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Research Article

THE MEASUREMENT OF CAPILLARY PRESSURE UNDER NATURAL CONDITIONS AND AFTER ARTERIOLAR DILATATION; IN NORMAL SUBJECTS AND IN PATIENTS WITH ARTERIAL HYPERTENSION AND WITH ARTERIOSCLEROSIS[1]

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INTRODUCTION

Measurements of capillary pressure have been made by various observers. The significance of the results is under dispute and there is no unanimity of opinion either as to the best method for determining capillary pressure or as to the absolute value of that pressure in man. The importance of the subject is self-evident. Not only is it highly desirable to know the pressure of the blood in those vessels which act as distributing stations for the tissues, but the normal capillary pressure must first be known before abnormal pressures can be evaluated. The knowledge of the capillary pressure is particularly important in arterial hypertension and in arteriosclerosis as an aid to our understanding of the nature of these conditions. The investigations reported in this paper concern the pressure in the capillaries of people with normal cardiovascular systems, and of patients with arterial hypertension and arteriosclerosis, both under natural conditions and when the arterioles have been artificially dilated.

Since von Kries (1) (2) first described a method for the determination of capillary pressure in 1875, many observers have reported values which have ranged from 4 to 70 mm. of Hg. No attempt will be made here to review completely the literature. This has been adequately done in the reviews of Friedenthal (3), Danzer and Hooker (4), and Tigerstedt (5).

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METHODS

There are three general methods for the measurement of capillary pressure. (A) The oldest and that most frequently employed is that of estimating the pressure necessary to cause a certain degree of blanching of the skin. The values, expressed in millimeters of mercury, obtained with this method for the normal capillary pressure by some of the investigators, are as follows: von Kries (2), 37.7; Natanson (6), 70.5; von Basch (7), 25–30; Rotermund (8), 26.8; von Recklinghausen (9), 52.5; Schiller (10), 40; Basler (11), 7; Landerer (12), 17–25; Goldmann (13), 8.5; Krauss (14), 6–9; Briscoe (15), 23.5; Krogh (16), 8. There is obviously a great discrepancy in the results. This is partly due to the various types of apparatus employed and partly to the various criteria of paling.

(B) The second method is based on the observation under the microscope of individual capillaries and the determination of the pressure necessary to cause an alteration in the velocity of blood flow through such a vessel. This technic was first devised by Roy and Brown (17) (18), in 1879, who observed that the capillaries in the web of a frog's foot can be made visible, and they obtained pressure readings of 7.3 to 11 mm. of mercury. Lombard (19) discovered that human capillaries in the nail bed of the finger can be observed by covering this region with a drop of oil, and E. Weiss (20) further studied corpuscular flow. Subsequently many other workers have reported results, among them Natanson (6), Lapinski (21), Krauss (14), Danzer and Hooker (4), Kylin (22), L. Hill (23), and Liebesny (24). Values obtained with this method are as highly divergent as those found by the first and simpler method. They too range in the normal from 4 to 70 mm. of mercury. Here again various criteria in the estimation of changes in the capillary blood flow partly explain the discrepancies.

(C) The third method is that of direct measurement of the pressure of the blood by puncturing the capillary. Krauss (14), Basler (11), (25), and E. Weiss (26) independently attempted this by pricking through the skin and determining the pressure of the blood as it emerged. Basler found a pressure of 7 mm. of mercury, and Krauss (14) obtained pressure values of from 7 to 10 mm. of mercury. Carrier and Rehberg (27) in a beautiful, but difficult experiment have cannulated a single capillary with a fine pipette and obtained pressure read-

ings of 3.5 to 6.0 mm. of mercury. Landis (37) has employed a somewhat similar technic in studying capillary pressure in the frog's mesentery and finds the pressure to average 11 mm. of Hg.

It will be seen that there are objections to each method.

(A) The first and paramount objection raised against the skin blanching method is that the skin color is largely determined by the blood in subpapillary venous plexuses, and therefore the pressure determined is not that of the capillaries but rather of the minute venules. It is true that the skin color is chiefly due to blood in the subpapillary venous plexuses and that in blanching the skin these plexuses are compressed. Nevertheless, when external pressure is applied over an area of several square centimeters, as is done in the skin blanching method, it seems reasonable that this pressure must be of the same order of magnitude as that normally prevailing in the capillaries, and not the venules, in order to cause the venules to collapse and the skin to pale. If a pressure is applied which is only equal to the normal pressure of the venules, there may be a tendency for a compression of these vessels, but immediately the higher pressures in the capillaries which are directly adjacent to the venules will be transmitted to them and the venules will reopen and remain open until the external pressure is raised to a point equal to the normal capillary pressure. Therefore, although the blanching of the skin is indeed due to a closure of the minute venules, the pressure relationships obtained may well be as accurate an index of true capillary pressure as is obtained by the more complicated and not undisputed method of microscopic examination.

