MYOCARDIAL INFARCTION

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Weigert (1880) was among the first to recognize infarction of the myocardium and to compare it with similar changes in other organs, for although in 1874 Hilton Fagge had described a series of cases of "fibroid disease" of the heart, which were probably myocardial infarcts, he considered them to be due to syphilis. Despite these observations it was not until some thirty years later that the condition began to attract the attention of clinicians. Herrick (1912) described the clinical features and Pardee (1920) discussed the electrocardiographic changes associated with its occurrence.

Any discussion of myocardial infarction should correlate the pathological changes with the anatomical structure of the heart. In this paper a review of the anatomy of the cardiac muscles and of the coronary arterial tree and the diseases thereof that may lead to muscle infarction is given. The consequences of interference with the blood flow in this tree are then discussed.

MUSCULATURE

It has been known for several centuries (Lower, 1669, and Gerdy, 1823) that the musculature of the mammalian cardiac ventricle does not form a homogeneous mass and can be dissected into several interlacing layers. In the present century (Mall, 1911; Flett, 1927; Robb, 1934; Lowe, 1939*a* and *b* and 1940; Robb and Robb, 1942) more detail has been added to the descriptions of the various layers of cardiac muscle in the ventricles, and it is now possible to recognize several muscles in the ventricular wall, which are in reality as distinct as the three glutei muscles making up the gluteal mass. The separation of these muscles was first shown by anatomical dissection, and has been confirmed by the demonstration of independent blood supplies and of their individual involvement in various pathological states (Lowe, 1940).

The musculature of the ventricles consists of two main parts. One, commencing superficially, spirals over the external surface of the heart and twists around itself at the apex of the ventricle (Fig. 1). It then passes upward to form the sub-intimal surface and papillary muscles of the left ventricle. It plays no part in the formation of the intimal surface of the right ventricle, but forms the full thickness of the muscle wall over the apical fourth of the left ventricle. Anatomically this muscle sheet can be divided into two halves, one arising from the sinus region, and the other from the bulbus region of the auriculo-ventricular ring. It is from these points of origin that the two halves take their names—*superficial sino-spiral* and *superficial bulbo-spiral* muscles.

The second main muscle mass (Fig. 2, 3, and 4) forms the deep layers and papillary muscles of the right ventricle, together with the portion of the left ventricle that lies between the pericardial and endocardial parts of the superficial sheet. In this deep mass are three separate muscles. One is confined to the wall of the left ventricle as a cylinder of spiralling fibres,

FIG. 1.—Photomicrograph of a longitudinal section through the apex of the left ventricle, L.V., illustrating the vortex formed by the two halves of the superficial muscle layer.

FIG. 2.—Section through the basal end of the interventricular septum showing the superficial muscle layer, (A), defined by a small artery, and the deep sino-spiral muscle, (B), splitting to enclose the right ventricle, R.V.

FIG. 3.—Section through the wall of the right ventricle to show the three muscle layers in contrast to the four layers in the left ventricle. (A) Superficial sino-spiral muscle. (B) Layer of deep muscle. (C) Endocardial portion of the deep sino-spiral muscle.

and is known from its site of attachment to the A-V ring as the *deep bulbo-spiral* muscle. The second can be recognized as a spiral sheet that surrounds the left ventricle and splits to enclose the right ventricle and form its innermost and chief muscle layer: the attachment of these fibres to the A-V ring is in the sinus region, and hence this muscle is known as the *deep sino-spiral*. The third encircles both ventricles in a spiral scroll manner, and is called the *scroll* muscle. These three deep muscles are confined to the upper three-quarters of the ventricular muscle mass.

Because of the spiral path of these muscles from base towards apex, it is often difficult to appreciate their independent existence in transverse sections. Unlike skeletal muscles, they are not separated by dense fascial sheets, but only by a small amount of loose connective

FIG. 4.—Section through the left ventricle near the base showing the four muscle layers. (A) Pericardial portion of superficial layer. (B) and (C) Two of the deep muscles. (D) Endocardial portion of the superficial layer. The peculiar arrangement of the muscular branches of the coronary arteries, by which the parent artery giving branches to the pericardial portion of a superficial muscle gives branches also to the endocardial portion of that muscle but not to the deep muscle in between, is indicated diagrammatically.

tissue. If a transverse section happens to be made in the plane of an artery, then the distinction between the bands may be quite obvious (Fig. 2).

