ATTEMPTS to determine the nature and extent of the collateral circulation to the myocardium have not been entirely satisfactory. Injection techniques upon post-mortem specimens have been employed to detect the presence of interconnections between coronary arteries, but they fail to yield information of a quantitative nature. Perfusion experiments have provided quantitative data in the human heart at autopsy and in the isolated, fibrillating dog's heart, but the results may not be identical with those in the beating heart. The most widely used method for assessing the extent of collateral circulation to an ischemic region of the myocardium is the measurement of retrograde flow from the distal end of the occluded artery. It is generally recognized, however, that this technique probably overestimates the magnitude of the actual interarterial collateral flow since more blood would be likely to flow through interarterial anastomoses and out a low resistance cannula than through the natural myocardial arterioles, capillaries, and veins.

Recently, the radioactive isotope of rubidium, Rb\textsuperscript{86}, has been employed to assess the rate of myocardial blood flow. In the present study, the myocardial clearance of Rb\textsuperscript{86} has been used to estimate the extent and distribution of collateral circulation to the region of myocardium ordinarily supplied by the left circumflex artery in the heart of the dog. The results indicate that the total collateral circulation is underestimated, not overestimated, by the retrograde flow technique, and that an appreciable fraction of the collateral channels is other than arterial-to-arterial in nature.

**Methods**

Sixty-seven experiments were conducted upon mongrel dogs, weighing 12.8 ± 3.0 (S.D.) Kg. They were anesthetized with sodium pentobarbital, 30 mg./Kg., intravenously. The chest was opened in the left fifth interspace, and artificial respiration was administered. The left circumflex coronary artery was exposed 1 to 2 cm. from its origin. After control arterial pressure and electrocardiogram (lead II) were recorded, heparin* (3 mg./Kg.) was administered intravenously, and the left circumflex coronary artery was ligated. In 40 of these experiments, a brass cannula was then inserted into the distal segment of the coronary artery to permit measurement of retrograde flow. The resistance of this cannula plus the attached rubber tubing was 0.38 mm. Hg/ml. blood/min., measured at room temperature at low flow rates. For the measurement of retrograde flow, the end of the rubber tubing was held at the same hydrostatic level as the tip of the coronary artery cannula. Usually, three one-minute determinations of retrograde flow were made, with a two-minute interval between each determination. The tubing was unclamped for 15 to 30 seconds prior to each measurement.

Soon after these data were obtained (10 to 20 minutes after ligation), myocardial Rb\textsuperscript{86} clearance was determined in all experiments in which

*Heparin furnished through the courtesy of Eli Lilly Laboratories.
ventricular fibrillation did not previously supervene. To accomplish this, a constant intravenous infusion of approximately 100 μc. Rb₈⁶ Cl (Abbott Laboratories; specific activity, 1.4 to 1.7 mc./mg.) was administered into the superior vena cava by means of a motor-driven syringe.

In the first 14 experiments in which Rb₈⁶ was infused, the rubber tubing connected to the coronary artery cannula was clamped after the last measurement of retrograde flow and remained clamped during the isotope infusion. In the remaining 26 experiments in which this isotope was infused, an alternating sequence was instituted in an attempt to estimate the fraction of the total collateral flow which is delivered by interarterial channels. In the odd-numbered experiments, the retrograde flow tubing was occluded, just as in the 14 experiments described above. In the even-numbered experiments, on the other hand, the tubing was left uncuffed after the last retrograde flow measurement, and the coronary arterial backflow was permitted to drain freely during the Rb₈⁶ infusion which followed in three to five minutes. Arterial blood samples were collected at 10-second intervals during the Rb₈⁶ infusion. At the end of exactly one minute, the infusion was automatically terminated; simultaneously, ventricular fibrillation was induced by means of an electrode attached to the pericardium.

The heart was removed immediately, washed briefly with tap water, and then blotted dry. Specimens of myocardium weighing from 0.2 to 0.5 Gm. were removed from selected areas in the normal and ischemic zones. They were placed in previously tared lusteroid tubes and weighed on an analytical balance. The Rb₈⁶ content of blood and tissue specimens was determined in a well-type scintillation detector.