The blanching method is also criticized on the grounds that different skins vary greatly in their intensity of coloring, due to the degree of dilatation of the subpapillary plexuses, and that the ease of determination of blanching is dependent not only on the degree of color but on the visual acuity and skill of the observer.

(B) In the method of microscopic examination one is studying very few capillaries in one location, i.e., the nail-bed. Even among these few, pressure values vary either because of varying tone of individual capillaries or because different capillaries lie at different depths from the surface, and certain of them receive greater protection than others from the surrounding tissues. It is also recognized that considerable spontaneous variations occur in the blood flow through the individual

capillary loop and the differentiation whether the change in the blood flow is due to the induced pressure or to spontaneous change may be difficult. Thus a less satisfactory composite picture of capillary reaction is obtained than when one studies the mass reaction at one time of all of the capillaries within a given area.

Another objection may be raised, namely, that the capillaries of the nail-bed are particularly subject to external influences, such as trauma and light, and they may not represent the pressures in other capillaries. The technic requires considerable exposure to light, heat and trauma, and thus arteriolar dilatation may occur which distinctly raises the capillary pressure. Moreover, the criteria for determining capillary pressure are by no means established, and it is certain that the higher values obtained by this method are really measurements of arteriolar pressure transmitted to the capillaries when the capillary blood flow stops because of the compression of these vessels.

(C) The third method, that requiring perforation of the skin and direct measurement of the pressure, is open to serious objections. If a simple puncture is made it is obvious that it is quite impossible to know definitely what class of vessels has been perforated. When the capillary is actually cannulated, as by the technic of Carrier and Rehberg (27), the pressure determined is not true capillary pressure, but that of the vessel adjacent to the tip of the cannula, i.e., the arteriole or the venule. Because of the structural position of the capillaries in the skin, the chances are great that the venule is adjacent to the portion of the capillary loop cannulated, thus the venous and not the capillary pressure is recorded. Landis, however, in the frog by modifying the technic of Carrier and Rehberg, has avoided this objection. Moreover, this method involves a distinct trauma to the tissue under study so that the pressure values can not be said to have been obtained under truly normal conditions.

In our work we have employed the color blanching method for determining the capillary pressure, not because we believe that it is an ideal method, but because it is as well adapted to our purpose as any other. It has the advantages of being simple and quick to employ, the technic of the procedure can not materially influence the capillaries themselves and it can be utilized over a variety of skin areas. Moreover, the results observed in the normal and certain pathological states are

entirely comparative. No claim is made that the values given are the absolute values for capillary pressure. In the following discussion the term "capillary pressure" is used to signify the pressure necessary to cause compression of the minute subpapillary venous plexuses, and whenever reference is made to healthy or normal persons we imply people with normal cardiovascular systems.

THE PROBLEM

Lewis (28) has extensively investigated the reactions of the skin vessels. He has found that when the vessels are subjected to any of various stimuli, in particular to stroking or to the injection of minute amounts of histamine, there results a three-fold response. First there is a local dilatation of the capillaries; then there is a fainter but much more widespread flare or flush; and lastly a local wheal. Lewis attributes this response to a liberation in the skin of a substance, the action of which is identical with histamine and, therefore, is called by him H-substance. He has shown that the surrounding flare is due to an arteriolar dilatation, for it does not occur if the arterial blood supply is shut off. This flare is the result of an axone reflex, for it also ceases to appear if the sensory nerves in the skin area in question have degenerated.

In a recent article Lewis and Haynal (29) have reported studies concerning the pressure in the minute vessels of such a flare by means of small modified von Recklinghausen capsules. They found the pressure to lie between 50 and 60 mm. of mercury in normal individuals. Krogh and Rehberg (16) also have studied this problem, using a similar method, and have obtained values of 6 to 11 cm. of water (5 to 8 mm. of mercury) in the same areas. The cause of a difference of about 50 mm. of mercury in the results lies in the criteria employed. Krogh and Rehberg determined the pressure necessary to produce the first distinct blanching. Lewis and Haynal on the other hand, measured the pressure necessary for the skin color to pale to that of the surrounding normal skin. They showed that this is the correct criterion to employ because it is necessary to take a definite end point, which is the color of the surrounding normal skin. Experimental demonstration supports this contention.

If Lewis and Haynal's conception is correct, and our work tends to

confirm their idea, the minute vessels relax passively when they are congested as the result of the arteriolar dilatation in the histamine flare. If they dilated actively, the pressure in them would be of a much lower order of magnitude, which seems not to be the case.

