Normal and Diseased Vascular Pattern of Myocardium of Human Heart

II. Pattern seen with Fibrosis of the Left Ventricular Free Wall

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This paper reports the vascular abnormalities that may be found in areas of fibrosis or infarction in the left ventricle of the human heart. The observations are based on a study which was carried out to establish the variation in the vascular pattern in the myocardium of the ventricles of a series of normal and diseased human hearts†.

There is little published about the vascular changes that occur in areas of myocardial fibrosis or infarction in the left ventricle of the human heart, and it is obvious that a greater knowledge of the microvasculature is required not only to correlate the site, size, and extent of infarction with the location and degree of coronary artery obstruction, but also to provide a satisfactory explanation as to why some patients have long survivals with no incapacity following a myocardial infarction. Furthermore, a more complete understanding of the variation of the normal pattern of the vessels in normal and diseased myocardium will almost certainly be needed to interpret coronary arteriograms as greater magnification of these x -rays is produced.

MATERIAL AND METHOD

Details of the hearts studied, the use of Chromopaque to inject the coronary arteries, and the technique of taking microradiographs of transverse ventricular myocardial slices on Kodak high resolution plates, and the gross and microscopical examination of each heart have already been outlined (Farrer-Brown, 1968a, b).

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† The results of this study as a whole have been presented in the form of a M.D. Thesis (Farrer-Brown, 1967).

RESULTS

Large Myocardial Scars. Large scars of the left ventricular myocardium were seen in 11 hearts. All of them showed the generally accepted microscopical and macroscopical features of a healed infarct and were considered to be the result of episodes of acute coronary ischaemia. In all these scars the microvascular pattern was altered in fairly distinctive ways.

In some scars which were judged to be of long standing because of the dense mature fibrous tissue and thinning of the wall of the ventricle, the myocardium contained remarkably few arterial vessels (Fig. 1). The normal vascular pattern was absent, with loss of both "branching" and "straight" type arteries (Farrer-Brown, 1968b). The vessels present were small in calibre and tended to run in a circumferential direction.

In other less densely fibrous scars, the pattern of the intramyocardial branches was also considerably altered. The tree-like pattern of the small branches was absent and the arteries within the myocardium were larger and more abundant than normal. Their course was erratic, often showing spiralling, and instead of passing directly through the myocardium they veered towards a circumferential or diagonal direction. Some reached the endocardial surface; others did not.

Arborizations were sparse, but the vessels appeared to anastomose not only in the subendocardial zone, but also deeper within the myocardium. This appearance will be referred to as an "abnormal large vessel type" pattern (Fig. 2).

Another abnormal pattern, seen in three of the hearts examined with evidence of severe coronary artery disease and old atheromatous occlusions, was

FIG. 1.—The fibrosed and thinned lateral wall of a left ventricle in which only a few small arteries remain.
($\times 2.4$.)

a localized increase in small vessel density (Fig. 3) which will be referred to as a "plexus". In each of these hearts such a "plexus" was present in the left ventricle and extended from the subendocardial zone into the middle of the myocardium while, in one heart, a "plexus" was also present in the posterior part of the left half of the interventricular septum.

The majority of vessels in these "plexuses" were about $40\text{--}50\ \mu$ in diameter, and ran parallel to muscle fibres and were consequently circumferen-

tial (Fig. 4), but other vessels were viewed end-on, where muscle bundles had been cut across (Fig. 5). In addition, numerous large (up to $400\ \mu$) branching arteries ran radially through these "plexuses". Their terminal small arteries and arterioles with their tree-like pattern were dilated and formed part of the "plexus". Fig. 6 shows the complex of vessels in the densest part of a "plexus".

Histology of these areas showed focal areas of fibrosis with no evidence of an inflammatory reaction. The vessels of the "plexus" were present

FIG. 2.—The “abnormal large vessel type pattern” seen in the left ventricular wall of an adult heart. ($\times 4.5$)

both within the fibrous bands and in the surrounding muscle fibres. Dilated capillary-like vessels were not extensive in two of the hearts, but they were in the third.