The atrial (auricular) musculature likewise consists of two parts. The superficial consists of a sheet of muscle running transversely over both atria, a few fibres dipping into the interatrial septum. The deep comprises two sets of looped fibres each of which arises from the fibrous ring around the auriculo-ventricular orifice and passes antero-posteriorly around one or other atrium. In addition to these looped fibres, annular fibres surrounds the extremities of the large vessels, the auricular appendages, and the foramen ovale. As the superficial muscles are exceedingly thin, the atrial walls are composed almost entirely of the deep muscle bundles.

CORONARY ARTERIAL TREE

Arising from the sinuses of Valsalva in the aorta, the right and left coronary arteries branch and subdivide to be distributed over the surface of the auricles and ventricles, and later enter

their walls. Some branches lie between the muscle layers in connective tissue planes, whilst others pass at right angles to the surface to reach deeper layers of the wall before they give off branches which run parallel to the surface (Fig. 4). Although there is some overlap in distribution, the right auricle is supplied principally by two branches of the right coronary artery, and the left auricle derives its blood supply from the main left coronary artery and its circumflex branch.

Large anastomotic channels of arterial size between the major coronary branches are easily demonstrated in the hearts of aged people (Gross, 1921). These anastomoses exist at all ages (Lowe, 1937 and 1941), although physiologically they are of much less importance in childhood and youth, and therefore not easily shown by the methods of macroscopic anatomy. Their presence shows they normally carry blood, for if they did not they would disappear as do the umbilical arteries after section of the cord. Pressure difference between the ends of any vessel is the factor that determines the direction of blood flow in that vessel. In a normal coronary circulation arterial anastomoses will have approximately the same pressure at either end, so that the blood flow will be small and may easily change in direction from time to time. In hearts the seat of obstructive arterial changes, marked difference of pressure between the ends of the anastomotic channels can easily occur, and then these vessels enlarge and become visible to the naked eye. It must be remembered that a free anastomosis exists at all ages in all capillary beds.

A study of the traditional descriptions of the fields of supply of the major coronary arteries reveals no unanimity between authors as to the areas supplied. If the right and left coronary arteries are perfused with coloured gelatine solutions of similar viscosity to that of blood and under carefully controlled pressures, the following average description of these fields of supply in the ventricular walls can be demonstrated. The left coronary supplies all the left ventricle except the right third of the posterior wall, and the posterior third of the septum; in addition it supplies the left third of the anterior wall of the right ventricle. The right coronary supplies the anterior two-thirds of the septum and the right ventricle except the portion of the anterior wall just mentioned as being supplied by the left vessel; it also supplies that portion of the posterior wall of the left ventricle already mentioned. There is, however, considerable anatomical variation in the arteries of different hearts so that this description can only be regarded as approximate.

When occlusive arterial disease occurs, these distributions will be upset by opening up of the various arterial anastomoses described. It will then be impossible to predict the field of supply of any one of the major coronary branches.

By injection methods and careful dissection it is possible to show that small coronary branches within the walls supply portions of the various ventricular muscles, but owing to frequent anatomical variations it is of little value to try to determine which branches supply which individual muscle. It can also be shown that in the normal heart the smaller vessels supply one part of one muscle only.

It is of importance in any discussion on infarction to remember that the parent artery, which gives branches to the pericardial portion of a superficial muscle, gives branches also to the endocardial portion of that muscle but not to the deep muscles in between. This is due to the peculiar arrangement of vessels by which some branches penetrate through the thickness of the ventricular wall without giving branches to the muscles of the deep layer through which they pass (Fig. 4). Further, no one arterial branch supplies the whole of any one ventricular muscle.

DISEASES OF THE CORONARY ARTERIES

No essential difference exists between diseases of the arteries of the heart and those of other organs of the body, but because of the vital nature of the tissues concerned, coronary arterial disease often assumes great clinical importance. No matter which portion of the

coronary tree is affected, the gravity of the lesion is largely, if not wholly, determined by the degree of vascular obstruction. The commonest disease that produces vascular obstruction is undoubtedly arteriosclerosis,* which commonly affects the larger arteries in contrast to rheumatic fever, polyarteritis nodosa, and other inflammatory processes, which more often involve the small branches and arterioles.

