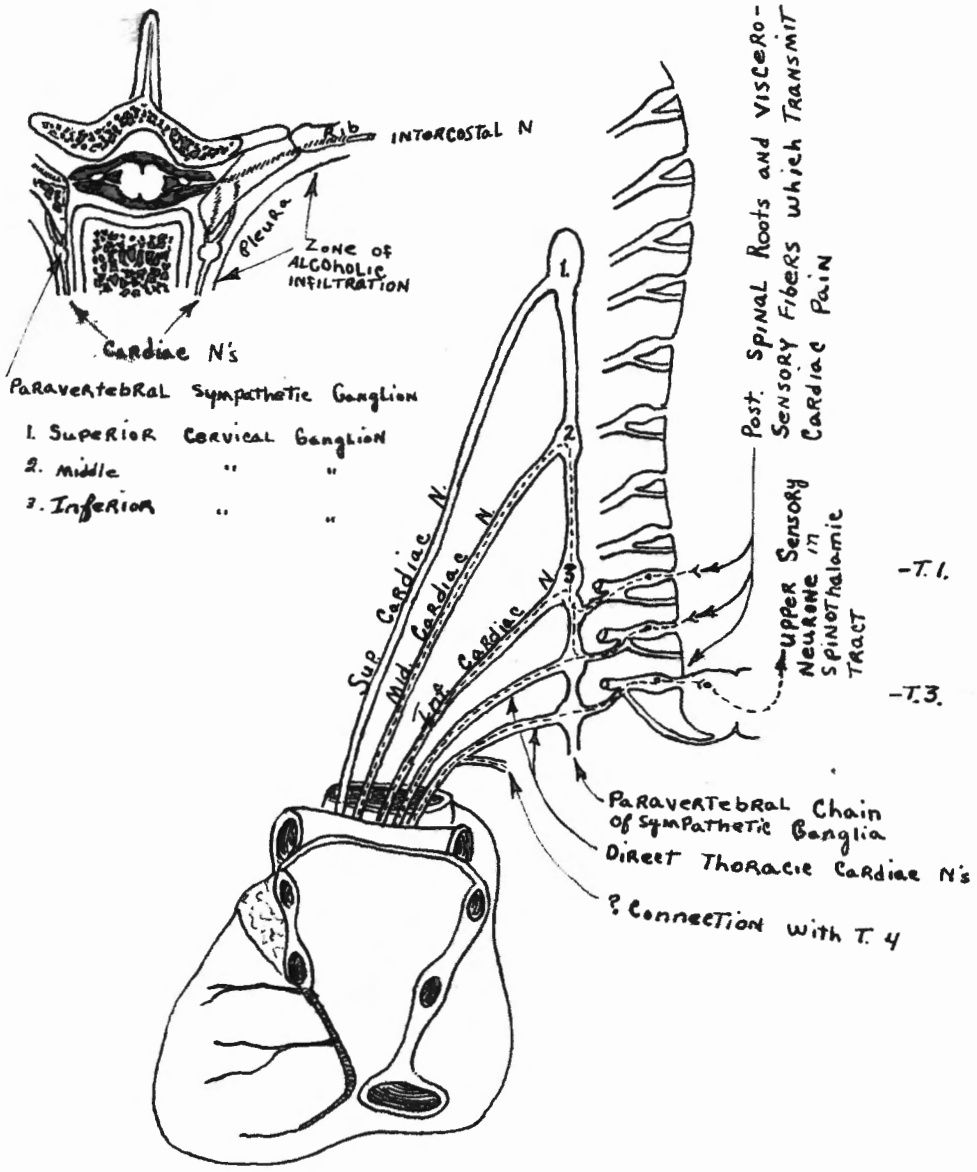
showed a tendency to return to normal. The improvement of the cardiogram did not always coincide with the relief of pain. He concluded that while the relief of pain achieved by the paravertebral block could be explained by the interruption of the sensory pathways, the improvement of the cardiogram was most probably produced by an increased coronary blood flow and a greater oxygen supply to the heart muscle. That the improved circulation might be a direct sequel of the blocking of the sympathetic nerves, or that the relief of pain might cause an abolition of reflex spasm in anatomically unaffected vessels and thus a dilatation of the coronary was assumed by Levy and Moore (1941).

To interrupt motor impulses to the heart, White (1935) felt that it would be necessary to remove all the sympathetic ganglia on both sides from the inferior cervical down through the fourth or fifth thoracic level, and that it would also be necessary to denervate the adrenal medullas, and that therefore this procedure was out of the question.

The logical method thus was the interruption of pathways carrying impulses causing pain, namely by thoracic sympathectomy paravertebral alcohol injections.

ANATOMICAL DIAGRAM OF THE CARDIAC AFFERENT FIBERS

FROM THE HEART (WHITE)



PARAVERTEBRAL ALCOHOL INJECTIONS

This procedure was first introduced by Mandl (1925 for the relief of severe angina pectoris. He showed that anginal pain could be relieved consistently, but only temporarily by the paravertebral injection of the upper thoracic sympathetic ganglia with procaine hydrochloride. Swetlow (1926) demonstrated that long-standing relief could be obtained by paravertebral block with alcohol. He reported on a series of eight patients with attacks of severe pre-cordial pain which were treated by paravertebral alcohol injections and secured prompt and satisfactory relief from pain in all the cases. He stated that there were no complications or serious after-effects, and that the procedure was both simple and well based. The relief secured usually after the first single injection lasted several months. Swetlow (1929) later reported on a series of forty-one patients who had severe angina pectoris and whom were treated with paravertebral block. All but four cases were relieved to a marked degree of their pain. He obtained poor results from cervical sympathectomy. As the review before has shown, it was shortly after this time that it was revealed that, in addition to the long known superior, middle, and inferior cardiac nerves, there were fine direct rami connecting the heart with the upper thoracic sympathetic ganglia. Proof that these connections carried important pain fibers was furnished by the dog experiments of White, Garrey, and Atkins (1933). Other investigators also

reported good results from paravertebral alcohol block. Levy and Moore (1931) treated nine cases by this method and obtained satisfactory results in all the cases. Since this time there have been numerous reports in the literature on the use of paravertebral alcohol block in the treatment of angina pectoris. White and his associates have been particularly active in this field. The procedure has become of close choice after sympathectomy, dorsal in location, because in experienced hands it is almost as effective itself and at the same time much less of a strain on the patient. It is therefore suitable for any case, even one quite ill from recent coronary thrombosis (White 1944).

