STUDIES ON THE MICROVASCULATURE OF HUMAN MYOCARDIUM

BY

Hidehiko ICHIKAWA*1 and Osamu MATSUBARA*2

ABSTRACT

The microvasculature of human myocardium was examined stereoscopically after the injection of Silicone rubber. Material were 40 normal hearts, three of infants, one of child, and 36 of adults, ranging in age from 27 to 79 years. Three types of arteries, subepicardial, branching, and straight type arteries, were confirmed. The microvascular pattern of left ventricular free wall, the posterior wall of the left ventricle, interventricular septum, right ventricular free wall, papillary muscles, trabeculae carneae, infant heart, and aged heart were also examined. The present study revealed that the inner one-third zone was supplied by the terminal branches of both branching and straight type arteries. In infant heart, the inner zone was wider than that of the adult. In the aged cases, reduction in filling with patchy deficit often appeared in this inner zone. The finding of the aged change was probably caused by the characteristic microvascular pattern, and this suggested that the same anatomical mechanism might commit myocardial infarction.

INTRODUCTION

While numerous investigations on the blood supply of the heart have mainly concentrated on the problem of coronary atherosclerosis and arterial anastomosis performed after myocardial infarction, little attention has been paid to the finer details of the microvasculature of the myocardium. The microcirculation and transmyocardial distribution of blood flow have recently offered an interesting theme in the pathophysiology of the coronary circulation.

In order to observe the finer microvasculature of the myocardium, injection with Silicone rubber media, was applied, which enabled the capillaries to emerge as a delicate and fine arborization, and the method of stereoscopic detection by naked eyes, as was already devised and published by one of the authors1,2.

The present paper is concerned with the normal and aged microvascular pattern of the ventricles of human heart, and confirms and extends the previous studies.

MATERIALS AND METHODS

The materials used for this study consisted of 40 hearts obtained at necropsy from patients who had died at Saku Central Hospital, Nagano Prefecture, Japan. The hearts were selected out of non-cardiogenic diseases. Of these hearts, three from persons aged one day to one year, and 37 from those aged 14–79 years, were considered normal by the examination of their clinical data and pathological study. The distribution of age and sex is shown in Table 1. The weight of

---

*1

*2

Department of Pathology (Chief: Prof. Z. Ishii), School of Medicine, Tokyo Medical and Dental University (Tokyo Ika Shika Daigaku).

Received for publication, November 10, 1976.
Table 1. Age and Sex Distribution

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>21–40</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>41–60</td>
<td>4</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>61–79</td>
<td>11</td>
<td>6</td>
<td>17</td>
</tr>
</tbody>
</table>

The vascular pattern of large coronary arteries in the epicardium is consistent with the description of Gross\(^3\) and Spalteholz\(^4\). *Left Ventricular Free Wall*: The outlook of the left ventricular free wall is shown in Fig. 1. It is composed of so much capillary plexus as though it was a mass of capillaries (Fig. 3).

The first branches from the main coronary arteries in the epicardium are diverged at right angles with their stems, running down the endocardium. While entering the myocardium, it branches off into small arteries which nourish the epicardium. These small arteries run straight, outward or inward (Fig. 7). Small branches also come into the subepicardial zone of the myocardium and then run in a circumferential direction, forming capillary plexus in the outermost zone of the myocardium. This type of arteries is called the subepicardial type arteries. Capillary plexus is very scanty in the epicardium and the small arteries are easily replaced by venous vessels.

Soon after entering the myocardium, the branches repeat to divide into two, forming a twigged tree-like pattern (Fig. 8), gradually diminishing their calibers. A large number of these arteries become the final arterioles in the outer and middle zones of the myocardium. The final arterioles take their course at obtuse angles with the direction of their stems and are terminated in the capillary plexus. The capillaries run parallel with muscle fibers, with moderate crossing connections.

In addition to these branching type arteries, a small number of straight type arteries (Fig. 9) appear in the middle zone of the myocardium. These characteristic arteries are not divided so much as the branching type arteries, but give off only a few twigs.
and supply mainly the subendocardial zone, papillary muscles, and trabeculae carneae. The final arterioles of these straight type ones run at acute angles and then terminate in the capillary plexus. Especially in the endocardial aspect, the most densely packed capillary plexus are accomplished. The inner zone is supplied by the peripheral branches, both of the branching and straight type arteries.

The nourishing arteries of each region are summarized in Table 2.

Table 2. Nourishing Artery

<table>
<thead>
<tr>
<th>Zone of the myocardium</th>
<th>Nourishing artery type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subepicardial zone</td>
<td>Subepicardial type</td>
</tr>
<tr>
<td>Outer 1/3 zone</td>
<td></td>
</tr>
<tr>
<td>Middle 1/3 zone</td>
<td>Branching type</td>
</tr>
<tr>
<td>Inner 1/3 zone</td>
<td></td>
</tr>
<tr>
<td>Subendocardial zone</td>
<td>Straight type</td>
</tr>
<tr>
<td>Endocardial side</td>
<td></td>
</tr>
</tbody>
</table>

Posterior Wall of the Left Ventricle: The right coronary artery was dominant in the supply of the posterior wall in 22/40 (55%) and the left one is dominant in 10/40 (25%), and remainder of the cases show intermediate variations. The border terrain between the two coronary arteries is very irregularly outlined. A large number of intercapillary anastomoses and small connections between the arterioles are observed.

Right Ventricular Free Wall: The basic pattern of the arterial tracks is most similar to that of the left ventricular free wall (Fig. 5) but, in contrast with the left ventricles, both branching and straight arteries run more tortuously and are less in amount than those of the left ventricle (Fig. 10). There is no difference in the density of arterioles and capillaries between the two ventricles.

