

## Quantitative study on the size of coronary artery supplying areas postmortem

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Hitherto only few attempts have been made to determine the size and the limits of myocardial supplying areas of single coronary arteries. Ahmed and associates<sup>1</sup> examined the hearts of 94 casualties by means of injection and corrosion techniques. They estimated the relative amount of myocardium supplied by the right and left coronary artery, taking the different thicknesses of the right and left ventricular wall into account. The result of the examination was that they found in most human hearts that the myocardium was equally supplied by both coronary arteries. Woods<sup>2</sup> determined the part of the myocardium supplied by the right coronary artery by means of angiography, as well as by the dissection and weighing of 28 normal and 19 hypertrophied human hearts. According to this investigation the right coronary artery supplies 20 to 46 per cent of the left ventricular myocardium, in addition to the whole of the right ventricle. de Oliveira<sup>3</sup> injected different colored media into the right and left coronary artery. After removing the atria and subepicardial fat, he weighed the portion of myocardium perfused by the right coronary artery. Its size lay between 13.1 and 63.2 per cent (average 38.4 per cent in 32 normal human hearts) and rarely exceeded 50 per cent (four out of 32 hearts). These methods have two disadvantages. First, the left ventricular myocardium must be dissected into the areas supplied by

each coronary artery. Second, the free part of the right ventricle must be severed from its attachment to the interventricular septum. This will complicate histologic and above all topographic studies.

Methodical investigations into the size of perfusion areas dependent upon the coronary vascular type are fully lacking. Schlesinger<sup>4</sup> has introduced the term of coronary artery "preponderance." His differentiation of coronary artery patterns into right or left preponderance and balanced circulation was based exclusively on anatomic criteria. However, it might create the impression of corresponding physiological preponderance of a coronary artery. But since the bulk of left ventricular myocardium is so much greater than the bulk of the right myocardium in the majority of all human hearts, the left coronary artery is the physiologically preponderant artery.<sup>5-9</sup> However, no measurements exist on the size of supplying regions.

We have been able to determine the size of supplying areas of the single coronary arteries by using injection and dissection techniques. This examination was carried out on normal and diseased human hearts of various coronary vascular types.

### Material and methods

Altogether 171 human hearts were examined. Age distribution is shown in Table I. Among the hearts of adults, 67 revealed distinct hypertrophy with heart weight of 500 Gm. and more. In 51 hearts there were old (28) or recent (23) infarctions. Ten hearts with recent infarcts showed additional former infarctions scars.

The method has been described in detail elsewhere.<sup>11</sup> To give a brief outline here, the coronary arteries were injected with x-ray contrast medium

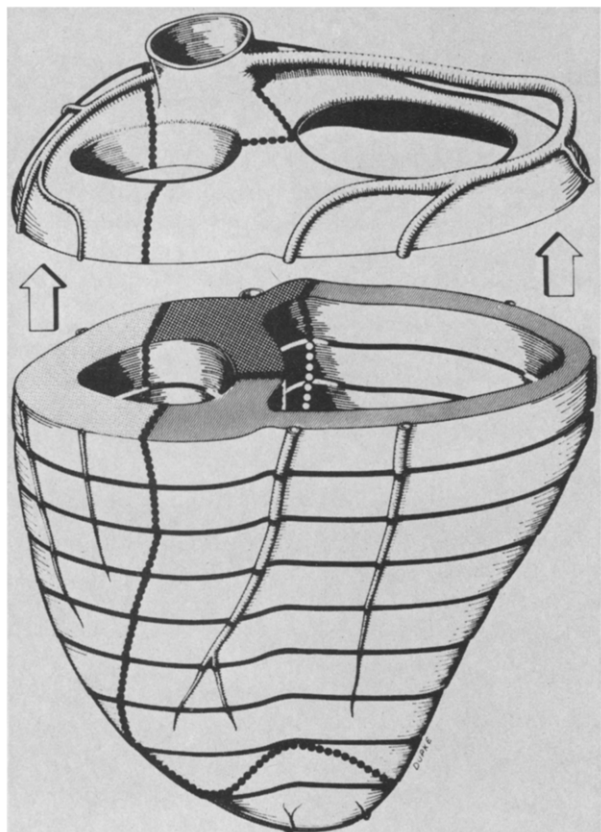
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This study was supported by a research grant from the Deutsche Forschungsgemeinschaft.

Received for publication May 4, 1976.

