EFFECT OF MUSCULAR EXERCISE UPON THE PERIPHERAL CIRCULATION IN PATIENTS WITH VALVULAR HEART DISEASE[1]

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Considerable controversy still exists as to the hemodynamics associated with organic involvement of the valves of the heart in man. With respect to aortic insufficiency, Stewart (1), mainly on the basis of animal experiments, advanced the view that the collapsing pulse in this state is due to an increased blood flow through the capillaries following reflex inhibition of the vasomotor center, and not to regurgitation into the left ventricle. Hill and Rowlands (2), in order explain the apparently greater blood pressure in the lower extremities as compared with that in the arms, postulated that the leg arteries are held in a contracted state, so that the brain might receive a sufficient supply of blood. However, Gladstone (3), also on theoretical grounds, came to the opposite conclusion, that the average rate of flow to the hand, arms, and kidneys is less than normal, while the legs receive a disproportionately large share of the total output of the heart.

In relation to the problem of hemodynamics in mitral stenosis, the experimental work has for the most part consisted of cardiac output studies. The results, however, have been contradictory, some of the investigators (4, 5) observing a decreased, and others (6, 7), a normal minute volume output in this state. With respect to the peripheral circulation, Meakins and his associates (4) reported a diminished oxygen saturation and an increased carbon dioxide content of venous blood from the arm. On the basis of these findings, they concluded that in this state the resting muscles in the extremities are partially deprived of their normal complement of arterial blood, in order that more essential organs might obtain an adequate supply of oxygen. According to them, some of the general symptoms observed in patients with mitral stenosis, such as cyanosis, weakness, and fatigue, are reflections of the diminished rate of peripheral blood flow. Stewart and his collaborators (8) studied the arm-to-tongue circulation time and noted that the average velocity of blood flow was somewhat decreased in this state.

Since the above views are for the most part contradictory or based on theoretical considerations, it was thought worthwhile to study the actual rate of peripheral blood flow in aortic insufficiency and mitral disease by means of the venous occlusion plethysmographic method.

METHOD

The study was performed upon 29 ambulatory patients with aortic insufficiency, resulting from either rheumatic or syphilitic infection, and upon 16 patients with stenosis of the mitral valve of rheumatic origin. Subjects with such complicating factors as congestive heart failure or double valvular lesions were excluded. All of the patients with aortic insufficiency demonstrated a wide pulse pressure, the characteristic blowing diastolic murmur in the second intercostal space to the right of the sternum, and the left ventricular enlargement. In some, a capillary pulse was also present. In the case of the patients with mitral valvular disease, the typical presystolic murmur at the apex and the enlargement of the left auricle and bulging of the conus region (as demonstrated by fluoroscopy or x-ray) were always present.

Blood flow determinations, in cc. per minute per 100 cc. limb volume, were obtained separately in the hand, forearm, and leg, according to the technique previously described (9). The bath temperature (temperature of water in plethysmograph) was maintained at 32° C. and the room temperature between 25° and 27° C. The procedure generally followed consisted of placing a hand and a contralateral forearm or leg into plethysmographs and recording 15 to 20 resting control blood flow readings of the 2 extremities over a period of approximately 1 hour. Then, in the majority of patients, the local circulatory response to a specified amount of exercise was studied. With the forearm in the plethysmograph, the pressure in an air-filled 5 gallon bottle was raised to a definite level (60 to 70 mm. Hg) by means of ipsilateral manual compression of a blood pressure bulb. The work was performed in a period of approximately 1 minute. Immediately after the termination of the exercise, blood flow readings were taken at short intervals (every 10 or 15 seconds at first and later every 30 seconds) until the local circulation had returned to the control resting level. From these determinations, a graph was constructed, and by means of a planimeter the quantity of excess blood flow, over and beyond the amount which would ordinarily

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have entered the forearm at rest, was obtained (10). The figure was expressed as the blood flow repayment per 100 cc. limb volume. The same procedure was performed upon a series of 16 normal subjects, no attempt being made to eliminate the variable factor of physical fitness either in these or in the patients with valvular disease.

RESULTS

Examination of Table I reveals that for the most part the measurements of blood flow in the hand in the patients with aortic insufficiency were either in the lower range of the readings for the normal group or definitely below it (the average being 6.7 cc. per minute per 100 cc. limb volume, as compared with 9.3 cc. (σ — 2.1) for the control series).[2] In the forearm, of the 27 patients studied, 21 demonstrated blood flow measurements which fell within the range of the normal series (1.8 cc. per minute per 100 cc. limb volume (σ — 0.7)), while 3 showed somewhat diminished and 3, significantly increased readings. The average for the whole group was 2.0 cc. per minute per 100 cc. limb volume. In the leg, 16 patients demonstrated blood flow measurements which were within the range of the normal series (1.4 cc. per minute per 100 cc. limb volume (σ — 0.5)), while 3 showed somewhat diminished and 6, significantly increased readings. The average for the whole group was 1.7 cc. per minute per 100 cc. limb volume.