Interventricular Septum: The interventricular septum is supplied by large branches of the anterior and posterior descending coronary arteries. The largest arteries lay in the middle shifted to the right, and run parallel to the endocardial surfaces. The large arteries give off the secondary branches, which form both the branching and straight type arteries. Each side of the septum takes a similar pattern, as is seen in the free wall of the same-sided ventricle (Fig. 6).

Papillary Muscles: The straight type arteries supplying the papillary muscles pass through the center of them and go upward, giving off small branches to the peripheral zone. The terminal arterioles make the longitudinal network of capillary plexus alongside the muscle fibers and the most condensed plexus in the endocardial aspect (Fig. 11).

Trabeculae Carneae: The straight type arteries also supply the trabeculae carneae. Small branches make up finger-like divisions in the subendocardial zone and condensed plexus in the endocardial aspect (Fig. 12).

Heart of Infants: There is no remarkable difference in the pattern of arterial tract between the two ventricles, and even the septal arteries run in the middle line of the septum. Particularly the following is observed, different from the adult hearts. The running pattern of branching and straight type arteries appears in a pliable fashion and the straight type arteries are more prominent than that of the adult heart. Small branches in the subepicardial zone are much smaller in amount. The longitudinal network of the capillary plexus lay in wider areas of the subendocardial zone (Fig. 13).

Heart of the Aged Men: Macroscopically, spotty areas of insufficient injection appeared in the inner zone of the heart from the aged case group (Fig. 2 and 14). While it appears in a few cases of the middle-age group, most of the aged cases show reduction in filling with patchy deficit to a various extent. The distribution of its appearance is
limited to the inner one-third myocardium of the left ventricle, excluding the subendocardial zone, papillary muscles, and trabeculae carneae (Fig. 15). This patchy deficit is not seen in any cases of the infant, child, and adult group.

Another finding is the tortuous running of the small arteries and arterioles in the whole myocardium (Fig. 16). Their caliber changes irregularly, and they run sometimes like a corkscrew. In addition, the arterioles branch off often at acute angles with small arteries. These findings are not prominent in the right ventricle.

**Discussion**

This injection study revealed that there are branching, straight, and subepicardial type arteries. The branching type arteries have been observed by previous investigators such as Gross, Campbell, Mitchell and Schwartz, Fulton, Estes, Farrer-Brown, and Handa, but the final conclusion has not been reached about the territory in myocardium that these arteries supplied. Estes et al. showed that these arteries are confined to the outer three-fourths to four-fifths of the myocardium, but Farrer-Brown stated that they supplied the subendocardial zone, innermost 2 to 3 mm of the myocardial wall, but did not include the trabeculae carneae. Our current study reveals that the inner one-third zone of the myocardium is supplied by the branches both of the branching and straight type arteries. The difference in these findings was probably due to the technical problem. Silicone rubber was more easily and uniformly injected than Micro-paque and Chromopaque. Secondly, the finer details of the smallest vessels could be observed by naked eyes with a stereomicroscope than the microradiographs.

The straight type arteries have been mentioned by Fulton, Estes, Farrer-Brown, and Handa as supplying the subendocardial zone, papillary muscles, and trabeculae carneae. This study confirmed their findings but revealed in addition that this type of arteries were preserved in the aged group and prominent in the infant group.

The finding that the reduction in filling leaving patchy deficit was commonly observed in the inner one-third zone of the myocardium in the aged group is very important, because that region proves to be most easily affected by the circulatory disturbance, and also is well known as the place where myocardial infraction often occurs. The inner one-third zone of the myocardium is the marginal region between the branching and straight type arteries, and where the terminal branches of both type arteries end. This characteristic microvascular pattern will be much related not only to the ischemic change of the inner zone in the aged group, but also the pathogenesis of inner or subendocardial infarcts of the myocardium.

**Acknowledgement**

The authors are most grateful to Mr. R. Yamashita, Mr. H. Ide, Mr. M. Haketa, and Mr. K. Shimazaki of the Branch of Pathology, Saku Central Hospital, for their kind co-operation. Thanks are also expressed to Mr. M. Takata and Mr. S. Ono of the Photo Center of our University for their valuable advice for taking photographs.

**References**


EXPLANATION OF FIGURES

Plate 1
Photographs of the injected heart.

Fig. 1. Normal adult material, 39-year-old female.
Fig. 2. Aged material, 78-year-old male.

Plates 2, 3, 4, 5, 6, 7 and 8
Photomicrographs of the injection cast.

Fig. 3. Left ventricular free wall of the normal adult. ×10
Fig. 4. Posterior wall of the left ventricle of the normal adult. ×10
Fig. 5. Right ventricular free wall of the normal adult. ×10
Fig. 6. Interventricular septum of the normal adult. ×10

Fig. 7. Epicardium and subepicardial type arteries. ×30
Fig. 8. Branching type artery. ×30
Fig. 9. Straight type artery. ×30
Fig. 10. Branching and straight type arteries of the right ventricle. ×30
Fig. 11. Papillary muscles. ×30
Fig. 12. Trabeculae carneae. ×30
Fig. 13. Left ventricular free wall of the infant, 14-day-old male. ×10
Fig. 14. Left ventricular free wall of the aged material, 78-year-old male. ×10
Fig. 15. Subendocardial zone of the aged material, 78-year-old male. ×30
Fig. 16. Middle zone of the aged material, 78-year-old male. ×30