**Results**

Of the 67 experiments which were conducted, ventricular fibrillation occurred in 27 before the Rb₈⁶ was administered. In the remaining experiments, the constant intravenous infusion resulted in a rapid rise in Rb₈⁶ concentration in the arterial blood during the first 20 seconds, then a more gradual rise during the last 40 seconds. The arterial blood concentration of this isotope was plotted as a function of time for each experiment, and the graph was integrated in order to determine the mean blood concentration during the infusion. The composite graph for these experiments is plotted in figure 1 in terms of per cent of the maximum blood concentration attained in each experiment.

The Rb₈⁶ clearance for the normal zone of the left ventricular myocardium bordering the intact anterior descending coronary artery (fig. 2, zones A and B) was determined by dividing the average tissue content of this isotope (in counts per minute (CPM) per gram of myocardium) by the mean blood content (in CPM per gram of blood). The clearance values are presented in table 1 for those experiments in which the coronary arterial backflow was not permitted to drain away during the isotope infusion. The mean Rb₈⁶ clearance for the normal region was 1.19 ± 0.044 (S.E.) ml./min./Gm. of tissue. As an index of the homogeneity of Rb₈⁶ uptake by different regions of the normal myocardium, the Rb₈⁶ clearance for zone B was 102.7 ± 2.9 per cent of that for zone A. The systolic arterial blood pressure was 144 ± 20 (S.D.) mm. Hg; diastolic, 104 ± 15 mm. Hg.

The distribution of Rb₈⁶ in the myocardium in these experiments is depicted in figure 2 in terms of per cent of the average uptake for normal zones A and B. The principal landmarks for the ischemic zone are (a) the circumflex artery itself, (b) the ramus sulei
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Table 1

<table>
<thead>
<tr>
<th>Region</th>
<th>$^{86}$Rb clearance (ml./min./Gm.)</th>
<th>Mean ± S.E.</th>
<th>No. of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A,B</td>
<td>1.185 ± 0.044</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.257 ± 0.051</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>0.789 ± 0.127</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>0.648 ± 0.119</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>0.335 ± 0.060</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>0.405 ± 0.072</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>0.525 ± 0.110</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1.261 ± 0.097</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>1.049 ± 0.108</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>0.622 ± 0.062</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>0.846 ± 0.073</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2

The distribution of $^{86}$Rb in the ventricular myocardium after ligation (indicated by the X) of the left circumflex artery (l.c.a.), for all experiments in which the retrograde flow cannula was occluded during the isotope infusion. The numbers represent the mean $^{86}$Rb clearance, expressed as per cent of the mean value in normal zones (A) and (B), lying along the intact anterior descending artery (a.d.a.). The shaded area represents the zone in which the $^{86}$Rb clearances were significantly reduced. The major coronary arteries shown, in addition to those mentioned above, are the right coronary artery (r.c.a.), the ramus suci longitudinalis posterioris (r.s.l.p.), and the ramus marginis obtusi (r.m.o.).

longitudinalis posterioris, and (c) the ramus marginis obtusi. This last-named branch originates about two-thirds of the distance from the origin of the circumflex artery to the point where it descends as the ramus suci longitudinalis posterioris. It descends along the epicardial surface of the left ventricle parallel to the posterior descending branch, and ends 10 to 15 mm. before reaching the apex.

In the region bounded by the circumflex artery, the posterior descending branch, the ramus marginis obtusi, and the apex, the rubidium clearances (table I, zones C through G) were least in the region bordering the atrioventricular groove (zones C and F), and progressively increased toward the apex (zones E and D). Also, in the basal region of the left ventricle just anterior to the ramus marginis obtusi (zone H), the $^{86}$Rb clearance was 44 per cent of that of the normal zone. Toward the apex (zone I), however, the clearance was not significantly different from that in the normal zone.

At the center of the right ventricle (zone L), the $^{86}$Rb clearance was 0.846 ± 0.073 ml./min./Gm. This disparity between $^{86}$Rb uptakes for the right and left ventricles is similar to that previously observed in the dog heart. In the region of the right ventricle bordering on the posterior descending branch of the left circumflex artery, the clearances were 1.049 ± 0.108 and 0.622 ± 0.062 for the apical (zone J) and basal (zone K) regions, respectively.

In six experiments, the $^{86}$Rb clearance was measured in the apical and anterior and posterior basal regions of the interventricular septum. The values were not significantly different from those observed in normal zones A and B. For example, in the posterior basal region of the septum, which is closest to the external zones (C and F) most dramatically affected by the coronary occlusion, the $^{86}$Rb clearance was 99.5 ± 6.9 per cent of that obtained in zones A and B.