ARTERIOSCLEROSIS

Many detailed studies have been made of the incidence of arteriosclerosis at different age periods and of its relationship to coronary artery obstruction (Kirch, 1930, and Wartman, 1933 and 1940), and they indicate that it is a process which is more severe in the latter half of life, although both early and advanced stages of the lesion may be seen in youth (Fig. 5).

The essential pathological change is in the intima, and is characterized by vascularization (Leary, 1935; Paterson, 1938; and Wartman, 1938), cellular infiltration, proliferative changes,

FIG. 5.

FIG. 6.

FIG. 5.—Section of descending ramus of the left coronary artery showing marked stenosing arteriosclerosis and recent thrombosis in an apparently healthy man of 23 years of age. In such cases it is not the mechanical block to the vessel that is important in causing death, but the rate of cessation of blood flow, and the state of the collateral circulation.

FIG. 6.—Macroscopic cross-sections of a stenosed femoral artery which have been cleared to show the vascularization, indicated by arrows, and hæmorrhage in the intima.

and deposition of lipid, calcium, soaps, and other substances, often giving the appearance of an inflammatory reaction. The intima is greatly thickened at the site of the lesion and not infrequently this produces an appreciable diminution or even occlusion of the lumen. Secondary changes are also seen in the media which becomes thinned with the gradual replacement of muscle fibrous tissue.

Obstruction of the affected vessel may follow gradually by the growth of the intimal changes to such size as to prevent blood flow, or suddenly by thrombosis or hæmorrhage into the intima (Fig. 6) or medial (Fig. 7) tissues. These hæmorrhages account for about 10 per cent of coronary artery obstructions (Wartman, 1940) and appear to be a sequel to the capillary vascularization of the wall (Moritz and Wartman, 1938; Wartman, Laipply, and Derr, 1943).

Intimal hæmorrhage may cause obstruction either by pushing forward the atheromatous

* The term arteriosclerosis is used in this paper as being synonymous with atherosclerosis, in accordance with the decision of the American Heart Association.

FIG. 7.—Section of a thrombosed popliteal artery to show hematomata (A) in the media. Weigert's and Van Giesen's stains.

FIG. 8.—Section of femoral artery showing a thrombus (T) which has formed at the site of a large intimal hematoma (A). Weigert's and Van Giesen's stains.

plaque into the lumen of the vessel or by destruction of the endothelium, which is followed by thrombosis (Paterson, 1938; Wartman, 1938; Winternitz, Thomas, and Le Compte, 1938; Nelson, 1941) (Fig. 8). Occasionally these hæmorrhages are large (hæmatomata) (Fig. 6) and may bulge externally and even give rise to serious bleeding into the surrounding tissues.

Somewhat similar hæmorrhages are seen in dissecting aneurysms of the aorta, but there they are confined to the media. They frequently start as multiple foci which join and form a channel in the media of the aorta, and this channel may communicate either with the lumen of the vessel or rupture to the exterior. These have occasionally been recorded in the coronary arteries.

OTHER ARTERIAL DISEASES

Other conditions that are occasionally responsible for coronary artery occlusion are the acute and chronic inflammatory arterial diseases and also embolism. None of these are common causes but will be discussed briefly.

Acute Arteritis. This may occur during the course of any acute infectious disease or it may arise by the extension of a neighbouring inflammatory lesion or yet be mycotic in origin. Rare examples of so-called primary or idiopathic acute arteritis have been recorded (Karsner, 1937). Secondary thrombosis on the damaged site produces arterial blockage in these cases.

Polyarteritis Nodosa (Periarteritis nodosa). It has been estimated that some 70 per cent of cases of polyarteritis nodosa have involvement of the coronary arteries, and Grant (1940) has indicated that this disease is neither so rare nor so fatal as is generally thought. The histological picture seen in the affected vessels is that of an inflammatory response to some unknown agent. Polyarteritis nodosa usually attacks the small coronary arteries in scattered foci. Resulting infarcts are, therefore, small and disseminated (Fig. 9).