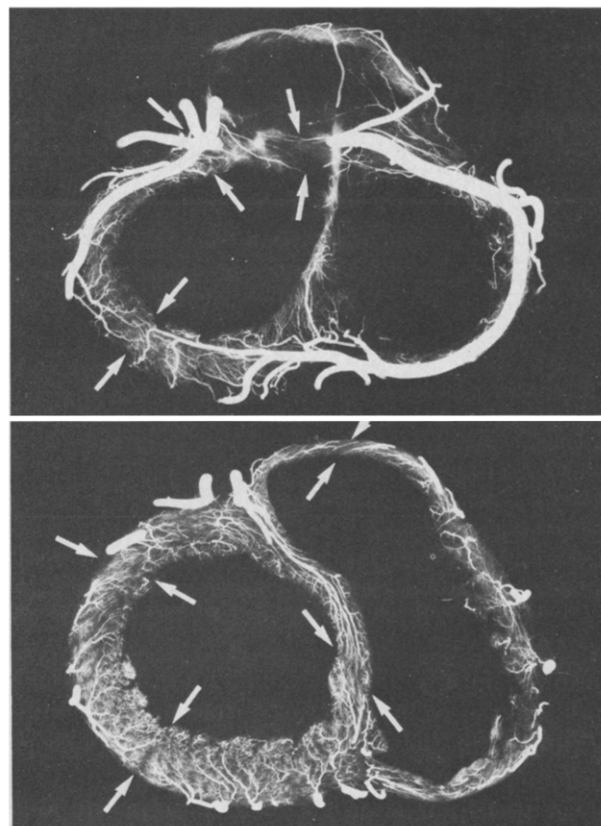
Accepted for publication May 13, 1976.

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**Fig. 1.** Diagram illustrating the manner in which the hearts were sliced. Drawing of the diaphragmatic surface of the heart. The basal slice is raised somewhat in order to reveal the vascular areas of the left descending (*cross-hatched area*), left circumflex (*stippled area*), and right coronary artery (*linear area*). The dotted lines on the surface mark the boundaries between the supplying areas.

Micropaque in 10 per cent gelatine solution under a constant pressure of 100 mm. Hg. Our usual procedure was not a single coronary injection but the filling of the twofold ligated aorta in order to obtain complete angiographs, even in cases of a third coronary ostium. After radiography in different planes and formalin fixation, the atria were detached from the ventricles at the level of the atrioventricular valve rings. The ventricular portion of the hearts was sliced into serial sections 8 mm. in thickness parallel to the basis of the heart (Fig. 1). Only the first section was frequently somewhat thicker because it enclosed the vascular ring of the right coronary artery and the left circumflex branch. Radiographs of the individual sections served as the basis for the evaluation of the coronary supplying areas (Fig. 2). The outlines of the myocardium, the free part of the right ventricle, and the limits between the



**Fig. 2.** In these radiographs of the basal slice (*upper figure*) and of a slice taken from the middle (*lower figure*) of the same heart (autopsy number S 590/72) the boundaries between the coronary vascular areas are indicated by arrows. There is a sharp line of demarcation between the areas. Of course one can only determine the vascular areas by comparison with the adjoining slices.

supplying areas of the left descending, left circumflex, and right coronary artery were drawn on contact copies of the ventricular slice roentgenograms.

As a rule the borderlines of the vascular supplying areas are easily recognizable if the radiographs of the myocardial sections are systematically analyzed from the base to the apex. The partial areas of all slices were measured by a planimeter and the percentage of the coronary supplying areas was calculated with respect to the total myocardial area. Moreover, the percentage may be expressed in grams of ventricular mass. In this way we got the relative part of myocardium perfused by a single coronary vessel. The hearts were subdivided into groups according to the coronary vascular type and to pathologic conditions, such as hypertrophy or myocardial infarctions.

**Table I.** Age frequency of cases studied

|                                           |     |
|-------------------------------------------|-----|
| Neonates and infants up to the first year | 4   |
| 1 to 19 years                             | 7   |
| 20 to 39 years                            | 12  |
| 40 to 59 years                            | 36  |
| 60 to 69 years                            | 56  |
| 70 to 79 years                            | 46  |
| 80 years and older                        | 10  |
| Total                                     | 171 |

## Results

**A. Mean values of all 171 hearts.** In this study the vascular areas of the three large coronaries (i.e., right coronary artery, left anterior descending, and left circumflex branch) were ascertained. The area of the right coronary artery can be defined without difficulty. It covers the part of myocardium supplied by all branches of the right coronary artery. On the other hand, the delimitation of the vascular regions of the two left coronary arteries is more problematic if there is an additional branch arising in the bifurcation of the left coronary stem. This is referred to in various ways, for instance *ramus medianus*,<sup>12</sup> *ramus obliquus*,<sup>13</sup> or *ramus diagonalis*.<sup>14</sup> Brink<sup>15</sup> used the term "third primary division" of the left coronary artery and Hoffmann and associates<sup>16</sup> used the term "Trifurkationstyp." We found such a trifurcation in 55 per cent of the hearts under study and even a multiple division of the left coronary trunk in 4.7 per cent. We always added the vascular area of the tripus branch to the area of the left anterior descending artery.