Retrograde flow from the distal end of the ligated left circumflex artery was measured in 40 experiments; the mean flow was 3.53 ± 0.40 (S.E.) ml./min. This value is close to the mean retrograde flows reported for several large series of experiments by Eckstein, Leighninger, and their collaborators. In 13 of our experiments, ventricular fibrillation supervened before the $^{86}$RbCl infusion was begun. The mean retrograde flow was 1.56 ± 0.15 ml./min. for these experiments, as compared to 4.47 ± 0.50 ml./min. for the 27 experiments in which fibrillation did not
Comparison between the clearance of $\text{Rb}^{86}$ (ordinates) for myocardial zone G (fig. 2) and retrograde flow (abscissae) from the distal end of the ligated left circumflex coronary artery, both expressed in terms of ml./min./100 Gm. of myocardium, for 17 experiments in which the retrograde flow cannula was occluded during the isotope infusion. The regression line (continuous line) for these data is represented by the equation $Y = 3.77X - 15.0$. The dotted line represents the regression line which would obtain if $\text{Rb}^{86}$ clearance and retrograde flow were equal in each experiment.

occur spontaneously ($P < 0.001$). In an additional 14 experiments, ventricular fibrillation developed even before any values of retrograde flow could be obtained.

The $\text{Rb}^{86}$ clearance tended to be greater in those experiments in which higher retrograde flows were obtained. In figure 3 are plotted the $\text{Rb}^{86}$ clearances (with backflow tubing clamped) for zone G, at the center of the ischemic region, as a function of retrograde flow for 17 experiments in which both measurements were made. The continuous, diagonal line represents the regression line for these data. A significant positive correlation exists between these two independent indices of collateral circulation to the ischemic myocardium ($r = 0.885; P < 0.001$). Retrograde flow is expressed in figure 3 in terms of flow per 100 Gm. of myocardium estimated to be supplied by the left circumflex coronary artery. The circumflex region is computed as 37 per cent of total heart weight, on the basis of data discussed below. The dotted line in the figure represents the regression line which would obtain if this index of collateral flow were exactly equal to the $\text{Rb}^{86}$ clearance, also expressed in terms of ml./min./100 Gm. of myocardium, for this zone in each experiment. It is evident that the estimate of collateral circulation derived from the clearance of $\text{Rb}^{86}$ is materially greater than that inferred from the retrograde flow data, since all points but one fall above the oblique dotted line.

Ligation of the left circumflex coronary artery produced considerable alterations in the electrocardiogram in the vast majority of experiments. When the clamp was removed from the tubing connected to the coronary artery cannula, as during a measurement of retrograde flow, these abnormalities were exaggerated in a reversible fashion. The sequence of tracings from standard lead II from a typical experiment are reproduced in the lower half of figure 4. After the chest was opened and the left circumflex coronary artery was dissected free, a control electrocardiogram (E) was recorded. The artery was
then ligated, and a cannula was inserted into the distal portion. A second record (F) was then obtained while the tubing connected to it was clamped. The electrocardiogram showed ST-T elevations which were quite characteristic for most of the experiments in this study. When the clamp was removed for a retrograde flow measurement, these alterations were considerably exaggerated (G). The changes were reversible, however, for when the clamp was reapplied, the tracings (H) again resembled those in record F. A similar sequence is displayed in the upper half of the figure, except that the electrocardiographic abnormalities were considerably more severe than average.

The data from the series of 26 experiments in which the backflow cannula was occluded in alternate experiments and patent in the remainder during the Rb86 infusion are shown in figure 5. For zones A through G (corresponding to the regions designated in fig. 2), each pair of bars represents data from all 26 experiments, whereas for zones H through L, clearances were measured in only the last 8 of these experiments. When the coronary artery cannula was patent during the Rb86 infusion (unshaded bars), the Rb86 clearance to the normal zones (A and B) was 103.0 ± 8.6 (S.E.) ml./min./100 Gm. With the cannula tubing clamped (shaded bars), the clearance was somewhat higher, 123.8 ± 5.9, although this difference is of questionable significance (P = 0.06). The mean values for either arterial blood pressure or retrograde flow were not statistically significantly different (0.3 < P < 0.4) under these two circumstances. Only at the basal (zones C and F) and central (zone G) regions of the ischemic area was there a significant difference (P = 0.02 for C; 0.03 for F; 0.01 for G) between the clearance values for the "clamped" series as compared to the "patent" series. In all of the other regions, which comprise the marginal zone of the ischemic area, the differences in clearance are insignificant.