The purpose of the present investigation was to make comparative studies of the capillary and arteriolar pressures (*a*) in normal people, (*b*) in patients with "essential" arterial hypertension, and (*c*) in patients with senile arteriosclerosis but with a normal blood pressure. For the evaluation of the results obtained in the pathological conditions a control group of subjects to which the same technic had been applied seemed essential. The cases with arterial hypertension were all of the so-called essential type, without signs of cardiac or renal failure at the time of the test. A few of the patients complained of slight dyspnea, and some showed mild renal disease. Occasionally evidence of peripheral arteriosclerosis was present.

The other group of patients, those with primary senile arteriosclerosis, but with normal arterial blood pressure, was selected in order to compare the pressure in their small vessels with that of the subjects with hypertension. Such a comparison may throw light on the much mooted question of the etiological and pathological relationship of arteriosclerosis and hypertension.

RESULTS

The method employed by us to determine the capillary pressure was essentially the same as that used by Lewis and Haynal (29). For a detailed description of the apparatus the reader is referred to their article. Both open and closed capsules were used. These capsules were in the form of brass rings of five centimeters diameter, and one centimeter depth. A circular piece of glass was cemented into the top, and two small brass tubes led into the sides. The open capsule was sealed to the skin by a rim of thin celloidin. The face of the other was covered by a membrane of goldbeaters skin, made transparent by immersion in glycerine. Any desired pressure could be thrown suddenly into the capsules from a large pressure bottle, connected with mercury and water manometers. The site chosen for the estimation of the capillary pressure was always the same; the skin over the manubrium and adjoining chest wall. This site was selected for the follow-

ing reasons: (1) With the subject prone, this area has a constant relation to the level of the heart, and is, in fact, essentially the same as that level; thus any influence of hydrostatic pressure is completely eliminated. (2) This region is normally unexposed, and the vessels therein are not chronically subjected to the external influences which may affect the vessels in the face and hands. (3) The vessels over the chest, usually respond with a marked flare to the injection of histamine.

TABLE 1

Comparison of pressure values obtained with the open and closed capsules

Number*	Capillary pressure			Arteriolar pressure		
	Open capsule	Closed capsule	Average	Open capsule	Closed capsule	Average
	mm. Hg	*mm. Hg*	*mm. Hg*	*mm. Hg*	*mm. Hg*	*mm. Hg*
1	6	15	11	59	50	55
2	6	6	6	55	50	53
3	8	6	7	40	40	40
4	12	12	12	50	55	53
5	9	8	9	50	55	53
6	9	9	9		60	
7	4	6	5	17	16	17
8	11	16	13	33	48	40
9	16	26	21	40	40	40
10	9	9	9	40	40	40
11	12	14	13	60	60	60
12	11	11	11	50	30	40
13	16	11	13	60	70	65
14	12	14	13	45	70	58
15	11	16	13	40	45	43
16	11	10	11		65	
17	17	17	17	40	40	40
18	14	15	14	40	45	43

* 1–6, normal subjects; 7–18, arteriosclerotic subjects.

(4) This region offers the most nearly plane surface of the body, thus enabling the open capsule to be sealed to the skin easily, and provides an underlying bony resistance which is a prerequisite for the proper application of the closed capsule.

Observations with both capsules were made in almost all cases, and the results obtained were in fair agreement (table 1). The values given in the other tables are an average of those obtained with the two cap-

sules whenever both methods were employed. Many of the observations were made by both of the authors together, and after some practice, the values obtained by each of the two observers were in close accord. The procedure of an observation was as follows: First there was determined the pressure necessary to cause the minimal distinct blanching in the normal skin. This criterion for capillary pressure measurement seems the most accurate, since it estimates the pressure necessary to compress the least protected and most superficial of the minute vessels of the skin; in other words, those nearest to the capillaries themselves.

A local dilatation of the arterioles in the skin was next produced by the formation of a flare resulting from the pricking in of a minute amount of a 1:1000 solution of histamine phosphate. As stated previously, this flare is the result of an arteriolar dilatation and therefore the pressure in the capillaries at this time must be nearly as high as normally exists at the commencement of the arteriolar circuit. This pressure was measured by throwing into the capsules an external pressure sufficient to blanch the skin to the color of the normal surrounding skin. Lewis and Haynal (29) have demonstrated that this is the valid criterion to apply. Thus the capillary and the arteriolar pressures have been successively measured in the same subject.

The brachial arterial blood pressure was estimated at the same time as the above measurements were made. The usual Riva-Rocci technic (38) was employed. The venous pressure, when measured, was determined with the method of Moritz and Tabora (30).