TABLE I

Resting blood flow in aortic insufficiency

Subject	Age	Etiology	Blood flow in cc. per minute per 100 cc. limb volume			Blood pressure
			Hand	Forearm	Leg	
	years					
M. C.		Luetic	5.8		2.6	158/30–0
G. S.	37	Rheumatic		1.3	1.6	112/30–0
L. E.	52	Luetic	3.4	0.7	0.5	118/48
M. C.	48	Luetic	6.0	2.5		212/92
O. H.	33	Luetic	5.4	1.1		176/50
H. S.	22	Rheumatic	8.0	1.4		164/50
I. R.	35	Rheumatic	9.3	1.9	1.9	124/74
A. D.	55	Rheumatic	8.1	1.9	1.8	138/68
E. B.	59	Luetic	9.1	2.5	2.3	166/48–0
W. J.	56	Luetic	5.0	2.4	2.0	150/50
R. G.	41	Luetic		1.5	2.0	148/66–0
G. P.	55	Luetic		1.2	1.4	124/60
J. H.	38	Luetic		1.3	1.5	110/20–0
S. M.	65	Luetic		1.8	1.8	126/46
J. D.	44	Luetic		1.2		128/82
P. M.	55	Luetic		2.0	1.2	194/76
L. W.	70	Luetic		3.1	1.7	212/40–0
D. P.	63	Luetic		1.7	2.7	180/82
W. H.	47	Luetic		1.5	2.0	108/30–0
E. A.	56	Luetic			1.6	230/50
C. S.	59	Luetic		2.1	1.5	116/36
S. D.	42	Luetic		1.2	0.8	136/20–0
J. L.	63	Luetic		0.8	0.7	164/40–0
S. R.	55	Luetic		1.0	0.9	124/58
P. S.	21	Luetic		1.3	1.0	110/30–0
E. R.	53	Luetic		7.9	3.6	198/80–0
R. M.	15	Rheumatic		5.8	3.0	160/0
C. J.	24	Rheumatic		1.8	1.2	130/70
R. S.	19	Rheumatic		1.2	2.1	108/64

TABLE II

Resting blood flow in mitral valvular disease

Subject	Age	Blood flow in cc. per minute per 100 cc. limb volume		Blood pressure	Circulation time
		Hand	Forearm		
	years				*seconds*
R. S.	28	7.2	1.0	104/68	
J. D.	38	5.2	1.6	120/70	16
H. S.	27	4.8	0.9	114/80	
W. J.	17	6.0	1.5	98/56	15
E. L.	35	8.0	1.5	110/64	
G. E.	13	7.6	2.8	120/82	9
A. T.	61	2.1	1.1	128/78	
M. S.	46	6.4	1.9	106/70	11
M. M.	35	7.2	3.5	124/70	
B. L.	43	8.2	1.1	110/80	
S. N.	33	9.0	1.9	100/58	
D. R.	18		1.3	114/70	
F. B.	14		2.5	104/62	
J. Y.	15		1.2	116/66	
J. C.	16		1.3	130/80	
L. C.	16		1.7		

Table II reveals that the rate of resting blood flow in the hand in the patients with mitral valvular disease also fell, either within the lower range of that obtained for normal subjects, or somewhat below it (an average of 6.5 cc. per minute per 100 cc. limb volume, as compared with an average control of 9.3 cc. (σ — 2.1)). In the forearm, the readings were, for the most part, similar to those of the normal series (an average of 1.7 cc. as compared with 1.8 cc. (σ — 0.7)). In only occasional cases did the determinations fall beyond the control range.

In respect to the response to a given quantity of work, in 10 of the 14 patients with aortic insufficiency, the excess blood flow elicited by the exercise was definitely greater than the average reading of 37.8 cc. per 100 cc. of limb volume for the control group, while in 4, the response was the same or less than this figure (Table III). It is

[2] For controls, the results obtained in a series of 90 normal subjects, previously reported (11), were used.

TABLE III

Response of the forearm to exercise in aortic insufficiency

Subject	Age	Post-exercise repayment	Subject	Age	Post-exercise repayment
	years			*years*	
S. R.	55	31.1	E. B.	59	67.9
C. S.	59	67.6	P. S.	21	60.7
W. J.	56	42.7	G. P.	55	33.8
R. G.	41	78.1	R. S.	19	42.6
W. H.	47	49.5	C. J.	24	58.0
D. P.	63	55.8	S. M.	65	114.5
J. D.	44	30.8	J. H.	38	24.7

Pressure in 5-gallon bottle raised to 60 to 70 mm. Hg by means of compression of a blood pressure bulb, 55 to 60 times, in approximately 1 minute.
Repayment—Quantity of excess blood flow for each 100 cc. limb volume, entering the extremity in post-exercise period.

of interest that in 3 of the latter subjects (G. P., J. D., and S. R.) there did not appear to be much disturbance of the hemodynamics, the diastolic pressure in each instance being within the normal range (Tables I and III).