Discussion

The initial rate of uptake of Rb86 by a tissue is dependent upon the rate of blood flow to that tissue and upon the rate of tissue exchange. The fraction of Rb86 extracted in each passage through the myocardial capillary bed is itself an inverse function of the rate of coronary blood flow. When the extraction is ascertained, the actual blood flow may be computed by dividing the clearance by the extraction fraction. In the present study, the tissue extraction could not be measured, since it was not possible to obtain separate venous samples from the normal and ischemic regions, or from the various subdivisions of the ischemic zone itself. The Rb86 clearance values, therefore, are an index of the actual blood flow. This index does represent a minimum value for flow, however, and the true blood flow must be in excess of the clearance value.

The mean Rb86 clearance in the normal region of the left ventricular myocardium in the present study was found to be 1.19 ± 0.044 (S.E.) ml. blood/min./Gm. of tissue (table 1). This rate, expressed in terms of whole blood, is somewhat lower than the value of 0.80 ml. plasma/min./Gm. of left ventricular myocardium reported in the closed-chest, anesthetized dog. In the myocardial region affected by ligation of the left circumflex
coronary artery, there is a considerable variation in Rb\textsuperscript{86} clearances, as shown in figure 2. The clearances are least in the basal region (zones C and F), intermediate in the central zone overlying the posterior papillary muscle (zone G), and still greater in the marginal region (zones E, D, H, and K). It has been well established that interarterial anastomoses account for some fraction of this collateral circulation. The retrograde flow technique furnishes an index of the extent of this type of collateral blood flow.

The data from the present study indicate that, in addition to such interarterial anastomoses, there must be other types of communications as well. These channels do not join major distal branches of the ligated vessel, but probably communicate with the vascular bed of the ischemic zone at the arteriolar or capillary level. Such channels would not be detected to any appreciable extent by the measurement of retrograde flow, since the resistance to forward flow would be considerably less than that to flow in the retrograde direction.

The data obtained in the present study afford three major types of evidence to support the hypothesis that channels other than interarterial vessels supply a significant collateral circulation to the ischemic myocardium. These lines of evidence are (a) the geographical distribution of Rb\textsuperscript{86} within the ischemic zone, (b) the comparison of the Rb\textsuperscript{86} clearances with the simultaneously obtained values of retrograde flow, and (c) the comparison of the Rb\textsuperscript{86} clearances obtained while the retrograde flow tubing was occluded with those obtained while the tubing was patent.

Relative to the geographical distribution of Rb\textsuperscript{86}, it has already been established\textsuperscript{12-14} that the uptake of Rb\textsuperscript{86} by the normal left ventricular myocardium is quite uniform. Therefore, if the collateral supply to the ischemic myocardium were exclusively by means of communication from the anterior descending or right coronary arteries to the larger distal branches of the ligated left circumflex artery, it would be anticipated that the distribution of this isotope would be rather homogeneous within the ischemic zone, except perhaps at the boundaries. The data (table 1, fig. 2) show, however, that there is a considerable variation in the clearances within the ischemic zone. Furthermore, other studies have shown that the infarct resulting from coronary artery occlusion is frequently not uniform, but contains many foci of living tissue.\textsuperscript{21, 22}

The second line of evidence is related to a comparison of Rb\textsuperscript{86} clearance values with simultaneously obtained measurements of retrograde flow. Since the clearances are expressed in terms of flow per unit weight of myocardium, retrograde flows must also be expressed in equivalent terms for purposes of comparison. The region of the myocardium supplied by the left circumflex coronary artery may be outlined rather sharply by the injection of dyes such as India ink. Dye injections were not made in the present study, however, for fear of altering the Rb\textsuperscript{86} content of the myocardium in that region. Fortunately, the dyed area represents a remarkably constant fraction of the total heart weight. In one study by Eckstein,\textsuperscript{23} mean values of 36 and 37 per cent were reported. Calculations from the data of Eckstein and Leighninger\textsuperscript{16} yield a value of 36.0 ± 1.1 (S.E.) per cent, while a percentage of 38.5 ± 1.1 is derived from unpublished data of R. M. Berne.