1. Capillary pressure

The capillary pressure values, obtained for each of the three groups of subjects, are presented in tables 2, 3, and 4, and in chart 1. Measurements are given for 10 normal persons, for 13 patients with arteriosclerosis, and for 23 patients with essential hypertension. The average capillary pressure for each of the three groups is as follows: normal 9 mm. of mercury, arteriosclerosis 13 mm. of mercury, hypertension 12 mm. of mercury. The close agreement between these three average figures is evident, although the capillary pressures in the pathological states appear to be slightly but definitely above normal. The higher capillary pressure may in part be explained by the techni-

TABLE 2

Brachial, arteriolar and capillary blood pressures in control subjects

Number	Age	Diagnosis	Brachial blood pressure		Arteriolar pressure	Capillary pressure
			Systolic	Diastolic		
			mm. Hg	*mm. Hg*	*mm. Hg*	*mm Hg*
1	14	Post rheumatic fever	128	64	55	11
2	29	No disease	124	80	63	
3	26	No disease	118	68	46	6
4	21	Convalescent pneumonia	128	64	53	6
5	23	No disease	108	65	65	8
6	45	Peptic ulcer	130	90	55	12
7	26	No disease	115	70	65	6
8	15	Diabetes mellitus	108	75	40	7
9	34	Peptic ulcer	124	78	53	12
10	14	Furunculosis	108	60	53	9
11	36	No disease	130	80	60	9
Average	26		121	72	55	9

TABLE 3

Brachial, arteriolar, capillary and venous blood pressures in subjects with arteriosclerosis

Number	Age	Diagnosis	Brachial blood pressure		Arteriolar pressure	Capillary pressure	Venous pressure
			Systolic	Diastolic			
			mm. Hg	*mm. Hg*	*mm. Hg*	*mm. Hg*	*mm. Hg*
1	58	Arteriosclerosis +++	124	86	17	5	
2	67	Arteriosclerosis +	105	45	40	13	+4
3	82	Arteriosclerosis +++	145	80	40	21	+2
4	73	Arteriosclerosis ++	145	100	40	9	+1
5	68	Arteriosclerosis ++ Post-cardiac decompensation	120	75	50	16	+3
6	73	Arteriosclerosis + Chronic myocarditis	118	80	60	13	+1
7	75	Arteriosclerosis ++	150	95	40	11	+2
8	70	Arteriosclerosis +++	149	80	65	13	+2
9	82	Arteriosclerosis +++ Cerebral accident	148	84	58	13	+5
10	66	Arteriosclerosis ++	110	70	70	—	−1
11	74	Arteriosclerosis ++	142	80	47	—	0
12	65	Arteriosclerosis +++	140	90	43	13	
13	54	Arteriosclerosis ++	124	80	65	11	
14	75	Arteriosclerosis ++ Herpes zoster	130	90	40	17	
15	73	Arteriosclerosis +++	135	70	43	14	−3
Average	70		132	80	48	13	+2

TABLE 4

Brachial, arteriolar, capillary and venous blood pressures in subjects with hypertension

Number	Age	Diagnosis	Brachial blood pressure		Arteriolar pressure	Capillary pressure	Venous pressure
			Systolic	Diastolic			
			mm. Hg	*mm. Hg*	*mm. Hg*	*mm. Hg*	*mm. Hg*
1	49	Hypertension	206	114	150+	8	+3
2	47	Hypertension	170	96	75	11	
3	57	Hypertension Arteriosclerosis +	158	110	120	7	+5
4	55	Hypertension Arteriosclerosis +	214	140	165	14	+6
5	60	Hypertension Arteriosclerosis +	170	110	125	8	
6	70	Hypertension Arteriosclerosis +++	195	75	60	20	+3
7	68	Hypertension Arteriosclerosis ++	170	75	60	13	+3
8	52	Hypertension	230	145	140+	6	+3
9	52	Hypertension Arteriosclerosis ++	184	118	100	14	+5
10	65	Hypertension Arteriosclerosis ++	205	105	80	15	+2
11	55	Hypertension Arteriosclerosis ++	185	105	70	9	+3
12	68	Hypertension Arteriosclerosis +++	280	150	60	9	+3
13	60	Hypertension	190	80	80	13	
14	55	Hypertension	180	124	100	12	+4
15	17	Hypertension	180	124	100	11	+8
16	72	Hypertension Arteriosclerosis +	175	120	110	15	+3
17	77	Hypertension Heart block—complete	270	65	130	9	+7
18	41	Hypertension	180	120	150	12	+5
19	41	Hypertension	280	160	150+	10	+9
20	52	Hypertension	160	80	130	14	
21	28	Hypertension	210	130	90	21	+4
22	41	Hypertension	160	90	110	13	+6
23	31	Malignant hypertension	230	120	130	11	
Average	53		200	111	108	12	+5

cal difficulty of estimating slight degrees of skin color change in the patients of the two abnormal groups, which consisted largely of sub-

jects whose skins tended to be pale, dry and wrinkled; whereas the normal individuals were as a rule younger with firm skins of a relatively high color. It can be stated, however, that the capillary pressures of normal persons, of patients with arteriosclerosis, and of subjects with hypertension, are of the same order of magnitude. The capillary pressure, therefore, is essentially normal in the two pathological conditions studied.