FIG. 9.—Comparison drawings of (A), the deep bulbo-spiral muscle and of (B), the multiple recent infarcts in the myocardium of a case of polyarteritis nodosa. Several small branch arteries were occluded and the infarcts were limited to the deep bulbo-spiral muscle.

Thrombo-Angiitis Obliterans. This is an occasional cause of coronary obstruction (Saphir, 1936), and consists of an inflammatory process in the vessel wall associated with thrombosis. A characteristic, although not universal, feature of the cellular response is the

presence of giant cells and infiltration with small round cells somewhat resembling a miliary tubercle.

Rheumatic Fever. In addition to producing a characteristic inflammatory lesion in the myocardium, this process also produces lesions in the walls of arteries. These are, however, rarely of clinical significance in comparison with the myocardial damage. Involvement of arterioles and small arterial branches is recorded (Karsner and Bayless, 1934) leading to occlusion with small scattered infarcts. Histological study of these vessels reveals no characteristic picture except for the occasional occurrence of Aschoff nodules. Holsti (1927) has recorded a peculiar verrucous endarteritis in which acidophilic material projects into the lumen of the affected vessels and closely resembles the vegetations seen on the cardiac valves.

Tuberculosis. Although tuberculous lesions of coronary arteries can be seen post-mortem (Gouley, Bellet, and McMillan, 1933) in cases dead of tuberculosis, it is of little clinical significance as a cause of coronary obstruction. The arteries are involved either as part of a miliary spread or as a local extension of mediastinal or pericardial disease.

Syphilis. Coronary artery occlusion is a well-established, even if uncommon, sequel of syphilitic aortitis. Obstruction of the coronary vessels usually occurs at the ostia of the arteries in the sinuses of Valsalva, especially if this opening is abnormally high. It is due to thickening of the intima and scarring of the medial coat of the adjacent aortic wall, and occasionally leads to sudden death, for it is a main coronary vessel that is obstructed.

Embolism. One of the rarest forms of coronary obstruction is that due to embolism. The emboli may be fragments of cardiac vegetations or of tumours invading the blood stream. Fat droplets gaining access to the blood stream from bone injuries or gas bubbles entering the circulation through wounds of the neck may also form emboli. Fat embolism is the commonest of these conditions and can be recognized by "streak-like" hæmorrhages in the myocardium. Microscopically fat droplets can be demonstrated in small vessels by appropriate stains. As a cause of death following trauma it may easily be overlooked.

MYOCARDIAL ISCHÆMIA

A detailed account of the effects of myocardial ischæmia may now be given under the six following headings.

- (1) Infarction of the ventricular wall.
- (2) Interference with ventricular function.
- (3) Rupture of the ventricle.
- (4) Ventricular aneurysms.
- (5) Infarction of the auricular wall.
- (6) Electrocardiographic changes.

Infarction of the Ventricular Wall (Lowe, 1937, 1940, and 1941a). Failure to maintain an adequate blood supply to any part of the myocardium results in death of tissue. This may follow complete or even partial occlusion of one or more coronary branches. Sudden obstruction of a vessel will reduce the hydrostatic pressure distal to the block to a very low level, and create pressure differences across the ends of the anastomotic channels in that area, favouring the passage of blood towards the blocked vessel. If the anastomoses are sufficiently numerous and of sufficient size, they can maintain the circulation beyond the obstruction, and lack of blood supply to the tissue need not result. This, however, rarely happens, for in a normal circulation the sudden obstruction of an artery by an embolus produces spasm of the vessel immediately distal to the block and the flow of blood through these channels is rendered impossible. The immediate effect of sudden blockage of a vessel is therefore to deprive a section of tissue of its blood supply. This causes death of tissue unless it can survive until the spasm passes off. In general, the block will last long enough for death of the essential cells of the cardiac muscle to occur, but the interstitial cells of the fibrous tissue often survive. The size of the block of tissue involved will be determined by the size and situation of the vessel

obstructed, and may vary from a portion of one muscle bundle to portions of several muscles, even to the full thickness of the ventricular wall.