In preparing the data for figure 3, therefore, the weight of the region supplied by the left circumflex coronary artery (and drained by the retrograde flow cannula) was calculated as being 37 per cent of the total heart weight. As figure 3 shows, the Rb\textsuperscript{86} clearance at the center of the ischemic region (zone G) materially exceeds the retrograde flow, expressed in equivalent units. When retrograde flow is computed on this basis for all experiments in which the cannula was subsequently occluded during the Rb\textsuperscript{86} infusion, a mean value of 16.3 ± 2.1 (S.E.) ml./min./100 Gm. is obtained. This value is within the range reported in other studies.\textsuperscript{7, 16, 17} Even at the basal regions of the ischemic myocardium (zones C and F) where minimal values of Rb\textsuperscript{86} clearance are obtained, the mean clearances (table 1) surpass this mean value for retrograde flow. The differences between Rb\textsuperscript{86} clearance and retrograde flow for the other
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ischemic loci (zones E, D, H, and K) are, of course, even more marked.

Furthermore, the disparity between the estimates of collateral blood flow derived from these two techniques becomes even more exaggerated when it is considered that (a) the extraction of Rb$^{86}$ by the myocardium is never complete, even when flow approaches zero,$^{20}$ and (b) the retrograde flow overestimates the actual extent of interarterial anastomotic flow.$^{7,8}$ With respect to the first of these considerations, there may be some alteration in cell membrane permeability in the ischemic zone in the present study. Potassium tends to leak from ischemic myocardial cells,$^{24}$ and the biological behavior of rubidium is very similar to that of potassium.$^{25}$ Thus, there may be an associated reduction in tissue uptake of rubidium by the ischemic myocardium. Therefore, the actual blood flow to this region may exceed the clearance value to an even greater extent than would be estimated on the basis of extraction fractions obtained in the normal myocardium. Since (a) retrograde flow overestimates the actual interarterial anastomotic flow, (b) Rb$^{86}$ clearances underestimate the total flow, and (c) Rb$^{86}$ clearances exceed retrograde flows expressed in equivalent units (fig. 3), it follows that the total collateral flow to the ischemic region must surpass that delivered by interarterial channels; i.e., other types of communications must also exist.

The third line of evidence afforded by the present study to support this contention is provided by the data in figure 5. In the basal and central regions (zones C, F, and G) of the ischemic zone, the Rb$^{86}$ clearance is significantly less when the retrograde flow cannula is patent during the Rb$^{86}$ infusion than when it is occluded (0.01 < $P$ < 0.03). This is undoubtedly due to the fact that flow through interarterial anastomoses is diverted from the capillary beds in the ischemic zone by the patent cannula. Since the backflow cannula with its attached tubing had a resistance of 0.38 mm. Hg/ml. blood/min., at the usual retrograde flow rates the mean pressure in the distal circumflex artery and its major branches could not have exceeded 2 or 3 mm. Hg when the tubing was unclamped. That this procedure had a functional effect is demonstrated by the electrocardiographic changes which were evoked (fig. 4, tracings C and G). The low resistance of this cannula makes it probable that the major fraction of the interarterial anastomotic flow must have been drained away by unclamping this tubing. Yet, when Rb$^{86}$ was infused in this situation, the Rb$^{86}$ clearance was still between 40 and 50 per cent of that which obtained with the cannula system occluded for zones C, F, and G. For all of the other regions tested, furthermore, clearance values were affected to an insignificant extent by diverting the interarterial flow away from the capillary beds.

Finally, as Wiggers$^{26}$ has asserted, the marginal areas of the territory supplied by a particular coronary artery must receive a dual blood supply. Convincing evidence for this is afforded by the fluorescein dye experiments of Prinzmetal and his collaborators,$^{27}$ by the polarographic studies of Sayen and his co-workers,$^{28}$ and by the results of fibrinolytic therapy reported by Nydick and his colleagues.$^{29}$ The higher Rb$^{86}$ clearances in the apical portions of the ischemic region in the present study are probably attributable to the fact that the larger terminal branches of the anterior descending and circumflex arteries tend to converge as the apex is approached (fig. 2). It is likely that more than one of these enter common capillary beds. The data in figure 5 show that for all portions of the marginal zone of the ischemic region (zones D, E, H, I, J, and K), the effect upon Rb$^{86}$ clearance of draining away the interarterial anastomotic flow is insignificant. This is consistent with the hypothesis that the vascular communications from collateral sources are made at the arteriolar or capillary levels within the marginal regions.