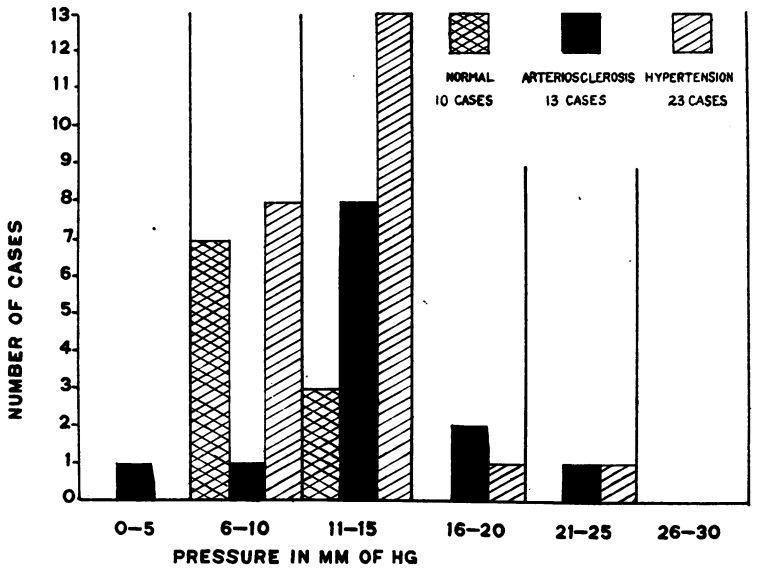

CHART 1. COMPARATIVE DISTRIBUTION OF CAPILLARY PRESSURES IN PERSONS WITH NORMAL CARDIOVASCULAR SYSTEMS AND IN SUBJECTS WITH ARTERIAL HYPERTENSION AND WITH ARTERIOSCLEROSIS

2. Arteriolar pressure

When we consider the comparative values for arteriolar pressure, obtained in vessels within a skin area in which a histamine flare has been produced, quite a different situation is found. The data is presented in tables 2, 3, and 4 and chart 2. The total number of cases studied is as follows: normal, 11; arteriosclerosis, 15; hypertension, 23. The average values for the normal subjects and those with senile arteriosclerosis are essentially the same, 55 and 48 mm. of mercury respec-

tively. In hypertension, however, the average measurement for arteriolar pressure is 108 mm. of mercury, or about 100 per cent higher than in the other two groups. The significance of this distinctly abnormal finding will be discussed presently.

3. Venous pressure

The venous pressure in every case in which it was determined falls within normal limits. It is less than 10 mm. of mercury, and the average value is 3 mm. of mercury.

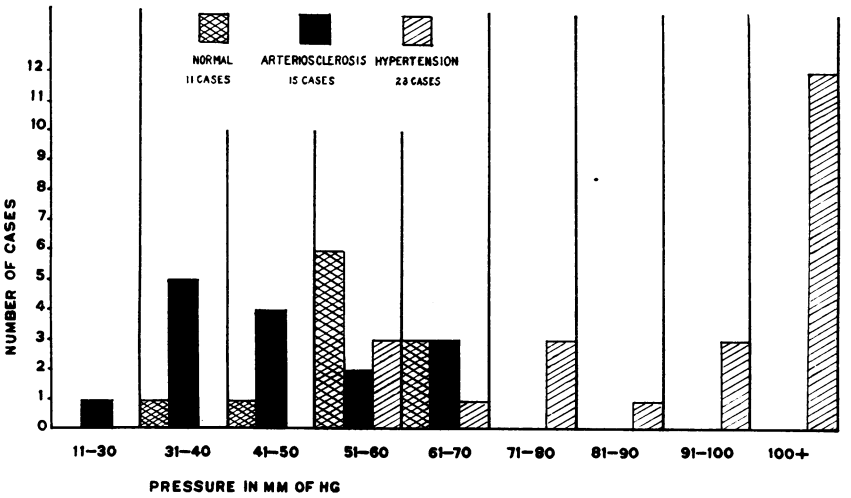

CHART 2. COMPARATIVE DISTRIBUTION OF ARTERIOLAR PRESSURE IN PERSONS WITH NORMAL CARDIOVASCULAR SYSTEMS AND IN SUBJECTS WITH ARTERIAL HYPERTENSION AND WITH ARTERIOSCLEROSIS

DISCUSSION

The values for normal capillary pressure which have been reported in the literature range all the way from 70 mm. of mercury to 4 mm. of mercury. The higher figures undoubtedly depend on the fact that the arteriolar, not the capillary pressure was measured, while the lower figures approach that of the venous pressure. It is probable that many values reported for capillary pressure have actually been for estimations of pressure in other portions of the vascular circuit. The

values which we and other recent investigators have found for capillary pressure in normal individuals range from 6 to 12 mm. of mercury.