Partial obstruction of a vessel will lower the pressure in the artery beyond the block and again favour the passage of blood through the anastomotic channels. In contrast to complete occlusion there will be no spasm to interfere with the flow of blood into the vessel, beyond the partial obstruction. This results in the establishment gradually, and simultaneously with the developing block, of an adequate anastomotic circulation, so that the final sudden blocking of the partially occluded vessel will have a minimal effect. Thus complete obstruction may, gradually produced, effect no disturbance whatever in blood supply to the tissue. On the other hand, should the parent vessel supplying the anastomotic circulation become suddenly blocked, the area deprived of blood supply will be much greater than that following blockage of a similar vessel in a normal circulation.

If a gradual occlusion develops in several vessels at the same time, then the establishment of the collateral circulation will depend not only on the pressure differences across the ends of the anastomotic channels—this will determine only the direction of blood flow—but also on the volume of blood carried by the parent vessel of the anastomotic circulation. If this vessel is itself partially occluded it will be unable to carry the additional blood to supply the anastomotic circulation and may even fail to maintain an adequate circulation to its normal area of distribution. This will result in portions of heart muscle being deprived of blood supply without complete obstruction to any vessel. These areas will lie at the points farthest removed from their respective parent arteries and the muscle there will be replaced by isolated islands of scar tissues.

Embolism in a coronary artery of a young adult, presumably not the subject of arterial disease, will produce either rapid death or the development of an infarct in the ventricular wall. In general the effect so produced will be greater than it would be in an older person with an established anastomotic circulation.

The following types of infarction may be expected in the ventricular wall:

- (a) massive infarction, involving the whole thickness of the ventricular wall or parts of several muscles;
- (b) infarction confined to a portion of one muscle; and
- (c) scattered small islands of scar tissue.

(a) Massive infarction arises from the blockage of a main coronary artery in a normal circulation, or from the obstruction of an anastomotic channel carrying a large amount of blood in a system with occlusive arterial disease. This is exemplified by sudden obstruction of the anterior descending coronary artery—"the artery of sudden death."

Massive infarction may involve the full thickness of the ventricular wall or, if less extensive, portions of two or more muscles (Fig. 10 and 11). These infarcts are frequently wedge shaped with their bases externally. The exact explanation of this wedge shape is uncertain. However, similar wedges may be produced by injecting gelatine media into major coronary branches if improperly balanced pressures are used. It is probable, therefore, that the wedge results from disturbances in the dynamic balance of blood flow through the coronary tree.

(b) Infarction of a portion of a single muscle (Fig. 12, 13, and 14) is due to interference with the blood supply through a small arterial branch in the thickness of the ventricular wall. It is not the mechanical block to the vessel that is important, but the rate of cessation of blood flow and the state of the collateral circulation. Although infarction of any portion of a deep muscle has been observed, involvement of the pericardial portion of a superficial muscle is rarely seen.

(c) Patchy fibrosis, while it may follow any lesion that destroys muscle tissue in a disseminated, discrete fashion, may be caused by the gradual inability of the coronary circulation to carry enough blood to nourish the whole of the muscle mass. Therefore those parts most

FIG. 10.

FIG. 10.—Aneurysm at the base of the left ventricle.

FIG. 11.

FIG. 11.—Wall of the aneurysm in Fig. 10 showing the two laminar scars at A and B.

FIG. 12.—Recent infarct involving the superficial muscles at the apex of the left ventricle and the lower end of the interventricular septum, with beginning aneurysm of the septum and mural thrombosis. Note the involvement of the papillary muscle, which is also composed of the superficial muscle bundles.

distant from the source of blood (aorta) will suffer most, i.e. small areas about the ends of arterioles which are supplied by the most obstructed channels.

Interference with Ventricular Function. Broadly speaking, interference with ventricular function can be considered under two headings.

(a) Interference with the ability adequately to expel blood. This depends on the amount of muscle tissue killed or damaged, and therefore ceasing to contribute to the force of cardiac

FIG. 13.

FIG. 13.—Aneurysm at the apex of the left ventricle showing a single laminar scar.

FIG. 14.

FIG. 14.—Wall of the aneurysmal sac in Fig. 13 showing the single laminar scar, A.

contraction. Following the sudden obstruction of a large vessel not previously constricted, there may be a gross drop in cardiac output and sudden death. If death does not result immediately, and if the damaged area is large enough, there will be a marked fall of systemic arterial blood pressure, and perhaps circulatory failure. This may end fatally, or a balance may occur and some of the anæmic muscle tissues recover, but the fall of blood pressure and circulatory failure that follow massive infarctions are likely to produce a vicious circle and lead to death in a few hours.