Thus it appears that this “plexus” consists of both radially running, dilated large branches, and a circumferential component of dilated small arteries, arterioles, and large capillary-like vessels. In foci of fibrous tissue, the smaller vessels are probably newly formed, but in the surrounding viable myocardium they appear to be previously existing vessels that have become dilated.

Small Localized Areas of Fibrosis. Small areas of fibrosis are best visualized when capillary filling

has been achieved. Fig. 7 shows a small area of fibrosis in the postero-lateral part of the free wall of the left ventricle. There is an absence of main arteries in the area and capillary vessels are few in number.

Fibrosis in Papillary Muscle of Left Ventricle. Fibrosis of both anterior and posterior papillary muscles was always associated with scarring of the left ventricular free wall, except in two cases in which isolated papillary muscle infarction was seen.

In a heart from a 76-year-old patient, who had died from carcinoma of the prostate with metastases, a small fibrotic area was present in the posterior papillary muscle. Grade I stenosis (World Health

FIG. 3.—An abnormal “plexus” of vessels is present in the posterior wall of the left ventricle adjacent to the interventricular septum. ($\times 1.8$.)

Organization, 1958) from atheroma was apparent in the main trunk of the left coronary artery and the right posterior descending artery.

An electrocardiogram taken during his last illness showed a non-specific myocardial abnormality suggesting some focal antero-septal subendocardial ischaemia. At that time, the patient's haemoglobin was 12.5 g./100 ml. No complete arterial obstruction was seen radiologically or histologically to explain this isolated papillary muscle fibrosis, but it seems logical to surmise that, though not generally showing fibrosis, a certain degree of ischaemia was present, and that a previous episode of severe ischaemia may have caused an infarct in the posterior papillary muscle. Presumably the blood supply via the “straight” type arteries was insufficient for the needs of the papillary muscle, but the remainder of the myocardial wall was sufficiently well nourished by the “branching” type arteries.

Mural Thrombus in Left Ventricle. In one heart a mural thrombus was firmly attached to the posterior wall of the left ventricle where the underlying

subendocardial zone showed muscle damage. A microradiograph showed the presence of vessels within this thrombus. There was no regular pattern and the vessels were few in number (Fig. 8), and occasional vessels were found which passed from the trabeculae carneae into the thrombus (Fig. 9). Histology confirmed the radiological impression of an organizing thrombus.

DISCUSSION

In this study it soon became apparent that three basic types of vascular pattern were seen associated with myocardial fibrosis.

First Pattern. The first pattern consisting of a “mesh” of vessels has only been seen in three previous studies.

Fulton (1956) described these areas as being composed of a network of dilated intercommunicating channels occupying the inner zone of the left ventricular wall. Mitchell and Schwartz (1963) interpreted these areas as being part of the “sub-

FIG. 4.—A higher magnification of the “plexus” seen in Fig. 3. ($\times 9$.)

endocardial plexus” and the consequence of a healing process of a large myocardial lesion in which the vessels were akin to those found in typical granulation tissue. They had no explanation for the circumferential orientation of the vessels of a “plexus”. In 1965, Fulton, in his book *The Coronary Arteries*, stated that these vessels “run more in an oblique and spiral direction and appear to be parallel with muscle bundles”. In discussing the vascular patterns in zones of fibrosis, Estes *et al.* (1966) described a dense “feltwork” of very fine vascular channels, which interrupted the regular arrangement of “branching” type arteries, but which in many cases

did not affect the subendocardial plexus of the “straight” type arteries.

Thus there exists a confusion of terms, the consequences of which have been well emphasized by Mitchell and Schwartz (1965). There is also disagreement about the composition of these “meshes”.