TABLE IV

Response of the forearm to exercise in mitral valvular disease

Subject	Age	Post-exercise repayment	Subject	Age	Post-exercise repayment
	years			*years*	
M. S.	46	60.1	D. R.	18	47.7
J. C.	16	58.2	F. B.	14	66.4
G. E.	13	55.2	J. Y.	15	53.8
M. M.	35	55.8	S. N.	33	32.6

Pressure in 5-gallon bottle raised to 60 to 70 mm. Hg by means of compression of a blood pressure bulb, 55 to 60 times in approximately 1 minute.
Repayment—Quantity of excess blood flow for each 100 cc. limb volume, entering extremity in post-exercise period.

The blood flow responses to exercise in the patients with mitral valvular disease were essentially similar to those reported above. In 7 of the patients, the excess blood flow elicited by the work was definitely greater than the average of 37.8 cc. per 100 cc. limb volume for the control subjects, while in 1, the response was less than normal (Table IV).

DISCUSSION

From the foregoing, it would appear that in the majority of patients with compensated aortic insufficiency and mitral valvular disease, the average rate of blood flow in the forearm or leg was not significantly altered. The increased or decreased peripheral circulation in some of the subjects in the two series could not, in any way, be correlated with the other objective signs, and no explanation can be offered for these exceptions. The results in the hand have not been given much significance, since it has been shown that the blood vessels in this site react markedly to all types of vasoconstricting stimuli; the vascular responses in the forearm and leg being much more representative of the peripheral circulation generally (12). With respect to aortic insufficiency, therefore, the findings, as a whole, would be in accord with the view that the peripheral resistance in the extremities is not materially altered in this state. In the case of mitral stenosis, the results do not support the conclusions of Meakins and his associates (4) that there is a shunting of blood from the extremities to other portions of the body in this condition, with a consequent diminution in peripheral circulation.

The blood flow repayment to exercise, however, was generally greater in the patients with valvular disease than in normal subjects, despite the fact that the amount of work performed was not sufficient to tax the compensatory mechanisms severely. Before discussing the significance of this finding, it is necessary to explain briefly the rationale for the procedure used. This is based on the assumption that, if the augmented circulation present during work is insufficient to meet entirely the increased demands of the tissues, a blood flow debt must be incurred; this, in turn, being repaid in the subsequent period of rest. The magnitude of the blood flow repayment would thus serve as an index of the efficiency of the circulatory response during exercise (10). It would appear from the data collected that in most of our patients with valvular disease the compensatory mechanisms, ordinarily elicited by the stimulus of work, were not as adequate as in normal subjects, and hence the blood flow repayment in the post-exercise period was necessarily of greater magnitude. Another possibility is that these patients utilized a greater amount of energy in the performance of the work and thus incurred a greater blood flow debt. It is probable that both mechanisms were responsible. The results with aortic insufficiency, therefore, do not support the view of Jokl and Suzman (13), who consider this state to be compatible with little or even practically no functional impairment. With respect to the response to exercise in mitral stenosis, Dennig and Prodger (14) and Nielsen (7) have expressed the opinion that the cardiac output under these conditions does not increase in accordance with the greater oxygen demands, and hence the amount of work which will produce fatigue is much less than that in normal subjects. Our findings in reference to the peripheral circulation help to support this view.

SUMMARY AND CONCLUSIONS

Using the venous occlusion plethysmographic method, the rate of resting peripheral blood flow and the circulatory response to exercise were studied in a series of 29 patients with insufficiency of the aortic semilunar valves, and in 16 subjects with mitral valvular disease.

The average circulation in the hand was found to be somewhat diminished in both series of patients as compared with that for the control series, while the readings in the forearm and leg in the majority of the cases fell within the normal range.

The post-exercise response of the blood vessels in the forearm to a specified amount of work was generally greater than that in the control group.

It was concluded that, in the majority of the patients with aortic insufficiency or mitral valvular disease, no evidence was found to indicate that excessive vasodilatation or vasoconstriction exists in the vessels of the forearm or leg.

On the basis of the results obtained with a period of exercise, it appears that either the compensatory circulatory mechanisms elicited by such a stimulus are not as effective as normal, that the work is performed with less efficiency, or possibly that both mechanisms are operating in this condition.

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