The quantity of blood flowing through a vessel is dependent on its lumen, and on the pressure difference across its ends. If the lumen is constant, as it is in many arteriosclerotic vessels, then the quantity of blood carried each minute is determined solely by the pressure differences. With the fall of systemic blood pressure following infarction of musculature, and the inability of rigid vessels to dilate, the area of muscle deprived of blood supply will increase, thus causing a further drop in systemic arterial pressure, and so establish a vicious circle. Frequently the damaged muscle is replaced by scar tissue and the resultant diminu-

tion of muscle means a reduction of ventricular power, manifested by a reduction in cardiac reserve (Lowe, 1941*b*).

The effects produced by the destruction of ventricular muscle depend both on the quantity of tissue destroyed and the particular muscle involved. The superficial muscles play a relatively unimportant part in the production of blood pressure (Robb and Robb, 1939), and destruction of portions of them may be unaccompanied by any circulatory change. By contrast, however, the deep muscles contribute the bulk of the ventricular power and involvement of one of them will produce marked disturbances.

(*b*) Rhythmic activity. If the infarcted tissue is in the interventricular septum, complete or partial heart block may follow. Damaged tissue at the margins of the infarct may act as an irritable focus and ventricular extrasystoles appear. Ventricular fibrillation sometimes develops, and is usually fatal as it is followed by failure of co-ordinated ventricular contraction.

Ventricular Rupture. Rupture of a ventricle may follow destruction of muscle in its wall. If an infarct involves the full thickness of the wall, then tearing of the dead muscle fibres occurs as soon as young granulation tissue appears and the muscle commences to break up. If only portion of the thickness of the wall is involved rupture occurs only occasionally. In such cases hæmorrhage from a large vessel in the damaged area, or communication with the ventricular cavity may allow blood to enter the muscle planes and so dissect a path to the pericardial cavity (Lowe, 1940). Bleeding into the pericardial cavity occurs and death results from pericardial tamponade.

These events usually follow within ten days of the arterial occlusion; after that time the scar tissue replacing the muscle seems strong enough to withstand the tensions developed in the wall, and although it may gradually stretch, it does not give way suddenly.

Aneurysm of the Ventricle. Weakening of the ventricular wall follows replacement of muscle by the inelastic collagen fibres of scar tissue, and the consequences of this are determined by the muscle involved. There may be merely a thinning of the wall or aneurysm formation. Ventricular aneurysms are of two types; basal (Fig. 10) and apical (Fig. 13).

At the apex of the left ventricle the wall is formed by the two layers of superficial muscle and involvement of the superficial musculature at the apex leads to thinning of the wall with the development of a laminar scar. However, if almost the full thickness of the wall is affected an aneurysm will develop (Fig. 13).

As there are several muscle layers near the base of the ventricles, the superficial muscles are unimportant in the production of thinning or aneurysm formation. A study of laminar scars (Lowe, 1941*c*) shows that involvement of a single deep muscle results in thinning of the wall without bulging. The presence of at least two laminar scars in the wall of basal aneurysms of the ventricle indicates that destruction of two deep muscle layers is essential to their formation (Fig. 11).

The physical basis of aneurysm formation is the same in both ventricle and aorta. In both places muscle tissue is active in withstanding pressure, and when enough of it is destroyed and replaced by collagen, gradual stretching and sac formation occurs.

Endocardial thrombosis (Fig. 12) is usually associated with massive infarction or an aneurysmal sac. It is rarely seen when the inner portion of a superficial muscle alone is involved because there is usually no endocardial damage as a thin layer of muscle between endocardium and infarcted tissue frequently survives, possibly deriving its nourishment directly from the ventricular cavity. Emboli may arise from these endocardial thrombi and produce infarction in any viscus as a sequel to myocardial infarction.