There are only a few reports in the literature of the measurement of capillary pressure in hypertension. Basler (11) using the skin blanching method and Kylin (22), using the technic of microscopic examination, conclude that, in essential hypertension the capillary blood pressure is normal. Kylin's values for the pressure, in both the normal and hypertensive states, lie between 80 and 200 mm. of water (6–15 mm. of mercury). Boas and Frant (31), and Boas and Mufson (32), employing essentially the same technic, found that the capillary pressure may be high or low in patients with cardiovascular disease. The patients with the two types of pressure are indistinguishable clinically.

For a proper comprehension of the significance of the capillary and arteriolar pressures it is essential to understand the nature of the fall of blood pressure in the arterial circuit from the great vessels to the capillaries. A considerable amount of work has been done upon these pressure relationships in vessels of different caliber both in man and in animals. Many results have been reported for blood pressure determinations in arteries of medium to large size, and these are not always in agreement and in certain instances appear paradoxical. In general, however, the results reported are similar to those of Volkmann (33), Hürthle (34), and Dawson (35). These workers, who studied the pressures in medium and large arteries in dogs, found that the arterial pressures in the vessels under consideration varied by only a few millimeters of mercury.

It has long been known that, in man, the pressure in the femoral artery may exceed considerably that in the brachial artery. Gladstone (36) has considered this phenomenon at length and has offered an explanation for it. His conception is that, whereas in the brachial artery only the pressure head of the blood stream is measured, in the femoral artery, which is continuous and in line with the aorta, not only is the pressure head measured, but also the velocity head, which creates an added increment to the pressure due to the velocity of the blood itself. This added pressure produced by the velocity of the blood stream is a feature peculiar to the femoral artery and does not obtain in the other and smaller arteries. It may be concluded that there is a slight fall of pressure as the blood passes through the large

and medium-sized arteries, but that this fall rarely, if ever, exceeds 20 mm. of mercury.

Few reports are available dealing with the fall of pressure between the medium-sized arteries and the arterioles. It is safe to assume that there is a moderate fall here, but from a consideration of the total diameter and length of these vesssels, there is no reason to believe that there is any important drop in the blood pressure.

There has been a controversy among physiologists as to whether the chief point of resistance in the vascular circuit lies in the arterioles or the capillaries. The earlier belief was that the capillaries themselves offer the greatest resistance and that the drop in pressure is most marked here. More recently, however, it is generally accepted that the blood pressure falls markedly in the arterioles (precapillaries), due to the resistance existing here, and therefore the pressure in the capillaries would tend to approach that in the veins. In the main, the many observations on capillary pressures tend to confirm this view.

In the accompanying diagrams (charts 3 and 4), there is a schematic representation of the fall of blood pressure from the large arteries to the veins in normal individuals and patients with hypertension and arteriosclerosis. The values are an average of the individual measurements in each group. The stars represent points in the vascular circuit at which actual measurements were made, namely, the brachial, capillary and venous blood pressures.

Under natural conditions, in normal individuals, there is a slight drop of pressure in the large and small arteries from the mean brachial pressure of 96 mm. of mercury. The total fall in these vessels is probably not greater than 20 mm. of mercury. When the arterioles are reached there is a marked fall of pressure due to the increased resistance interposed here. In the capillaries of the normal subjects studied the average pressure is 9 mm. of mercury. That the most striking drop of pressure actually does take place in the arterioles is confirmed by the findings after the production of a histamine flare. Under such circumstances the arterioles are dilated, thus diminishing the resistance, so that the pressure in the capillaries at once becomes nearly as high as in the arterioles, and was found in our cases to average 55 mm. of mercury. This change in the pressure gradient following histamine injection is diagramatically represented in the shaded area of charts

3 and 4. The pressure then falls rapidly to the normal value in the veins.

