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Dynamics of Collateral Circulation Following Chronic Occlusion of Coronary Arteries.*

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The exact mechanism by which the myocardium is nourished in the presence of chronic obstruction of the coronary arteries is still controversial.[1, 2] The reason for this appears to be that the studies have been largely anatomical and give only qualitative data regarding collateral blood flow.[3] In the normal heart the controversy has been cleared to a large extent by physiological studies. The majority view is best expressed by Wiggers:[4] "The collateral flow is extremely small and insufficient to support contraction in an area rendered [acutely] ischemic by ligation of a main [coronary artery] branch." However, since anatomical connections normally exist between a given coronary artery and (a) other coronary arteries,[5] (b) extracardiac arteries[6] and (c) ventricular cavities,[7] the work of Wiggers does not rule out the possibility of enlargement of existing collateral channels or the development and enlargement of new connections. Indeed, it is known that following acute experimental occlusion of a coronary artery, the infarcted area is generally much smaller than the area originally supplied by the occluded artery.[8] We have, therefore, attempted to devise ways and means of stimulating the development of such an accessory circulation and to study its *physiological extent.*

It seemed to us that the ultimate solution of the problem of the development, source, and determinants of collateral coronary flow might be reached by studying the peripheral coronary pressure (P.C.P.) and blood flow from coronary arteries that have been occluded for varying lengths of time and in hearts with increasing extent of coronary arterial occlusion.

* Aided by a grant from the Josiah Macy, Jr. Foundation.

1 Wearn, J. T., *J. Exp. Med.*, 1928, **47**, 293.

2 Wiggers, C. J., in Levy, R. L., *Diseases of the Coronary Arteries and Cardiac Pain*, Macmillan Co., New York, 1936.

3 Mautz, F. R., and Beck, C. S., *J. Thoracic Surg.*, in press.

4 Wiggers, C. J., *Am. Heart J.*, 1936, **11**, 641.

5 Spalteholtz, W., *Die Arterien der Herzwand*, Leipzig, 1924.

6 Moritz, A. R., Hudson, C. L., and Orgain, E. S., *J. Exp. Med.*, 1932, **56**, 927.

7 Wearn, J. T., Mettier, S. R., Klumpp, T. G., and Zschiesche, L. J., *Am. Heart J.*, 1933, **9**, 143.

8 Smith, F. M., *Arch. Int. Med.*, 1918, **22**, 8.

In the present study chronic coronary artery occlusion was produced in dogs by 2 methods: The right coronary artery or the left descending ramus was occluded by complete ligation of the vessels about one cm. from the aortic ostium. It was noted at the time of ligation that the portion of the ventricular walls supplied by the artery ligated invariably became cyanotic and bulged with each systole. This operation carries a high mortality and preferably should be done in stages. The circumflex branch of the left coronary artery was occluded in 4 stages at the point of origin by means of a silver screw clamp.[9]

Five successful experiments were carried out on hearts 2 to 12 months after complete occlusion of a major coronary artery. After intratracheal ether anesthesia, a combination of heparin, 15 units per kilo and chlorazol fast pink, 0.080 gm. per kilo, was introduced into the circulation to prevent coagulation. A cannula was introduced into the occluded coronary artery just below the point of occlusion and connected to an optical pressure manometer of improved design.[10] Peripheral coronary blood flow was recorded by connecting the P.C.P. manometer to either an Archimedes bucket for mean flow or to a new type of optical recording meter for phasic flow. Aortic and either right or left ventricular pressures were similarly and simultaneously recorded. On exposure of the hearts with remote coronary artery occlusion, the areas which at the time of ligation were cyanotic and bulging now were of normal red color, except for occasional white scars, and definitely showed systolic shortening. Finally, the hearts after death were injected with a barium sulphate gelatin mass using the technique described by Gross.[11] The anatomical increase in collateral communications was determined by Röntgenograms and by dissection of the heart. The degree of infarction was estimated from gross inspection of the sectioned heart.