On the average, the left coronary artery of all hearts examined supplied just under two-thirds of the entire ventricular myocardium—63.8 per cent, while slightly over one-third is supplied by the right coronary artery—36.2 per cent. The anterior descending branch is responsible for the greater part of the supplying area of the left coronary artery. It supplied on average 41.5 per cent of the entire ventricular myocardium.

The musculature of the left ventricle, consisting of the free left chamber wall and the whole interventricular septum, was supplied on the average of 79 per cent by the left coronary artery. About two thirds of this came from the anterior descending branch. Twenty-one per cent of the left ventricular myocardium was supplied by the right coronary artery.

**B. The sizes of supplying areas dependent upon coronary vascular types.** We defined the

**Table II.** Size of the supplying areas as a percentage of the whole ventricular myocardium related to the coronary vascular types

| Coronary vascular type      | No. | Per cent supplied myocardium |      |      |
|-----------------------------|-----|------------------------------|------|------|
|                             |     | R                            | Lad  | Lc   |
| Left coronary artery type   | 19  | 16.4                         | 43.8 | 39.8 |
| Normal coronary artery type | 129 | 37.3                         | 41.7 | 21.0 |
| Right coronary artery type  | 23  | 46.4                         | 39.0 | 14.6 |

Abbreviations: R = right coronary artery; Lad = left descending coronary artery; Lc = left circumflex coronary artery.

coronary vascular types as follows<sup>17</sup>:

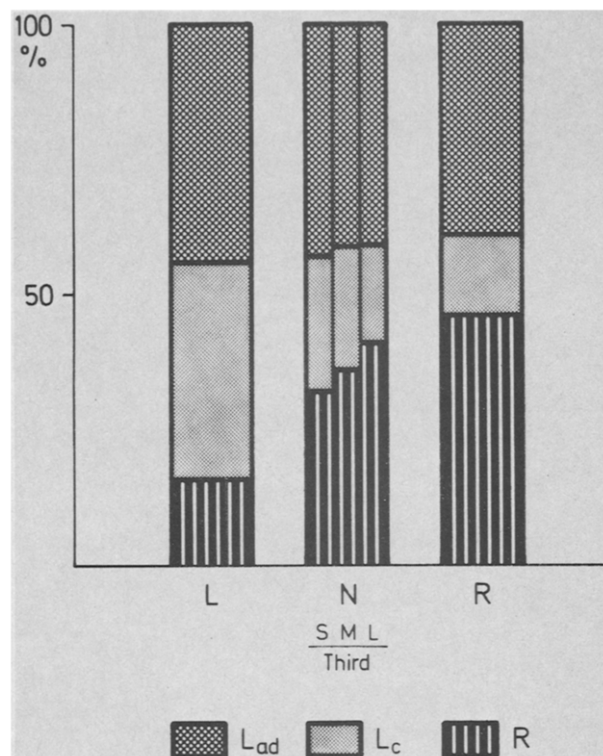
**Left coronary artery type:** The *ramus descendens posterior* stems from the left circumflex branch and the latter may even transverse the posterior interventricular sulcus and terminate at the posterior wall of the right ventricle.

**Right coronary artery type:** The right coronary artery ends at the *margo obtusus* or may reach the left anterior wall.

**Normal coronary artery type:** All the remaining hearts, which represent the majority, rank among normal types. In these the left posterior ventricular wall is supplied by both the right and left branches.

The mean values for the different coronary vascular types among all 171 hearts are shown in Table II.