It seems preferable to name the anastomotic vessels running in the subendocardial zone and trabeculae carneae the “subendocardial anastomoses”, and reserve the word “plexus” for this abnormal “mesh” of vessels, and this terminology will be used throughout the remainder of this discussion.

FIG. 5.—The x-ray appearance of vessels in the “plexus” cut end-on is seen adjacent to a collection of dilated small arteries forming the termination of a main arterial branch. ($\times 45$.)

The “plexus” was not localized to the subendocardial region, but involved the inner half of the myocardium including both superficial and deep muscle bundles. Consequently, there does not seem to be any reason for concluding that it is part

of the “subendocardial anastomoses”, nor that it has any specific relation to the blood supply of the deep spiral muscles, as suggested by Mitchell and Schwartz (1965) and Fulton (1965), respectively. It consisted of dilated small arteries, dilated arteri-

FIG. 6.—The central area of the “plexus” showing both the radially running arteries and their branches and the numerous circumferential vessels. ($\times 16$.)

FIG. 7.—A small area of fibrosis in the free wall of the left ventricle in a heart in which capillary filling is present. ($\times 5$.)

FIG. 8.—Small blood vessels present in an organizing thrombus. No pattern is present. ($\times 30$.)

FIG. 9.—A blood vessel passing from a trabeculae carneae into a portion of thrombus. ($\times 30$.)

oles, and large capillary-like vessels which mainly ran parallel to muscle fibres. In addition, there was a radial component of dilated large branching arteries which supplied the plexus.

The fibrosis in these areas was only focal and no evidence of a recent inflammatory reaction was seen. The smaller vessels of the plexus ran both through these bands of fibrous tissue and also in the surrounding viable muscle fibres.

It is suggested that the vessels within the foci of fibrous tissue were newly formed vessels, akin to those formed by granulation tissue in the rest of the body, as suggested by Mitchell and Schwartz (1965), but that the remainder and greater part of the "plexus" consisted of previously existing vessels that had dilated.

Each heart in which the "plexus" was observed also showed severe coronary artery disease with one or more old occlusions of the main coronary arteries. The findings suggested that these changes were the result of an episode of acute ischaemia which must have occurred at least 6 weeks previously or possibly much earlier.

Second Pattern. In contrast to the areas of focal fibrosis with an increased vascular density were regions of dense scar tissue with almost complete loss of muscle fibres. No vascular pattern could be made out and the dense bands of fibrous tissue were traversed by relatively few small arteries which ran in a more circumferential direction compared to normal. This second type of pattern, which has also been recently described by Estes *et al.* (1966), is comparable to the relative avascularity of dense fibrous tissue elsewhere in the body.

Third Pattern. A third abnormal vascular pattern was seen in areas of fibrosis, of density intermediate between the patterns already described. The fibrous areas were larger than in the focal fibrosis, and involved the whole width of the myocardium, but a considerable amount of apparently healthy myocardium remained. The predominant vessels seen were large arteries which veered towards a circumferential or diagonal direction and gave off few branches, but formed abundant anastomoses in the middle of the myocardium as well as in the subendocardial region. This appearance has been called an "abnormal large vessel type pattern".

In view of the histological findings and the extent and maturity of the fibrous tissue, it is suggested that these three vascular patterns show different stages of ischaemic damage of the myocardium.

Vascular Pattern in a Mural Thrombus. Mitchell and Schwartz (1965) showed a histological picture

of organization of a mural thrombus, but it appears that the heart findings in this study have provided the first radiological evidence that vessels do pass out from the trabeculae carneae and that they course indiscriminately within a thrombus, forming no particular pattern. Presumably fibrous tissue is laid down, and with subsequent shrinkage produces a thickened endocardium. A similar assumption was made by Mitchell and Schwartz (1965) in considering the aetiology of fibro-elastic thickening of endocardium overlying areas of massive cardiac necrosis.