The criteria for our belief that a considerable collateral circulation develops following chronic occlusion of coronary arteries are: (1) large increases in P.C.P. over normal values, (2) a peripheral coronary blood flow far in excess of normal, (3) a minimum of infarction together with macroscopic evidence of contraction, and finally (4) enlargement of preëxisting or new anatomical connections between occluded and non-occluded arteries.

A portion of this evidence is summarized in Table I. In 4 of 5

[9] Mautz, F. R., unpublished.

[10] Gregg, D. E., Eckstein, R. W., and Fineberg, M. H., *Am. J. Physiol.*, 1937, **118**, 399.

[11] Gross, L., *The Blood Supply to the Heart*, Paul Hoeber, New York, 1921.

TABLE I.
Data Demonstrating Increased Collateral Circulation After Chronic Coronary Arterial Obstruction.

Exp.	Condition	Weight		Blood Press. (mm. Hg.) Syst./Diast.				Cor. flow cc./min.	Amt. infarction	Principal collateral (anatomical)
		Dog, kg.	Heart, gm.	Aortic	Periph. Cor.	Ventricle Right	Ventricle Left			
					Right Coronary					
EE25										
R31a	Control*	14.0		140/97	30/24	45/1		†		
GM2										
R8	Occlusion 8 mos.	8.7	73	80/50	11/10	15/0		0.12	complete	none
GM3										
R12	Occlusion 8 mos.	21.2	195	105/62	71/43	32/3		27.0	moderate	Left circumflex
GM4										
R4	Occlusion 12 mos.	17.5	181	128/104	110/90	18/1		70.0	slight	" "
					Left Circumflex					
DD36										
R21	Control*			110/88	29/18			†		
GM1	Occlusion 4 mos.	11.5	122		109/48		117/5	not taken	slight	Left descendens Right circumflex
					Left Descendens					
DD41										
R24a	Control*			88/52	36/22			†		
GM6										
R0	Occlusion 2 mos.	8.9	72	82/54	67/40			14.0	moderate	Left circumflex

*These controls were selected because they have P.C.P. values as high as were found in approximately 100 normal control experiments.[2]

† Control flows in excess of 1.5 cc. per min. have not been observed.[12]

[12] Wiggers, C. J., and Green, H. D., *Am. Heart J.*, 1936, **11**, 527.

experiments† there is definite evidence of the development of a collateral circulation following chronic coronary artery occlusion in that (a) the P.C.P. rises to values which approach the aortic pressure, (b) there is a large increase of peripheral blood flow, (c) a minimum of infarction, and (d) an increase in anatomical collateral channels. The extent of this peripheral blood flow with aortic pressures ranging from 82/54 to 128/104 mm. Hg. after complete occlusion of the coronary artery in question is from 14 to 70 cc. per min. The upper range of this volume flow, experiment GM-4, approaches the normal inflow into a coronary artery.‡ Correlating the anatomical data with the blood flow in GM-4, the largest collateral communications found in this series of experiments were present between the right coronary artery and the left circumflex in the posterior A-V sulcus (Fig. 1B as compared with a normal control, Fig. 1A).

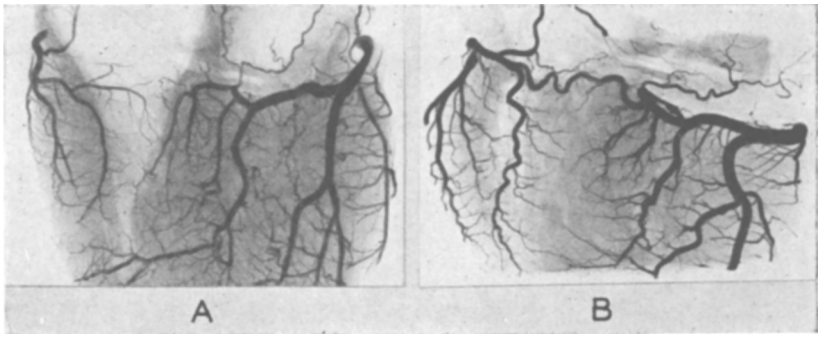

FIG. 1.
B, Röntgenogram showing enlarged collateral channel between right coronary and left circumflex 12 months after right coronary ligation (Exp. GM-4) as compared with normal, A.