The percentage of myocardium supplied by the left anterior descending branch varied only slightly. In left coronary artery types it was on the average slightly larger, in right types slightly smaller than in normal types. Considerable variations emerged, however, in the sizes of supplying areas of the right and left circumflex coronary artery (Fig. 3). They revealed a reciprocal ratio: In hearts of right coronary type the perfusion area of the right coronary artery is large, that of the left circumflex branch small. In these hearts, the right coronary artery supplied slightly less than half of the whole ventricular myocardium. In the hearts of the left coronary type, the vascular area of the left circumflex branch is large, covering on the average 40 per cent of the entire ventricular musculature. That of the right coronary artery on the other hand is small. The further subdivision of normal coronary types is possible, depending on the boundaries on the left posterior wall.<sup>18</sup> The size of the supplying areas in subtypes is shown in Table III. As expected, the



**Fig. 3.** Summary of results. Size of supplying areas (expressed as a percentage of the entire ventricular myocardium) of left descending ( $L_{ad}$ ), left circumflex ( $L_c$ ) and right coronary artery ( $R$ ) in each of the coronary artery types.  $L$  = left type;  $N$  = normal type;  $R$  = right type. The normal type is subdivided according to the boundaries between the right and left circumflex branch in the septal ( $S$ ), medial ( $M$ ), or lateral ( $L$ ) third of the posterior left ventricular wall.

supplying area of the right coronary artery increases as it extends over the posterior left wall to the left side wall. At the same time the supplying area of the left circumflex branch diminishes accordingly.

**C. Hearts with right preponderant coronary artery.** In our study material, the left coronary artery with its branches generally supplied a greater part of the myocardium with blood than the right coronary artery. This included the hearts of the right coronary vascular type, hearts of neonates with their physiological right ventricular hypertrophy, and adult hearts with right ventricular hypertrophy. Of the hearts studied, there were only nine in which more than half of the ventricular myocardium was supplied by the right coronary artery. In six of these nine hearts a right coronary type existed, four of which were combined with right ventricular hypertrophy. The remaining three hearts were of the normal

**Table III.** Size of the supplying areas of subtypes of normal coronary type. Position of the boundary between the right and left circumflex coronary artery in the septal, medial, and lateral third of the posterior left ventricular wall

| Coronary vascular type | No. | Per cent supplied myocardium |      |      |
|------------------------|-----|------------------------------|------|------|
|                        |     | R                            | Lad  | Lc   |
| Septal                 | 25  | 31.8                         | 43.0 | 25.2 |
| Medial                 | 55  | 36.5                         | 41.5 | 22.0 |
| Lateral                | 49  | 41.1                         | 41.0 | 17.9 |

**Table IV.** Size of the supplying areas related to left or right ventricular hypertrophy

**A. Hearts with unilateral or prevailing left hypertrophy**

| Weight (Gm.) | N. | Per cent of free part of right ventricular wall | Per cent of supplied myocardium |      |      |
|--------------|----|-------------------------------------------------|---------------------------------|------|------|
|              |    |                                                 | R*                              | Lad  | Lc   |
| 603          | 22 | 17.6                                            | 34.8                            | 43.2 | 22.0 |

**B. Hearts with unilateral or prevailing right hypertrophy**

| Weight (Gm.) | N. | Per cent of free part of right ventricular wall | Per cent of supplied myocardium |      |      |
|--------------|----|-------------------------------------------------|---------------------------------|------|------|
|              |    |                                                 | R                               | Lad  | Lc   |
| 577          | 16 | 33.0                                            | 44.1                            | 40.4 | 15.5 |

\*See Table II for abbreviations.

type, but with a hypoplastic left circumflex branch. It did in fact reach the left posterior wall at the basis of the heart, but barely descended, so that the bulk of the left posterior ventricular wall was perfused solely by branches of the right coronary artery. Moreover, all three hearts showed a distinct right ventricular hypertrophy. In our test material the highest figure for the vascular area of the right coronary artery—57.8 per cent—was encountered in a heart with a marked eccentric right and left ventricular hypertrophy in primary cardiomyopathy with hypoplasia of the left circumflex branch.

**D. Hearts with right or left hypertrophy.** Altogether our observation material included 38 hearts of the normal vascular type, with unilateral or prevailing hypertrophy of one cham-

ber. A relative weight portion of the free right chamber wall of more than 26 per cent served as the criterion for distinct right ventricular hypertrophy. Less than 20 per cent served as the criterion for left ventricular hypertrophy. Table IV shows the sizes of supplying areas in hearts with left or right ventricular hypertrophy.

The supplying area of the right coronary artery in cases of right hypertrophy is, on the average, larger than in cases of left hypertrophy. These differences are significant for the right coronary artery. In hearts with bilateral hypertrophy, including hearts with old or recent infarctions, we observed no significant differences in the size of coronary supplying areas between the individual coronary vascular types.