When the same curve for the pressures of hypertensive patients is considered (chart 3) it is found to vary in its contour from the normal. The mean brachial pressure is, of course, distinctly higher, in our

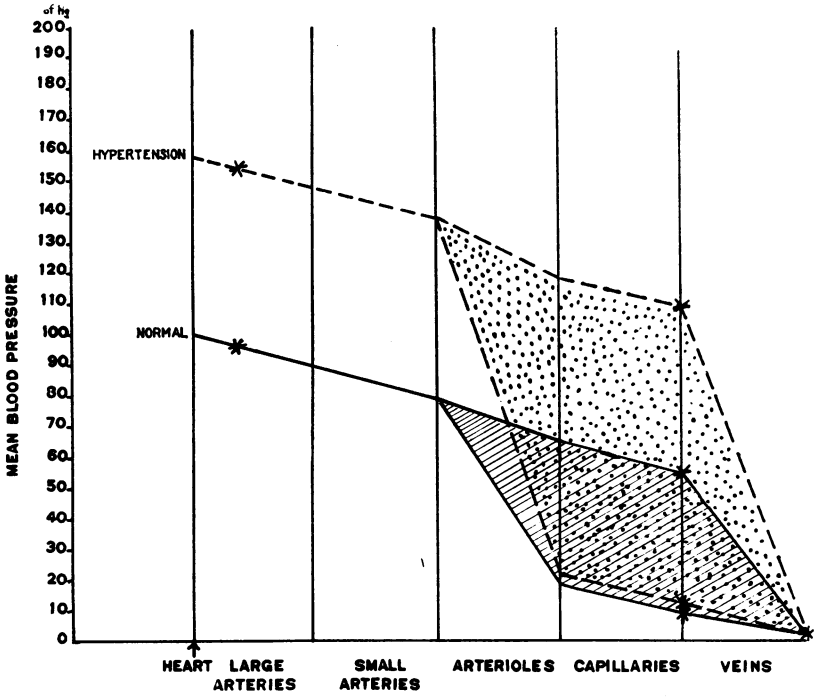

CHART 3. DIAGRAMMATIC REPRESENTATION OF FALL IN BLOOD PRESSURE IN VASCULAR CIRCUIT IN SUBJECTS WITH HYPERTENSION COMPARED WITH THE NORMAL

Shaded and stippled areas represent alteration in the pressure relationships in the skin vessels after the injection of histamine. The lower boundaries of these areas represent the pressure gradient under natural conditions; the upper boundaries this gradient after the injection of histamine.

cases being 155 mm. of mercury. The capillary pressure, on the other hand, is of essentially the same order of magnitude as in the normal patients, 12 mm. of mercury. There must be, therefore, a distinctly greater fall in the arterial circuit than in normal subjects. There is

no reason to believe that in essential hypertension the resistance interposed by the arteries themselves is markedly greater than under normal conditions. The increased resistance in hypertension must accordingly be in the arteriolar portion of the circuit so that the fall in pressure occurs here. In arterial hypertension when the arteriolar

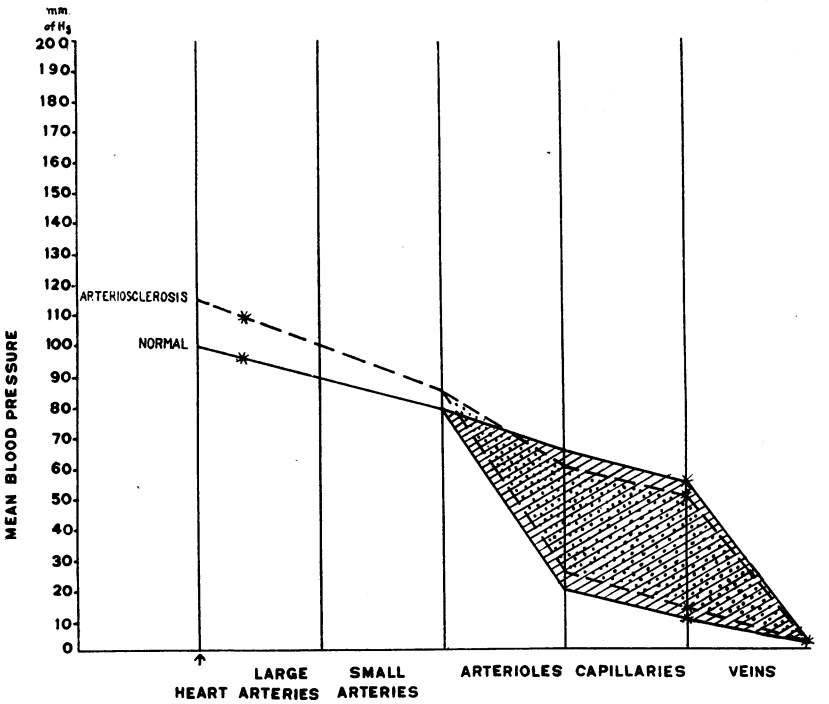

CHART 4. DIAGRAMMATIC REPRESENTATION OF FALL IN BLOOD PRESSURE IN VASCULAR CIRCUIT IN SUBJECTS WITH ARTERIOSCLEROSIS COMPARED WITH THE NORMAL