Localization of Fibrosis. The explanation of the localization of the fibrosis to the subendocardial zone in some hearts remains conjectural.

Hearts in this series showed that this fibrosis resulted not only from acute coronary insufficiency but also when occlusions of main coronary arteries were present. Friedberg and Horn (1939) suggested that fibrosis localized to the subendocardial area might be due to the remoteness of its blood supply, and Johnson and Di Palma (1939) showed that the gradient of pressure diminished from the inner to the outer layers of the left ventricle. Horn *et al.* (1950) suggested that increased nutritional demand of the papillary muscles might be a factor, but Fulton (1965) queried this assumption of a greater need. The importance of the subendocardial anastomoses in supplying this region was stressed by Fulton (1965).

Estes *et al.* (1966) postulated that a decrease in pressure and blood flow of "straight" type vessels might be responsible for subendocardial infarcts or even infarcts extending to the middle of the myocardium. This may be correct in regard to the supply of the myocardium adjacent to the papillary muscles to which the "straight" type arteries are large, but in the remainder of the left ventricular free wall the "straight" type arteries are smaller and the importance of the terminal branches of the "branching" type arteries appears greater. It should not be forgotten that decreased blood flow and factors such as decreased aortic pressure and increased peripheral pressure will naturally affect both types of arteries as they arise from the same main artery.

The finding of an isolated papillary muscle fibrosis, however, fits in with the assumption that the blood supply via the main "straight" type vessels may become insufficient. The subendocardial zone in these hearts is adequately nourished by blood from the terminal arterioles of the "branching" type arteries. The failure to find occluding thrombi in the small arteries in the two hearts in which this type of fibrosis was present is similar to the observation of Horn *et al.* (1950), and suggests that there

may have been an episode of acute insufficiency in these cases.

It is thought that, probably, a combination of factors determines whether the patient dies immediately, or survives having suffered an extensive degree of heart damage or simply a subendocardial infarction. These factors include the rapidity of onset of an occlusion, or ischaemia, the degree of enlargement of the anastomotic vessels, the remoteness of the blood supply, the pressure gradients, the aortic pressure, and the peripheral blood pressure.

This study has been primarily concerned with the pathology of the hearts of patients who survived an initial episode of myocardial infarction. From the available evidence it appears that the subendocardial anastomotic network may play a key part in providing an adequate blood supply in the initial stage of infarct, but it appears that the subsequent long-term survival of some patients may depend on their ability to form anastomotic vessels in the middle of the left ventricular wall, particularly when occlusion of the supplying main coronary artery was present. This capacity may be of special importance when focal areas of fibrosis are present and a considerable amount of interspersed surviving muscle fibres remains, as is seen in a "plexus". Following survival of a more severely damaged area there is a greater replacement fibrosis with only a few arteries remaining. The lack of muscle fibres in such an area appears to obviate the need for a better blood supply.

In hearts in which there was generalized severe coronary artery disease with extensive fibrosis of the left ventricle, the normal arterial pattern was replaced by a network of irregular, more circumferentially running arteries. These vessels must consequently be newly formed vessels which remain after the healing of a damaged area, and this origin may explain why, like the arterial pattern of granulation tissue from which they must have been formed, their arrangement is more haphazard and the number of communications with similar vessels extensive. This ability of the heart to form new blood vessels in damaged areas throughout the whole width of the left ventricular myocardial wall is probably of great importance in patients who survive an initial myocardial infarction.

SUMMARY

The vascular patterns seen in areas of fibrosis or scarring in the left ventricle of human hearts was

studied *post mortem* by injection of a radiopaque medium, Chromopaque, and the taking of micro-radiographs of transverse myocardial slices on Kodak high resolution plates.

Three types of vascular pattern, namely a "plexus", "an abnormal large vessel type pattern", and an "avascular pattern in dense scar tissue" are described and their possible significance discussed.

The vascular pattern seen in a mural thrombus of the left ventricle is also illustrated.

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