The procedure itself should be considered next. Mandl, Swetlow, White, and others first routinely used diagnostic injection with procaine before attempting a permanent block with alcohol. However, today, we know that all the sensory pathways from the heart run through the upper three or four thoracic sympathetic ganglia and diagnostic block with procaine is no longer necessary unless anginal pain is referred to unusual areas. The procedure requires expert anatomic knowledge and experience in injections, as inaccurate injections may irritate and injure the pleura, sometimes causing a very disagreeable and perhaps dangerous immediate reaction (pain and collapse); also, it may fail to reach the proper spot, resulting in failure to relieve pain. (White, 1944).

The technic as outlined by White (1940) and others is briefly as follows; the site for injection is carefully marked

out over the nerve roots four centimeters from the midline of the back, with the patient lying on the opposite side from that to be injected. The injection is of the upper five dorsal communicant rami, through which the bulk of the afferent impulses enter the central nervous system from the heart. Usually the second andthird thoracic dorsal roots are the most important tracks over which afferent cardiac impulses pass and their injection therefore relieves most of the pain, as has been noted in the case of patients who happened to have attacks of angina pectoris while the injections were being made and so were able to tell through which nerve roots most of their pain was felt. If the angina pectoris is bilateral a second series of injections can at a later date be made on the other side. Four or five long needles (eight to ten centimeters in length) are inserted to reach the first four or five dorsal nerve roots, one at a time, from above downwards, procaine (one per cent solution) being injected during their insertion and a small amount, 2-5cc., in each needle after it is in place. After a few minutes, when the hand has become warm and skin anesthesia is established, 3 to 5 cc. of eighty-five per cent alcohol is injected through each needle and all the needles are then withdrawn. General anesthesia is not necessary; with care little or no discomfort is said to be felt by the patient during the injection.

SELECTION OF PATIENTS FOR PARAVERTEBRAL ALCOHOL INJECTION

When this method of treatment of angina pectoris was first introduced it was usually used for the control of pain in the most severe cases of angina pectoris. It was used in cases that did not respond to medical measures mainly. Today, however, it is reserved only for the poorest surgical risk cases since it does not relieve pain in the percentage of cases that sympathectomy does. Bland and White (1936-1944) in a series of forty-two patients selected their cases purely on the basis of the intensity of their pain, and the only ones accepted were ones who had not responded to medical treatment and who had continued to suffer so severely that the pain was unendurable. Few were able to perform any kind of work, and several were having frequent attacks while at rest in bed. Neither syphilitic aortitis nor active rheumatic fever were considered a contraindication to injection. Many of the patients had suffered attacks of coronary thrombosis, and a few were in congestive failure. Blumgart (1933) who was a strong advocate of total thyroidectomy for the relief of anginal pain, felt that alcohol injection was the procedure of choice in; (1) old men with recent coronary thrombosis and bouts of unbearable pain; (2) patients with rapidly progressive cardiac disease secondary to syphilitic aortitis; (3) young individuals with active rheumatic fever and aortic regurgitation; (4) cases in which the basal metabolic rate was low. Palmer (1947) differs somewhat in his opinion, or at least enthusiasm for the procedure.

He thinks few cardiologists are eager to recommend any operation that merely interrupts the pain pathways, but that if such a decision is made, and a neurosurgeon is not available, then alcohol injection of the upper thoracic chain is the operation of choice.

REVIEW OF CLINICAL RESULTS

The reports of early investigators has already been covered; Mandl (1925), Swetlow (1929), Levy and Moore (1931), and others. The most comprehensive analysis is that by White and Bland (1947) which covers the results of a twenty year experience on seventy-five patients treated by chemical blocking of the cardiosensory fibers from the heart.

PARAVERTEBRAL ALCOHOL INJECTION FOR ANGINA PECTORIS (WHITE & BLAND)

RESULTS	No. of Cases	Per Cent
Excellent	42	56%
Fair	16	21.3%
Failures	6	8%
Unclassified	5	6.7%
Operative Deaths	6	8%

Among the fifty-six per cent listed as good results were included those patients who were completely or nearly completely relieved of their pain on the side of injection. The twenty-one and three tenths per cent with fair results comprised a group in whom intractable angina pectoris was so reduced that the patients

could be maintained in a state of relative comfort by routine medical measures without the use of narcotic drugs. Excluding the five patients listed as "unclassified" because of inadequate follow-up or other reasons (all of whom appeared to have good results), eighty-four per cent of the entire series obtained excellent to fair results, so that even the least satisfactory felt that they were distinctly improved. There were eight per cent who, because of incomplete block, failed to derive adequate relief and were classified as failures. In addition, eight per cent died as direct result of the procedure. White did not feel that this mortality rate was at all high, since the group included the very worst risk cases with severe coronary disease, threatened decompensation, extreme old age, and other conditions which would have resulted in a prohibitive mortality had any neurosurgical procedure been attempted. Some recurrence of anginal pain took place in eighteen per cent after periods of from two and one-half months to five years, but on the other hand, most of the remaining patients were known to have maintained full benefit for periods ranging up to nine years.

SYMPATHECTOMY IN THE RELIEF OF CARDIAC PAIN

It was following the prediction of Francois-Franck in 1899 that medically intractable angina pectoris could be relieved by sympathectomy that Jonnesco (1916) first removed the cervical sympathetic ganglia. In his first patient the relief of pain was striking and complete, but in the next decade after the operation had been used more it was found that the procedure gave satisfactory relief in only about sixty per cent of the cases. Levine and Newton (1926) reported on eight patients who had cervical sympathectomy for severe angina pectoris. Six of the eight were absolutely or largely relieved of their pain. Other observors however were not so enthusiastic in their reports, such as Richardson and White (1929). Again, as in the evolution of paravertebral injections of alcohol, it became apparent that the cause of surgical failure was incomplete anatomical knowledge of the pathways of pain from the heart. With the correct understanding of these pathways in later years, as has been already reviewed, a sound basis for the surgical excision of the upper thoracic ganglia or the division of the five upper thoracic pasterior spinal roots was established.