Shaded and stippled areas represent alteration in pressure relationships in the skin vessels after the injection of histamine. The lower boundaries of these areas represent the pressure gradient under natural conditions; the upper boundaries this gradient after the injection of histamine.

pressure in vessels dilated with histamine was determined, it was found to be on the average 108 mm. of mercury, or twice as high as in the normal individuals. The increase above normal is, in fact, approximately of the same order of magnitude as the increase of

brachial mean blood pressure. From this important fact several conclusions can be drawn. First, the chief resistance in the arterial circuit in hypertension lies in the same portion of the circuit as in health, but is of much greater magnitude. Second, this resistance, in the arterioles of the skin at least, is partly of a functional and not an organic character, because it can be overcome by a reflex induced by the injection of histamine, when the raised arterial pressure is transmitted into the capillaries.

Since the capillary pressure in arterial hypertension is normal, and there exists a definitely increased resistance in the arterioles, it is suggested that the hypertension is a compensatory mechanism on the part of the human organism to maintain a normal capillary blood pressure. If no hypertension existed, the fall in pressure in the arterioles would be so great that the capillary pressure would be far below normal, the exchange of gases with the tissues would be seriously interfered with, and bodily functions would be markedly hampered.

The curve for the average pressure of the arteriosclerotic group of patients is similar to that for normals (chart 4). It can, therefore, be concluded that arteriosclerosis, per se, does not necessarily interfere with normal capillary pressure nor does it produce a greatly increased resistance in the arterioles. Indeed, the fact that the arteriolar pressure, in proportion to that in the brachial artery is somewhat lower than in normal persons, is evidence that the resistance in arteriosclerosis is increased relatively in the larger vessels and not in the arterioles. Histological observations are often in accord with this.

The 23 patients with arterial hypertension may be divided into two groups, one comprising seventeen patients with either no or slight clinical evidence of arteriosclerosis, and the other including six patients with distinct or marked arteriosclerosis. One finds that the average arteriolar pressure of the first group is 121 mm. of mercury, and of the second group is 71 mm. of mercury. The average capillary pressure, however, is about the same in each group. The reason for the relatively low value for arteriolar pressure in the second group with marked arteriosclerosis may be dependent upon the fact that either (*a*) the mean pressure drops to a considerable degree before the arteriolar system is reached as a result of organic changes in the large arteries, or (*b*) the true pressure in the arterioles is actually of the same height

in both groups, but because of the presence of arteriosclerosis, the arterioles can not respond to histamine as extensively with a functional dilatation as in the group where there is little or no organic narrowing of these vessels. The clinical behavior of these patients favors this second explanation.

The observation that the pressure in the capillary system when the arterioles are under the effect of histamine is higher than normal in patients with hypertension suggests that under certain physiological conditions demanding increased blood supply, such individuals with hypertension have a greater capacity to respond with increased localized blood flow than do normal persons. According to chart 4, patients with senile arteriosclerosis and a normal blood pressure tend to have less capacity than normal individuals to respond to the same demand.

The difference between the pressure gradient curve obtained in senile arteriosclerosis with normal arterial blood pressure and that in hypertension without arteriosclerosis is striking, and is evidence toward the belief that senile, nodular arteriosclerosis, and essential hypertension are two distinct entities, although, as is so often the case, they may exist coincidentally.

SUMMARY

1. A study is presented of the brachial, arteriolar, and capillary blood pressures in three groups of individuals: (1) persons with normal cardiovascular systems; (2) patients with arterial hypertension; and (3) patients with senile, nodular arteriosclerosis.

2. The capillary pressures in these three groups are of the same order of magnitude. The average capillary pressure in normal subjects is 9 mm. of mercury, that of patients with hypertension 12 mm. of mercury, and in patients with senile arteriosclerosis 13 mm. of mercury.

3. The arteriolar pressure in arteriosclerosis is normal, but is greatly increased in arterial hypertension. The average arteriolar pressure in normal subjects is 55 mm. of mercury, that of patients with arterial hypertension 108 mm. of mercury, and in patients with senile arteriosclerosis 48 mm. of mercury.

4. The chief resistance in the vascular circuit normally lies in the arteriolar (precapillary) portion of the vessels.

5. Hypertension is due to an increased resistance in the vascular

circuit. Evidence is presented that this resistance lies in the arteriolar portion, as in normal persons, and in the absence of marked arteriosclerosis, is functional in character. Hypertension may be a compensatory phenomenon designed to maintain normal tissue oxidation through a normal capillary blood flow.

6. Evidence for the basic difference between arterial hypertension and senile arteriosclerosis is given.

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