*Infarction of Cardiac Auricles.** The principles outlined in discussing ventricular infarcts are strictly applicable to those occurring in the walls of the auricles. In one reported series

* As the term "auricle" is by custom used in clinical and electrocardiographic terminology, it has been retained in place of "atrium" and refers to the whole chamber and not merely to the appendage.

of post-mortem examinations, auricular infarcts were seen 31 times in 182 (17 per cent) cases of ventricular infarction (Cushing, Feil, Stanton, and Wartman, 1942). Most of them were in the right auricle and involved the appendage more often than other parts of the chamber. Endocardial thrombosis was common in these instances and was due to the frequent involvement of the deep muscles of the auricle, which form the bulk of the auricular wall.

Electrocardiographic Changes. Following myocardial infarction electrocardiographic changes occur but their interpretation is difficult (Lowe, 1941a). The origin of the cardiac potentials is uncertain, but if, as seems probable, they are produced by the spread of the "impulse" along muscle bundles, and not by a current of action, then until the route of spread of that impulse is known definitely, any interpretation of changes following infarction must be empirical. When muscle is damaged the route of impulse spread is presumably disturbed and the cardiographic tracing will change from the normal, and such a change is likely to be permanent. In addition to this change in route, there will be a current of injury superimposed on the record, but this current is only transitory, and varies from hour to hour, finally disappearing. Non-fatal infarcts rarely involve a very large amount of any one muscle and the permanent disturbance of the electrocardiographic record is often small, whereas the immediate change is often gross.

Attempts to localize the site of infarction by cardiographic tracings must be based on both empirical observations and the anatomical structure of the heart. Most of the investigations so far recorded have considered massive infarctions involving several muscles at various positions in the ventricular wall. There are well-recognized tracings associated with anterior apical and posterior basal infarctions. However, some success has been achieved recently in recognizing tracings corresponding to involvement of single muscle bundles. At present it seems unlikely that any further localization than this is possible, because experimental observations indicate that an injury anywhere along the course of a single muscle produces the same electrocardiographic disturbance.

The disturbances in rhythmic activity of the ventricular muscle are also reflected in the cardiograph as ventricular extrasystoles, heart block, or even terminally as ventricular fibrillation.

Abnormalities in the auricular complex of the cardiogram are present in many cases of auricular infarction. These indicate variations in either the rhythmical activity or disturbance in the path of the impulse through the auricular wall. The former is represented by extrasystoles, fibrillation, wandering pacemaker, or nodal rhythm, and the latter by depression of the P-Q interval ("cupule").

Both in a carefully studied series of human cases (Cushing *et al.*, 1942) and in animal experiments no one of these disturbances was present in every case. Any disturbance in auricular electrical activity may therefore suggest auricular muscle damage—possibly due to infarction.

To conclude this essay we may indicate the directions in which these studies should aid the clinician now and in the future. It will be readily appreciated from the foregoing account of the structure and function of the heart that many of the indications of the existence of a myocardial infarct have a ready explanation. Fall of arterial blood pressure is in most cases due either to the amount of muscle tissue destroyed or to the particular muscle involved. Abnormalities in cardiac rhythm and the electrocardiographic changes will be better understood when sufficient data have been compiled relating to the problems of the electrical activity of the heart. Accurate localization of the specific muscle bundles involved may enable us to predict when rupture of the ventricles or even when congestive cardiac failure is to be expected.

The prognosis of a case of myocardial infarction depends as much upon the disease

causing the arterial block as it does upon the extent of the muscle damage. This factor determines the size of the infarct that follows the obstruction of any given vessel and whether or not a recurrence of the episode is to be expected. The varying condition of the coronary arteries is probably the cause of the great variation in the expectation of life after myocardial infarction—a variation from a few moments to some fifteen years.

A knowledge of the behaviour of diseased coronary vessels is essential in discussing the surgical procedures advocated for improving the myocardial blood supply in coronary artery disease. These procedures aim at establishing new anastomotic channels between extra-cardiac and cardiac arteries by placing intercostal muscles or omentum in contact with the pericardium. It is assumed in these procedures that the arterial pressure gradient will force blood from the extracardiac to the cardiac vessels. There is however no guarantee that such a gradient will exist. In those cases generally suitable for operative interference the one deficient in blood supply will frequently be deep in the ventricular wall. It is then very doubtful if a satisfactory pressure gradient will exist to transfer any quantity of blood to the heart, and it is possible that the flow will be in the opposite direction. This unpredictable factor probably causes the very variable results that follow these surgical procedures.

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