As in paravertebral block, the principle of thoracic sympathectomy is to interrupt sensory pathways from the heart. Posterior rhizotomy or the section of the upper thoracic ganglia spinal sensory roots is a similar procedure in principle. Other

effects of sympathectomy have recently been investigated. Yodice (1941) in experiments on dogs, in which he first performed bilateral sympathectomy down to the eight, ninth, and tenth thoracic level, and then ligated the descending ramus of the left coronary artery, found that sympathectomy was not an effective method of reducing the mortality rate or the size of the infarcts formed. Sympathectomy however may have a beneficial effect on the coronary circulation. Levy and Moore (1941) reported improvements in the electrocardiograms of fourteen out of sixteen patients with angina pectoris treated in this manner. Braun (1946) showed improvement in the cardiograms of eight out of eleven patients after interruption of the sensory pathways. Both indicate an improvement in the coronary circulation.

It must be realized that there are some disagreeable after-effects that frequently and usually result from cervical or dorsal sympathectomy; these include ptosis of the upper eyelid and contraction of the pupil (Horner's syndrome) on the side on which the nerves are cut, hyperesthesia and burning sensations in the face, mouth, ear, neck, or upper chest along with varying degrees of anesthesia. The extent of these after-effects is extremely variable in intensity and duration, some patients suffering but little from them and for only a few days postoperatively, while others complain of discomfort for weeks or months. Generally in the course of time these disagreeable results of the sympathectomy fade away more or less completely.

This is not so apt to happen after paravertebral alcohol injections. However in the injection technic there is usually a transitory period of alcoholic neuritis of the infiltrated intercostal nerves. This does not occur in sympathectomy and posterior rhizotomy. Return of normal sensation in the chest wall may require from a few weeks to several months. White (1944) states that most patients regard the neuritis as a relatively minor objection in view of the relief obtained from their former agonizing attacks of angina pectoris. Some men felt that the anginal pain was a warning signal and prevented over-taxing of the heart, and surgical relief of this important sign might actually be undesirable. White (1940) thought this no disadvantage since warning signs, which consist of dsypnea, palpitation, a peculiar clutching sensation in the suprasternal notch, or the flushing of the skin, remained after the loss of pain. He warned his patients that their cardiac reserve was not necessarily increased by operation, and that their physical activity should be curtailed when these tell-tale signs occured. Nitrites could be used as before operation when these signs were present.

There remains to be discussed which procedure, paravertebral alcohol block or thoracic sympathectomy, should be used in the treatment of angina pectoris. A great deal was learned from extensive early experience with the injection method for control of severe cases of angina pectoris. Today, however, this method

has largely been superseded by resection of the upper three or four thoracic sympathectic ganglia or cutting the corresponding posterior spinal roots. White (1947) states that today paravertebral alcohol injection is reserved only for the poorest risk cases, since it fails to give effective block of cardiac pain in some eight per cent of cases and is followed by troublesome intercostal neuralgia in ten per cent. Recurrence secondary to nerve regeneration has been about eighteen per cent and is usually mild. While (1947) after reviewing his series of seventy-five alcoholic injections, felt that about one-half of them could have been submitted to ganglionectomy without undue risk. In his latest series of eight patients in which thoracic ganglionectomy T1-T2 was done, there was an excellent result in all with but one partial recurrence after a year, and one operative death at one month. The survival periods ranged from three to nine years, with three patients now continuing to lead active and useful lives.

Contraindications to open surgical intervention on the cardiac nerves are extreme old age and cachexia from other conditions, active rheumatic fever and syphilis, angina decubitus, and recent coronary occlusion with progressive increase in anginal attacks. Under these circumstances chemical block with alcohol can still be used with relative safety and often with dramatic success.

At the present time resection of the upper thoracic

ganglia or section of the corresponding spinal sensory roots is preferrable to paravertebral injection of alcohol, provided the patient can tollerate a major operative procedure. These two operations do not cause neuralgia, and abolition of cardiac pain is reasonably certain and permanent.

TOTAL THYROIDECTOMY

Total Thyroidectomy in the treatment of non-thyrogenous heart disease was first proposed by Blumgart, Levine, and Berlin in 1933. They studied this problem extensively and drew the conclusion that persons with normal metabolism who suffer from congestive failure might show striking improvement if a hypothyroid state, as indicated by the metabolic rate, were brought about. The hearts of such persons might supply enough blood for the lessened metabolic needs. Blumgart, Levine and Berlin (1933) studied at first the effect of maximal subtotal thyroidectomy in several patients who showed no evidence of thyrotoxicosis; the results were disappointing. Following operation there was definite clinical improvement which was accompanied by a slight fall in metabolic rate. Within a few weeks, however, the basal metabolism gradually returned to the preoperative normal level and clinical improvement was no longer maintained. These results suggested to them that the residual fragments of thyroid had hypertrophied and that complete removal of every vestige of normal thyroid gland might accomplish the desired end.

MECHANISM OF THE RELIEF OF SYMPTOMS AND SIGNS OF ANGINA PECTORIS AND CONGESTIVE FAILURE

Extensive studies have been made of the exact mechanisms whereby the hypothyroid state affords relief to patients with heart disease. Blumgart and Weiss (1927-1928) studied the consequences of circulatory failure in several hundred patients

by measuring the pulmonary and peripheral velocity of blood flow, the venous pressure, the vital capacity, the blood pressure and heart rate; and the findings were interpreted in relation to the clinical manifestations of the various disorders of the circulation. In patients without heart disease, the speed of blood flow was found to be related to the basal metabolic needs of the body. Uncomplicated thyrotoxicosis was always accompanied by increased speed of blood flow, and, conversely, uncomplicated myxedema by considerable slowing. The observations in patients with congestive failure before and after total thyroidectomy are in accord with these views. Before operation, in patients with congestive failure, the velocity of blood flow is usually already slowed; the basal metabolic rate is normal. Following operation, the velocity of blood flow may remain unchanged as the metabloic rate falls, until these two measurements assume the same relationship as in hypothyroidism. At rest, the signs and symptoms of congestive failure then disappear. If the basal metabolic rate becomes further reduced, the velocity of blood flow likewise diminishes and may, in fact, become slower than before operation. Similar considerations underlie the benefits conferred upon patients with angina pectoris. A like discrepancy exists within the heart between tissue demands and blood supply. Angina pectoris is usually regarded as due to an insufficient supply of blood to the heart through the coronary arteries when the work of the

heart is increased by exertion or emotion, though the supply may be sufficient when the body is at rest. Thyroidectomy presumably diminished the demand upon the heart so that the previous flow through the coronary arteries is sufficient, even during strain. The work of Altschule and Volk (1935) showed that, after thyroidectomy, the cardiac output and the velocity of blood flow are considerably reduced and the work of the heart is greatly lessened. With reduced demand for oxygen, the blood supply becomes sufficient.