In Fig. 2, graphic evidence in the form of reproductions of original P.C.P. curves from the major coronary rami in acutely and chronically occluded arteries is set forth. Inspection of the peripheral right coronary pressure in control A-2 as compared with A-1 shows that following chronic right coronary occlusion, the P.C.P. rises from a probable maximum of 30/24 to 110/90 mm. Hg., a value very close to the prevailing aortic pressure, while its contour

† We consider experiment GM-2 as our best control. Here there was remote occlusion of the right coronary artery and a collateral circulation failed to develop as evidenced by applying the criteria previously listed.

‡ It should be emphasized that since all volume flows were measured against zero resistance, the actual inflows into the ischemic zone of the intact heart would be somewhat less.

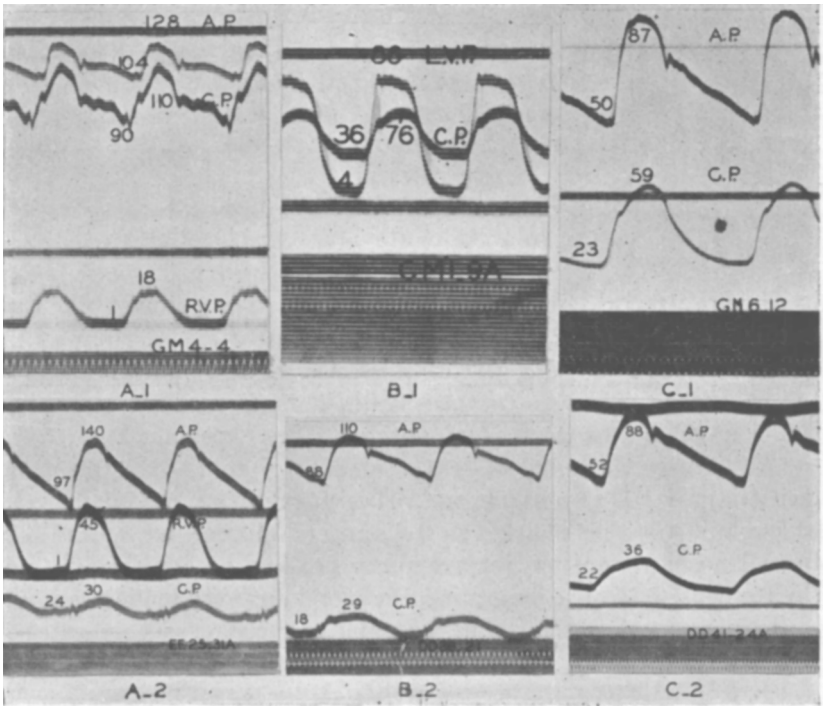

FIG. 2.

A-1, B-1, C-1 are P.C.P. curves after chronic obstruction of right coronary, left circumflex, and left descendens respectively for which A-2, B-2, C-2 are respective controls. AP, aortic pressure; CP, peripheral coronary pressure; RVP, right ventricular pressure; LVP, left ventricular pressure. Time = 0.02 second.

is patterned after the aortic, even showing an incisura. We have always obtained such a rise of the P.C.P. except in experiment GM-2, Table 1, in which collaterals failed to develop and the P.C.P. was 11/10 mm. Hg.

Marked augmentation of the P.C.P. also occurs after chronic occlusion of the left circumflex (B-1 as compared with B-2). The P.C.P. rises from a control value of 29/18 in B-2 to 76/36 mm. Hg. in B-1, or to a value only 10 mm. Hg. below the left ventricular pressure.

Chronic occlusion of the left descendens also shows a definite increase in the P.C.P., C-1 as compared with C-2. Detailed analysis of these pressure curves is reserved for a later publication.

Such experiments, therefore, lead us to the conclusion that following chronic obstruction of a major coronary arterial ramus there develops a massive new collateral coronary circulation. The sources and determinants of such a new myocardial blood supply are now being investigated.