### Discussion

The method employed in this study to determine the size of coronary supplying areas presupposes a successful coronary angiography. It is sometimes difficult to determine the boundaries of vascular regions if they appear flat due to highly developed collateral vessels. The simple serial cross-sectioning of the ventricles has the advantage of permitting the preparation of paraffin large-sections through the entire right and left ventricular myocardium. The method is not without possible sources of error. The possibility of error lies chiefly in the various thicknesses of the myocardial slices. An electric slicer helps to obtain fairly uniform thickness of the serial sections. Sometimes however, there are deviations in the thickness of the first manually dissected basal slice and also in the last remaining apical slice. These are of course very small. Yet control examinations of ten hearts<sup>11</sup> revealed only slight consequences of these inaccuracies on the relative size of the coronary supplying areas. Of course one has to realize that the results are a reasonable approximation of the real values. A comparison of planimetrically determined values and those values obtained by additional weighing, shows on the average merely the following differences:

Right coronary artery: 0.85 per cent (0.02 to 1.67 per cent).

Left anterior descending branch: 1.02 per cent (0.26 to 2.27 per cent).

Left circumflex branch: 0.25 per cent (0.01 to 0.70 per cent).

The present study shows that the left coronary

artery with its anterior descending and circumflex branches, perfused in almost every case the major portion of ventricular myocardium. This accounts for the larger mass of the left ventricular musculature. The right coronary artery is as a rule very long and its vascular area on the cardiac surface is correspondingly large. But this vessel mainly supplies the thin-walled right ventricle and only parts of the posterior ventricular septum and posterior left ventricular wall. The sizes of supplying areas vary above all, according to the different coronary vascular types. First and foremost, the area of the right and left circumflex coronary artery is affected.<sup>17, 19</sup> In so far as the long right coronary artery corresponds with a short left circumflex branch and vice versa, the supplying areas of these vessels are in an inverse ratio to each other. The same applies to the reciprocal length, the size of the supplying area of the posterior descending branch and the anterior descending left coronary artery.

Contrary to the supplying area of the right and left circumflex coronary artery, that of the anterior descending left branch is almost constant, even in different coronary vascular types. It was noted that the average values for the vascular area of this vessel in the normal vascular type lie slightly above those of the right coronary type. In the left coronary type the increase is more obvious. The explanation for this tendency could be that the left anterior descending branch in right coronary types, scarcely ascends into the posterior interventricular groove, having run round the cardiac apex. In normal or left coronary types, it frequently supplies the entire cardiac apical region ascending to various degrees into the posterior sulcus.<sup>19</sup>

A marked cardiac right or left hypertrophy is usually of less importance to the size of the coronary supplying area, than is an extreme coronary vascular type. There must be a unilateral hypertrophy to a high degree before the size of the coronary supplying area is affected.

Our study group has determined that the diameters of coronary vessels without, or with only slight sclerotic lesions, give an approximate indication of the size of the supplying areas. Coronary arterial lumens have been seen to correlate best with the size of supplying areas, in accordance with earlier investigations.<sup>2, 6</sup>

The sizes of supplying areas are not only of anatomical interest. Under pathologic conditions

it is, for example, of importance if parts of the conducting system are involved by pathologic changes in the supplying branch. The A-V node artery in hearts of the normal or right coronary vascular type stems from the right coronary artery, but in the left coronary type, usually from the left circumflex branch.

In infarcted hearts the consequences for hemodynamics will be more pronounced the more extensive the vascular supplying area beyond the occlusion is. Beyond that, the determination of the boundaries of the supplying areas presents the opportunity to analyze topographic relations between ischemic myocardial changes and the supplied area of one single coronary artery branch behind a stenosis or an occlusion.

### Summary

The relative amount of myocardium perfused by the three large coronary arteries was determined in 171 human hearts postmortem. Roentgenograms of transverse serial sections of the ventricular myocardium enabled planimetric measurements. With little variation, an average of 41.5 per cent of the entire ventricular myocardium was supplied by the left descending coronary artery. Both left branches supplied an average of 63.8 per cent and the right coronary artery supplied 36.2 per cent of the myocardium. The size of supplying areas, in particular that of the right coronary artery and the left circumflex branch, was mainly dependent upon the coronary artery types. As a rule cardiac hypertrophy did not influence the size of coronary supplying areas as much as did the coronary artery types. Only very few hearts revealed that the myocardium was supplied to a greater extent by the right coronary artery than by the left (5.3 per cent). There is a close relationship between the size of the myocardial supplying area and the lumen of the corresponding coronary artery.

The authors gratefully acknowledge the contribution of Drs. Milzner-Schwarz, Köhler, Frenzel, and Heipel in the injection of hearts and in the preparation of radiographs. We also wish to acknowledge the help of Mr. Staubitz in photographic documentation and the technical assistance of Mrs. Schwaiger and Mrs. Holland.

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