THE MECHANISM OF THE EARLY TEMPORARY RELIEF OF THE SYMPTOMS OF ANGINA PECTORIS

Weinstein et. al. (1934), Cutlerand Schnitker (1934), and Riseman (1935) all came to the conclusion that the early relief from pain in the chest was due to interruption of nerve impulses from the heart to the central nervous system. Weinstein found that the superior cardiac nerve was in intimate relationship with the posterior surface of the thyroid lobes and with the branches of the inferior thyroid artery in approximately sixty per cent of his cases. In almost fifty per cent, the middle cardiac nerve was also in a similar situation. This frequency of the close relationship between cardiac nerves and thyroid gland corresponded to the incidence of relief from pain immediately after operation.

It was thought by Eppinger and Levine (1933-1934) that the absence of anginal pain immediately after total thyroidectomy

might be due to a lessened sensitivity to epinephrine. Cutler and Schnitker (1934) also suggested that the adrenal secretion might be an important factor in the attacks of angina pectoris. Riseman (1935) however, felt that patients with angina pectoris and those with congestive heart failure were not more sensitive to epinephrine than patients with no evidences of cardiovascular pathologic changes, and that the relief from pain in these angina pectoris patients immediately after total thyroidectomy when there was no change in the basal metabolic rate or in sensitivity to epinephrine, was due to the interruption of sensory impulses from the heart to the central nervous system.

CLINICAL RESULTS IN PATIENTS WITH ANGINA PECTORIS TREATED BY TOTAL THYROIDECTOMY

Total removal of the thyroid gland proved to be helpful in a good many cases during the years in which it was popular. However investigators in the past few years have not been as enthusiastic as their predecessors were. White (1944) stated that total thyroidectomy acted to relieve angina pectoris apparently by three effects; first, by the interruption of some of the cardiac nerve connections themselves removed at the time of the thyroidectomy; second, by the marked reduction of basal metabolic rate in the course of several months, even down to a minus thirty five or forty per cent with resulting decrease in the demands on the coronary circulation; and third, by the long rest incident to the operation.

A brief review of the results of various investigators will show the success with which they met. Levine, Cutler, and Eppinger (1933) reported early a small series of cases in which partial and complete removal of the thyroid was performed on twelve patients suffering from most severe heart disease. These were divided into four patients with severe angina pectoris, four patients with valvular heart disease, and four patients with non-valvular congestive heart failure. All were hopeless and bed-ridden. Their results were; marked improvement in six cases; slight to moderate improvement in three cases; and no improvement in one case. They concluded that the operation was most promising in patients with angina pectoris. Mixter et al (1934) reported a series of twenty five cases with angina pectoris. After total thyroidectomy thirty five per cent of their patients were completely relieved of pain, and an additional fifty per cent were moderately improved, making a total of eighty five per cent benefited by surgery. They stated that the fifteen per cent showing no improvement should not have been operated on since their pre-operative BMR's were low. They warned against indiscriminate use of thyroidectomy in improperly selected and unprepared cases. Blumgart (1936) analyzed the results of total thyroidectomy for angina pectoris in ninety five cases. There were excellent results in forty five cases, or forty seven per cent; twenty nine cases, or thirty one per cent, were moderately improved; eleven cases or twelve per cent were slightly improved; ten cases,

or eleven per cent, showed no improvement; and there was no operative mortality. Cutler and Hoerr (1940) reported on a five year follow-up study of fifty seven patients who had had total thyroidectomy at the Peter Bent Brigham Hospital in the years 1932, 1933, and 1934. Thirty-two of the patients had had intractable angina pectoris; they did better than the twenty five cases of congestive heart failure. Of the angina pectoris group twenty six of the twenty seven cases who survived six months were relieved of pain in some degree for six months or longer, and eight of the twelve who survived for five years had sustained relief. Parsons and Purks (1942) reported three hundred sixty two cases of total thyroidectomy for cardiac disease. The mortality rate for the operation performed on angina pectoris patients was 3.75 per cent and the results were satisfactory or partially satisfactory in more than eighty per cent of the cases.

Recent investigations in the past few years have not claimed the same success however. White (1944) was of the opinion that the procedure was helpful in many cases, but that it was a long, serious operation, and that it was being largely abandoned because the results had not been sufficiently favorable to justify the difficulty and hazards of the operation and the establishment of a new disease, namely, myxedema. Palmer (1947) states "total thyroidectomy has no place now in the treatment of angina pectoris for which it was once recommended. The low basal metabolic rate necessary to maintain freedom from pain is

such that a good many patients have to be kept at the myxedema level. It may be that the operation has some value in congestive heart failure, provided it can be shown that the patient has enough cardiac reserve to enable him to become free from edema on rest in bed." Thus between the optimistic attitude of various observers in the 1930's and the present rather pessimistic attitude of today's observers toward the benefits gained by total thyroidectomy for angina pectoris, we see the rather common "popularity cycle" change. A new development is greeted with much enthusiasm which persists until further investigation reveals disadvantages and short-comings which before had not been known. Thyroidectomy for angina pectoris has passed through this same cycle. One should not be misled into thinking that the procedure has altogether been abandoned however. White (1944), Parsons (1942), and Palmer (1947), all concede that there is a place for this new therapy but that it is limited in its application.