One might question, therefore, the validity of expressing retrograde flow in terms of the weight of the entire myocardial regions which may be injected with dye through a given coronary artery. In so doing, it is implied that the interarterial anastomotic flow is distributed rather homogeneously to the entire region. The capillary hydrostatic pressure
would undoubtedly be greater in the marginal than in the central regions of an ischemic zone because of this dual supply to the boundaries. The interarterial anastomotic flow, therefore, would probably be distributed more richly to the central than to the peripheral regions of the ischemic area.

The data from the present experiments indicate that the marginal zone is quite extensive. As stated above, the weight of the myocardium stained by dye injected into the distal end of the left circumflex coronary artery is about 37 per cent of the total heart weight. In the present study, the region of the left ventricle bounded by the left circumflex artery, the ramus marginis obtusi, the posterior descending branch, and the apex was excised and weighed. In hearts weighing 80.1 ± 3.0 Gm., this zone comprised 17.1 ± 0.6 per cent of the total heart weight. This region, therefore, represents slightly less than one-half of the weight of the region outlined by dye injection. Unquestionably, the basal region of the left ventricle just anterior to the ramus marginis obtusi (fig. 2, zone H) also is rendered ischemic by ligation of the left circumflex artery. Also, the basal region of the right ventricle adjacent to the posterior descending branch (zone K) is affected, since its Rb80 clearance is less \( \bar{P} = 0.03 \) than that for the mid-right ventricle (zone L). Even with the inclusion of zones II and K, however, the weight of the ischemic region as defined by the Rb86 clearance technique would be considerably smaller than the area outlined by the injection of dye. This is consonant with the observation that the extent of an infarct is usually appreciably smaller than the size of the vascular bed supplied by a particular branch, the ramus marginis obtusi, and the apex. The diminution of clearance of this isotope was most marked in the basal region, and improved progressively toward the apex. Clearances were also decreased in the basal regions just anterior and posterior to this zone.

The weight of the ischemic zone, as defined by the Rb86 clearance technique, was approximately half of that outlined in other studies by injection of dye into the distal end of the occluded circumflex artery. This implies that the marginal zone of the territory supplied by the left circumflex coronary artery must receive a dual blood supply. Also, the Rb86 clearance in the ischemic zone exceeds the estimates of collateral flow provided by simultaneously measured retrograde flows. This was true despite the facts that (a) actual blood flows must exceed the measured Rb86 clearances, since extraction is never complete, and (b) retrograde flows overestimate the true value for interarterial collateral flow. When the interarterial collateral flow is drained away by leaving the low resistance cannula system unclamped during the isotope infusion, the Rb86 clearance is not appreciably affected in the marginal zone and is reduced by 50 to 60 per cent in the central and basal portions of the ischemic region. These findings signify that an appreciable circulation must be provided by vessels which communicate with the capillary beds within the ischemic zone and, therefore, would contribute to the measured retrograde flow to only a negligible extent.

Summary

The left circumflex coronary artery was ligated in anesthetized dogs, and the blood flow to the normal and ischemic regions was estimated by means of the Rb86 clearance technique. The occlusion of this coronary artery resulted in an appreciable reduction in the Rb86 clearance, principally in the posterior region of the left ventricle bounded by the circumflex artery, the posterior descending branch, the ramus marginis obtusi, and the apex. The diminution of clearance of this isotope was most marked in the basal region, and improved progressively toward the apex. Clearances were also decreased in the basal regions just anterior and posterior to this zone.

The weight of the ischemic zone, as defined by the Rb86 clearance technique, was approximately half of that outlined in other studies by injection of dye into the distal end of the occluded circumflex artery. This implies that the marginal zone of the territory supplied by the left circumflex coronary artery must receive a dual blood supply. Also, the Rb86 clearance in the ischemic zone exceeds the estimates of collateral flow provided by simultaneously measured retrograde flows. This was true despite the facts that (a) actual blood flows must exceed the measured Rb86 clearances, since extraction is never complete, and (b) retrograde flows overestimate the true value for interarterial collateral flow. When the interarterial collateral flow is drained away by leaving the low resistance cannula system unclamped during the isotope infusion, the Rb86 clearance is not appreciably affected in the marginal zone and is reduced by 50 to 60 per cent in the central and basal portions of the ischemic region. These findings signify that an appreciable circulation must be provided by vessels which communicate with the capillary beds within the ischemic zone and, therefore, would contribute to the measured retrograde flow to only a negligible extent.

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Collateral Blood Flow to the Myocardium as Determined by the Clearance of Rubidium$^{86}$ Chloride

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