SELECTION OF PATIENTS FOR OPERATION

It was only through experience of numerous investigators that the criteria for selecting patients for operation was arrived at. Blumgart (1936) advised against operation in the presence of the following factors: (1) rapidly progressive cardiovascular disease (such as malignant hypertension, syphilitic cardiovascular disease); (2) terminal or extremely advanced symptoms; (3) low basal metabolism; (4) recent coronary occlusion; (5) active

infection; and (6) renal insufficiency (other than that due to congestive heart failure). He believed that the patients who might be expected to gain the greatest benefit were those in whom cardiac disease had been relatively stationary or only progressive over a period of one or more years, even though they were seriously incapacitated by congestive failure and subject to angina pectoris at rest in bed. The basal metabolic rate before operation should be within the standard normal limits. There should be evidence of cardiac reserve, such as the ability to become free from edema on rest in bed. Finally, the extent to which clinical improvement is likely to increase the general welfare of the patient must be taken into consideration (for example the operation may not be indicated in a wealthy business man who experiences attacks of angina pectoris only on moderate exertion in the pursuit of pleasure, such as golf; whereas the inability to undertake equivalent exertion in another person may imply unemployment and suffering for himself and his dependents). The operation should be undertaken only when all available medical measures have been employed without satisfactory result. Parsons (1942) states that the hypothetic subject in whom the best results are obtained from operation would be a man forty to sixty years of age who has had angina pectoris for at least nine months, whose attacks are sufficiently frequent to prevent his following a gainful occupation, who has received adequate medical care but whose attacks have not been controlled

by this treatment, who does not have a prohibitive amount of organic damage either in the heart or in the vascular system generally and who presents evidence that he is of the type with a high emotional level. White (1944) lists as contraindications for total thyroidectomy in these cases the following; fresh or very recent coronary thrombosis, uncontrollable congestive failure, syphilitic aortitis, and nephritis. Levy (1936) warned against operating on patients with low basal metabolic rates. It was found that, regardless of the preoperative rate, practically all patients required the administration of small doses of thyroid extract to compensate for the symptoms and signs of myxedema when the metabolic rate was approximately minus thirty per cent. Therefore, in patients with low rates, such as minus twenty per cent before operation, a further decrease of only approximately ten per cent could be permitted before thyroid medication was required. But this reduction was not adequate to relieve the heart of its burden. Blumgart, Levine, Berlin, Davis, and Riseman (1933-1935) all hesitated to operate on any patient with any type of heart disease whose basal rate was below minus fifteen per cent, and refused to perform thyroidectomy when the rate was a minus twenty per cent or below. Failure to observe this factor caused many of the unsatisfactory results that were obtained (Mixter 1934).

Undesirable Effects of Total Thyroidectomy for Angina Pectoris

The extent of permanent relief has, in general, been related to the degree of reduction in the basal metabolic rate. With a lowering of the metabolic rate, patients show what may be termed

the mild symptoms and signs of myxedema, which consist of increased sensitivity to cold, somewhat thickened and dry skin, and slow growth of hair. With metabolic rates of minus thirty per cent or lower, most patients suffer from puffiness of the face, weakness of the legs, and irritability. Blumgart et al (1933-1934) administered small doses of thyroid and successfully maintained the rate at a level of a minus twenty five per cent to a minus thirty per cent. At this level, most of their patients were free from untoward symptoms and the demands on the heart were greatly lessened. They found that fifteen mgn. (1/4 gr.) of thyroid extract was usually sufficient to maintain the optimum level. They also found that an increase in daily dosage of thyroid of a little as six mgm. (1/10 gr.) might decide the difference between the presence and the absence of discomfort from myxedema, and that angina pectoris or congestive failure might be abolished by a reduction of 1/10 gr. of thyroid and the patients still remain free from the discomforts of myxedema. Thyroid extract was not given until the symptoms or signs of myxedema were evident. In some cases, medication was instituted within three weeks after operation, and in others it was not needed for six to ten months after thyroidectomy, while in rare cases no thyroid medication at all was required. White (1944) thought myxedema of any serious or crippling grade could be prevented by the establishment of thyroid therapy using one half to one grains of thyroid extract, beginning some six to ten weeks after the operation and maintaining

the basal metabolic rate so that the demands on the coronary circulation were minimal and anginal pain was largely or completely abolished.

However in many cases the results are not good, such as when the degree of coronary disease is very high or when myxedematous symptoms and signs are very difficult to control by the use of thyroid extract without inducing angina pectoris again. Palmer (1947) maintained that the very low basal metabolic rate necessary to maintain freedom from pain in angina pectoris was such that a good many patients had to be kept at the myxedema level. This is the main objection today to this method of treatment of angina pectoris and congestive heart failure.

LIGATION OF THE GREAT CARDIAC VEIN AND PERICORONARY NEURECTOMY

An entirely different approach to the problem of improving the myocardial circulation has just recently been introduced by Fauteux (1940). It has been known for the past quarter of a century that venous ligation was an aid to the development of a collateral circulation and this principle was utilized as far back as 1913 by Oppel when he ligated the popliteal vein in the treatment of senile gangrene of the foot. Leriche (1931), after being impressed with the beneficial results of partial arteriectomy for vascular diseases of the extremities, suggested that it might be used to advantage in the treatment of coronary artery diseases also. This procedure interrupts vasoconstrictive pathways and brings about vasodilatation and thus improves considerably the blood supply to the ischemic area. Thus Fauteux in 1940 began his experiments to observe the effect of these two procedures: (a) partial coronary resection and (b) partial coronary resection combined with ligation of the accompanying vein.

In his experimental work he found that when partial resection of the ramus descendens at a high level was done a high mortality resulted in the dogs. When the same procedure was carried out after venous ligation all dogs, apart from those dying of operative complications and intercurrect diseases, remained healthy for over a year. It was demonstrated that ligation of the vena magna cordis

had a protective effect against the ventricular fibrillation which so often occured in acute ischemic conditions and also minimized the myocardial changes which followed occlusion or partial resection of the ramus descendens. Gross (1937) had shown that ligation of the coronary sinus appeared to compensate in some way for later ligation of coronary artery. Fauteux found that coronary sinus ligation gave a high mortality and that occlusion of the venous drainage at such a high level was unnecessary to produce the desired effects. His results by experiments suggested that in cases properly selected coronary vein ligation might be expected to act as a preventive measure against a second attack of coronary thrombosis and also to improve the coronary circulation sufficiently to relieve the pain of angina of effort.

Some of the newer anatomical discoveries are highly pertinent. Wearn (1936) has shown that the myocardial blood sinusoids are in direct communication with small branches of the coronary arteries by means of small vessels ranging in size from 50-250 micra (capillaries measure only eight to twelve micra). That direct arterio-venous anastomoses also exist in the human heart has been know for many years. Recently Prinzmetal (1946) has demonstrated that glass beads ranging in size from eighty to one hundred seventy micra can be recovered from the coronary sinus after their being injected into a coronary artery. It is therefore evident that the coronary arterioles, the sinusoids, and the venous system

are communicating with each other by vessels of large calibre.

The above considerations suggest that after ligation of the vein in the human patient suffering from localized coronary ischemia, the pressure gradient is such that retrograde flow into this ischemic area is brought about. Provided then that the Thebesian system continues to carry off only its estimated normal sixty per cent of the coronary outflow, considerable benefit to the ischemic muscle would follow this in spite of the fact that the myocardium probably derives some of its oxygen from venous blood, (Robertson, 1941). A good deal of pooling in the sinusoidal system must occur as a result of the dilation of these thin-walled vessels by the rise in venous pressure. This dilatation can persist and was demonstrated in one of Fauteux's cases at autopsy two and one half years after operation. It is quite possible that the mechanical distention of venous and arterial channels is the most important effect of Fauteux's operation. A likely reason for his high proportion of clinical successes is that the great cardiac vein drains the whole apical region, in which occur most of the damaged areas that give rise to cardiac pain.

The decision followed to apply these results to the treatment of myocardial ischemia in man, and subsequently he operated in Montreal on a series of ten patients. Fauteux and Palmer (1941) reported their first case and the remainder in 1946. Nine of the patients were suffering from severe angina pectoris, and the other

one had had several attacks of coronary occlusion. The non-anginal patient died post-operatively of a tension preumothorax, the only operative death in the series. The others were entirely free from anginal pain except one, and he was much improved. Two patients died since operation, one three months later, and one two and one half years later. The remaining seven are alive and working at their old occupation, at the present time from four to six years after operation.

Fauteux (1946) has increased the scope of his operation to include removal of the sympathetic and para-sympathetic nerve plexuses at the root of the pulmonary artery and the aorta. All impulses reaching and leaving the myocardium by the way of the coronary vessels are thereby interrupted, but the nerve supply to the pace maker is not involved. He calls this "pericoronary neurectomy". The object of this neurectomy is to break the reflex arc through the sympathectic and vagus fibres upon which the development of ventricular fibrillation seems to depend, and thus prevent sudden death should a future coronary accident occur. Pain pathways at the same time are removed. It is still an experimental procedure and its value may be difficult to determine clinically. The pronounced tendency for the post-ganglionic sympathetic fibres to regenerate will doubtless be responsible for some failures. During the past two years Fauteux has done the combined operation of great vein ligation and pericoronary neurectomy in ten cases. There were three deaths,

two from post-operative thrombophlebitis, and one from coronary occlusion three months later. The other seven are all working, and apart from some tightness in the chest of two of them when they are tired, all have lost their pain.

In regard to selection of patients Fauteux and Palmer (1946) feel that the operation should be regarded as a treatment for angina pectoris, at the same time stressing the point that it brings about its results through improving the circulation rather than through mere interuption of pain pathways. - They said this because, in spite of its subjectivity, angina still remains the best guide to the severity of local ischemia. They did not recommend the operation for patients who had recovered from one or more attacks of coronary occlusion but who did not have angina pectoris.

SUMMARY AND CONCLUSIONS

(1) It has been shown experimentally that the heart can be given a collateral circulation by operation. This was accomplished by the use of grafting vascular tissues onto the myocardium, and by the formation of cardio-pericardial vascular adhesions. This markedly reduced the death rate after coronary artery ligation experimentally. The procedure was then applied to patients with severe coronary artery disease. Beck operated on thirty-seven patients with an operative mortality of thirty-eight per cent. Of the twenty-three patients who survived, fourteen had an excellent result and five more a good result. An exact statement as to its relative worth cannot be made as yet since the procedure has too recently been introduced to properly evaluate. The cases that have been successful must be followed over a longer period of time in order to ascertain the true lasting benefits derived. It is true however, that these procedures attempt to decrease or retard the underlying coronary artery disease, whereas the other methods give largely only symptomatic relief of the condition.

(2) Neurosurgical operations for the relief of cardiac pain for the most part consist of interrupting the sensory pathways from the heart. This was first attempted by cervical sympathectomy which proved unsuccessful in many cases. It was not until a proper understanding of the sensory pathways from the heart to the spinal cord was known that successful results were obtained. The two most popular procedures used were paravertebral alcohol injections, and thoracic sympathectomy.

Both were used on patients with severe angina pectoris and associated coronary disease. Paravertebral block did not give relief of pain in about eight per cent of the cases while resection of the upper three of four thoracic sympathectic ganglia or cutting the corresponding posterior spinal roots gave relief of pain in almost all cases. Intercostal neuralgia is a disagreeable after-effect that may follow alcohol injections, but does not follow sympathectomy. On the other hand Horner's syndrome more commonly follows sympathectomy than alcohol block, with the former carrying also a higher operative mortality. This method of treatment has not hoped to prolong the life of the patient but mainly is to relieve him of severe anginal pain when medical management is no longer beneficial or helpful in relieving the pain. Minor subjective sensations of the anginal attack remained even after operation and so could serve as a warning signal to the patient.

(3) Total thyroidectomy was used to relieve anginal pain also. This acted by the reduction of the basal metabolic rate with a resulting decrease in the demands on the coronary circulation and also probably by interruption of some of the cardiac nerve connections in close contact with the thyroid at the time of operation. However, the procedure has largely been abandoned today because such a low basal metabolic rate was necessary to give relief from anginal pain that most of the patients developed myxedema. It in no way alters the progression of

the underlying coronary artery disease.

(4) A relatively new treatment of angina pectoris and coronary sclerosis or thrombosis is ligation of the great cardiac vein and pericoronary neurectomy. Similar procedures had previously been used with success in the treatment of arterial disease of the extremities and so it was applied to the treatment of angina pectoris and coronary thrombosis after a considerable amount of experimental work on animals. By ligating the coronary vein retrograde blood flow occurred thus helping to relieve the ischemic myocardial area. Neurectomy served to interrupt pain pathways and also possibly prevent ventricular fibrillation in case of a coronary occlusion. Fauteux introduced this procedure and in the ten cases he operated on (severe angina pectoris in nine and one patient who had suffered several attacks of coronary occlusion) seven patients are completely relieved of their pain and working four to six years after operation.

Thus it can be seen that the surgical treatment of angina pectoris and coronary thrombosis or occlusion, although a relatively new development, has shown some promising features. The proper value of these procedures cannot be stated at this early stage of their development. It has been shown however that the surgical treatment of a failing coronary circulation is possible, and that methods are available not only which seek to relieve the cardiac pain but which also attempt to improve the underlying

pathologic processes or compensate for them, thus possibly retarding or decreasing the progression of the disease.

SELECTIVE BIBLIOGRAPHY

Altschule, M.D. and Volk, M.C. 1935 The Minute Volume Output and the Work of the Heart in Hypothyroidism, J. Clin. Invest. 14:385.

Beck, C. S. 1935 The Development of a New Blood Supply to the Heart by Operation, Ann. Surg. 102: 801-810.

Beck, C. S. 1935-36 Further Data on the Establishment of a New Blood Supply to the Heart by Operation, Jour. Thor. Surg. 5: 604-611.

Beck, C. S. 1941 The Coronary Operation, Am. Heart. J. 22:539-44

Beck, C. S. 1943 Principles Underlying the Operative Approach to the Treatment of Myocardial Ischemia, Ann. Surg. 118:788.

Beck, C. S. and Tichy V. L. 1935 The Production of a Collateral Circulation to the Heart; An Experimental Study, Am. Heart. J. 10: 849-73.

Berlin, D.D. 1935 Total Thyroidectomy for Intractable Heart Disease. Summary of Two and One Half Years' Surgical Experience, J.A.M.A. 105: 1104.

Blumgart, H. L. and Weiss, S. 1928 Clinical Studies of the Velocity of Blood Flow. The Pulmonary Circulation Time, the Velocity of Venous Blood Flow to the Heart, and Related Aspects of the Circulation in Patients with Cardio Vascular Disease, J. Clin. Invest. 5: 343.

Blumgart, H. L.; Levine, S. A. and Berlin, D.D. 1933 Congestive Heart Failure and Angina Pectoris. The Therapeutic Effect of Thyroidectomy on Patients without Clinical or Pathologic Evidence of Thyroid Toxicity. Arch. Int. Med. 51: 866.

Blumgart, H. L.; Berlin, D.D.; Davis, D.; Riseman, J.E.F.; and Weinstein, A.A. 1933-34 Treatment of Angina Pectoris and Congestive Heart Failure by Total Ablation of the Thyroid in Patients without Thyrotoxicosis. X. With Particular Reference to the Pre- and Postoperative Medical Management. Ann. Int. Med., 7, 1469.

Braun, K. 1946 Paravertebral Block and the Electrocardiogram in Angina Pectoris, Brit. Heart. J. 8: 47-52.

Coffey, W. B., Brown, P. K. 1923 The Surgical Treatment of Angina Pectoris, Arch. Int. Med., 31:200.

Cutler, E.C. 1927 Summary of Experiences up-to-date in the Surgical Treatment of Angina Pectoris, Am. Jour. Med. Sc., 173:613.

Cutler, E.C. and Schnitker, M. T. 1934 Total Thyroidectomy for Angina Pectoris, Ann. Surg. 100: 578-97

Cutler, E.C. and Hoerr, S. O. 1941 Total Thyroidectomy for Heart Disease. Five year Follow-up Study, Ann. Surg., 113, 245.

Davis, D. T., and Mansell, H. F., and O'Shaughnessy, L. 1938 Surgical Treatment of Angina Pectoris and Allied Conditions. Lancet 1-10, 76-82.

Fauteux, M. and Palmer, J. H. 1941 Treatment of Angina Pectoris of Atheromatous Origin by Ligation of the Great Cardia Vein, Can. Med. Assn. Jour. 45: 295.

Fauteux, M. 1946 Treatment of Coronary Disease with Angina by Pericoronary Neurectomy Combined with Ligation of the Great Cardiac Vein, Am. Heart Jour. 31: 260-69.

Fauteux, M.; and Swenson, O. 1946 Pericoronary Neurectomy in Abolishing Anginal Pain in Coronary Disease; Experimental Evaluation, Arch. Surg. 53: 169-181.

Feil, H., and Beck, C. S. 1941 Coronary Sclerosis and Angina Pectoris: Report of 30 Patients Treated by the Beck Operation. Jour. Thor. Surg., 10, 529.

Feil, H. 1943 Clinical Appraisal of the Beck Operation Ann.. Surg.: 118: 807.

Gross, L., Blum, L., Silverman, C. 1937 Experimental Attempts to Increase the Blood Supply to the Dog's Heart by Means of Coronary Sinus Occlusion. J. Exper. Med., 65: 91.

Heinbecker, P. 1933 Anatomico and Physiologico Criteria for the Surgical Relief of Cardiac Pain, Journ Thor. Surg. 2: 517-26.

Heinbecker, P. and Barton, W. A. 1940 Operation for the Development of a Collateral Circulation to the Heart, Journ Thor. Surg. 9: 431-38.

Hosler and Williams, 1935-36 Study of Cardio Pericardial Adhesions, Jour. Thor. Surg. 5: 629-39.

Jonnesco, D. 1928 On the Pathogenesis and Surgical Treatment of Angina Pectoris, Am. Heart. J. 3: 747-48.

Kerr, H. H. 1925 The Surgical Treatment of Angina Pectoris Ann. Surg. 82: 354.

Lericke, R. and Fontaine, R. 1928 The Surgical Treatment of Angina Pectoria; What It is and What It Should Be Am. Heart. J. 3: 649-70.

Levine, S. and Newton, F. 1926 The Selection of Patients with Angina Pectoris for Sympathectomy with a Report of Additional Cases, Am. Heart. J. 1: 41-61.

Levine, S. A., Culler, E. C., Eppinger, E. C. 1933 Thyroidectomy in the Treatment of Advanced Congestive Heart Failure and Angina Pectoris New. Eng. J. Med. 209: 667-679.

Levy, R. L., and Moore, R. L. 1931 Paravertebral Injection of Alcohol for the Relief of Cardiac Pain. A Review of Experience to Date and a Report of Nine Cases Arch. Int. Med. 48: 146.

Levy, R. L. and Moore, R. L. 1941 Parvertebral Sympathetic Block with Alcohol for the Relief of Cardiac Pain. Report of Forty-five Cases. J.A.M.A. 116: 2563.

Mixter, C. G., Blumgart, H. L., and Berlin, D.D. 1934 Total Ablation of the Thyroid Gland for Angina Pectoris and Congestive Heart Failure. Ann. Surg. 100: 570-577.

Mixter, C. G., Blumgart, H. L., and Berlin, D.D. 1934 Total Ablation of the Thyroid Gland for Angina Pectoris and Congestive Failure. Results of Eighteen Months Service. Ann. Surg. 100: 570.

Moritz, A. R., Hudson, C. L., and Orgain, E. S. 1932 Augmentation of the Extracardiac Anastomoses of the Coronary Arteries Through Pericardial Adhesions. J. Exp. Med. 56: 927.

O'Shaughnessy, L. 1936 An Experimental Method for Providing a Collateral Circulation to the Heart. Brit. Ann. Surg. 23: 665.

O'Shaughnessy, L. 1938 Surgical Treatment of Angina Pectoris and Allied Conditions. Lancet 1: 1 & 76.

O'Shaughnessy, L., and Watson, F., 1939 Surgical Revascularization of the Heart. The Experimental Basis. Lancet, 1: 665.

Prinzmetal, M. 1946 Modern Concepts of Cardio-Vascular Disease. 15: No. 10.

Palmer, J. H., 1947 The Surgery of Heart Disease. Can. Med. Ass. Jour. 56: 380-85.

Parsons, S. H. and Purks, W. K. 1942 Total Thyroidectomy for Cardiac Disease; Re-evaulation. Arch. Surg. 45- 44-54.

Ranson, S. W. and Billingsley, P. R. 1918 The Superior Cervical Sympathetic Ganglion and Cervical Portion of the Sympathetic Trunk. J. Comp. Neurol. 29: 313.

Richardson, E. P. and White, P. D. 1929 Sympathectomy in the Treatment of Angina Pectoris; Comparison of Results with those from Paravertebral Alcohol Injection. 'Am. J. Med. Sc. 177: 161-178.

Riseman, J. F. 1935 Treatment of Congestive Heart Failure and Angina Pectoris by Total Ablation of the Normal Thyroid Gland. Arch. Int. Med. 56: 38-58.

Riseman, J. E. F., Gilligan, D. R., and Blumgart, H. L. 1935 Treatment of Congestive Heart Failure and Angina Pectoris by Total Ablation of the Normal Thyroid Gland XVI. The Sensitivity of Man to Epinephrine Injected Intravenously before and after Total Thyroidectomy. Arch. Int. Med. 56: 38.

Robertson, H. F. 1941 Physiology, Pathology, and Clinical Significance of Experimental Coronary Sinus Obstruction; Its Relation to Cardiac Surgery, Coronary Thrombosis, and Nutrition of the Heart by the Thebesian Vessels or Coronary Sinus Backflow. Surgery, 9: 1.

Schildt, P., Stanton, E. and Beck, C. S. 1943
Communications Between the Coronary Arteries Produced by the Application of Inflammatory Agents to the Surface of the Heart. Ann. Surg. 118: 34.

Stanton, E. J., Schildt, P., and Beck, C. S. 1941
The Effect of Abrasion of the Surface of the Heart Upon Intercoronary Communications. Am. Heart. J. 22: 529-538.

Swetlow, C. I. 1926 Paravertebral Alcohol Block in Cardiac Pain. Am. Heart. Jour. 1: 393.

Swetlow, C. I. 1929 A Clinco-Physiologic Study of the Pathway of Pain Impulses in Cardiac Disease.
Am. Jour. Med. Sc. 178;345.

Thompson, S. A., and Raisbeck, M. J. 1942 Cardiopericardiopexy. Surgical Treatment of Coronary Arterial Disease by Establishment of Adhesive Pericarditis. Ann. Int. Med. 16: 495.

Vineberg, A. M. and Jewett, B. L. 1947 Development of an Anastomosis between the Coronary Vessels and a Transplanted Internal Mammary Artery. Can. Med. Ass. J. 56: 609-614.

Wearn, J. T. 1936 In Levy's Disease of the Coronary Arteries and Cardiac Pain, MacMillan, New York.

Wedd, A. M., and Smith R. E. 1935 Observations and Prognosis in Angina Pectoris. Am. Jour. Med. Sc. 189: 690.

Weinstein, M. O., Shafiroff, B. 1946 Grafts of Free Muscle Transplants upon the Myocardium. Science, 104: 410.

Weinstein, A.A., Davis, D., Berlin, D.D., and Blumgart, H. L. 1934
The Mechanisim of the Early Relief of Pain in Patients with Angina Pectoris and Congestive Failure After Total Ablation of the Normal Thyroid Gland. Am. J. M. Sc. 187: 753.

White, J. C., Garrey, W. E., and Atkins, J. A. 1933 Cardiac Innervation: Experimental & Clinical Studies. Arch. Surg. 26: 765-786.

White, J. C. 1933 Experimental and Clinical Studies in the Surgical Treatment of Angina Pectoris. Ann. Int. Med. 7: 229-39.

White, J. C. 1940 Technic of Paravertebral Alcohol Injection: Methods and Safeguards in Its Use in the Treatment of Angina Pectoris. Surg. Gynec. and Obst. 71: 334-343.

White, J. C. 1947 Procaine Block of the Sympathetic Nerves in the Study of Intractable Pain and Circulatory Disorders. Surg. Clin. N. Am. 27: 1263-1280.

White, P. D. and Bland, E. F. 1931 A Further Report on the Prognosis of Angina Pectoris and Coronary Thrombosis: A Study of 500 Cases of the Former Condition and 200 of the Latter. Am. Heart Jour. 7: 1.

White, J. C., and Bland, E. F. 1947 The Surgical Relief of Severe Anginal Pectoris. Bull. N. Eng. M. Center 9: 1-8.

Yodice, Y. 1941 Sympathectomy and Experiment Occlusion of a Coronary Artery. Am. Heart. J. 22: 545-48.