A STUDY OF THE BLOOD PRESSURE BY THE METHOD OF GAERTNER, ESPECIALLY IN PATIENTS SUFFERING FROM FIBRILLATION OF THE AURICLES.

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INTRODUCTION.

A number of years ago Mackenzie (1) called attention to the difficulty in estimating the blood pressure in persons suffering from fibrillation of the auricles. There was general agreement that the difficulty existed, but there seemed to be no method for improving the technique of making clinical determinations. The beats which were heard first by auscultation or felt first on palpation, when pressure in the cuff system was allowed to escape, continued to be taken as the measure of the systolic pressure. A method was then suggested by James and Hart (2), later called the fractional method by Kilgore (3), by which not the maximum pressure of a few beats is taken as the measure of pressure, but the average of the systolic pressures of all the beats. Their technique consists in counting for 1 minute the number of beats felt below the brachial cuff at the radial artery at levels 10 mm. of mercury apart. The figure obtained is multiplied by the level of pressure, all the products are then added, and the sum is divided by the apex rate. Slight modifications and certain extensions of the method have since been suggested by Kilgore. He employed auscultation in addition to palpation, especially in calculating diastolic pressure.

This method presents certain difficulties, but before considering them we wish to review again certain points underlying the current clinical technique of estimating blood pressure. The peripheral arteries are regarded as representing an elastic reservoir kept filled by the action of the heart. It is the tendency of this reservoir to return to a position of rest, and in doing so to empty itself continuously into the smallest arteries and capillaries. By this effort these vessels are kept constantly filled.[1] So far as the constancy of the filling is concerned it makes no difference whether the elastic reservoir is filled by

[1] Cases in which there is a capillary pulse are exceptions to this rule.

volumes of blood equal in amount as normally, or unequal as in fibrillation of the auricles; or whether these volumes are delivered at equal or at somewhat unequal intervals. It matters only that the total volume in succeeding units of time, minutes for instance, is kept constant. Under ordinary circumstances this maintenance of constant volume is accomplished by uniform filling, but, failing this, it can be brought about by a compensating increase (or decrease) of resistance offered at the outflow of the reservoir system. It is an advantage to have the minute volume output of the left ventricle divided in roughly equal fractions throughout the minute. The point at which the reservoir empties into the smaller vessels may be regarded as the point where the head of pressure in the reservoir becomes effective. We speak then of the "effective pressure"[2] at this point.

The clinical habit of estimating arterial pressure in the brachial artery is adopted, not because the pressure here is especially important, but because it serves, on the one hand, as a rough indicator for the pressure level at the root of the aorta or in the left ventricle itself; that is, a difference is assumed between aortic and brachial pressure, sufficiently constant to permit the brachial pressure to serve as a valuable guide. On the other hand, brachial pressure may also serve as a suitable guide for judging the level of effective pressure, the pressure at the exit from the arterial into the capillary system. So far as the capillary system is concerned, there is no difficulty in this convention as long as the filling of the reservoir is maintained by even and uniform strokes; when the strokes are no longer uniform as in fibrillation, the difference between effective pressure, which tends to stay constant or alters only within narrow limits, and brachial pressure, which varies, must fluctuate so that the brachial pressure can no longer serve as an index of effective pressure.[3]

These considerations are important in relation to the technique of estimating systolic pressure when the auricles are fibrillating, for it is precisely in this condition that brachial pressure fluctuates and fails as an index of effective pressure. It has been found on closer study (3) that in auricular fibrillation not only the systolic, but also

[2] This phrase is used by James and Hart (2).

[3] See experiments reported by Cohn, A. E., and Lundsgaard, C., *J. Exp. Med.*, 1918, xxvii, 505.

the diastolic pressure of succeeding beats varies. These fluctuations necessarily result in irregularities in the pulse pressure. The pulse pressure does, in fact, undergo large alterations in the brachial artery. Further toward the periphery, however, the pulse pressure becomes progressively smaller, until, in the capillaries, it ceases to exist[1] and the flow is constant and continuous. The point at which this takes place is the point where, as has been said, the head of pressure becomes effective. Here a constant reading can be obtained. But since for clinical purposes no practicable technique exists for this, a point just proximal to the capillaries may be chosen. In the small arteries, of the size of the digital, the pulse pressure is small and alterations from mean pressure can from beat to beat be shown to be relatively unimportant.[4] For taking the pressure at this point a technique already exists. It is the method formerly employed by Gaertner and described by him in 1899 (4). The values obtained may be regarded as effective blood pressure. Readings so obtained are direct and the technique is simple. By this method we have taken the blood pressure of a few persons suffering from fibrillation of the auricles and have plotted, parallel to these curves, others made day after day by the fractional method of James and Hart, with the view of ascertaining the difference between the brachial and digital pressures. We have, in addition, studied a number of other individuals, some with normal and some with abnormal hearts, but all having hearts the mechanism of which was normal.

Technique.

The following technique was employed. One finger,—the ring finger,—was rendered bloodless by rolling a thick rubber ring from the tip to a small pneumatic cuff which was applied to the first (base) phalanx. The cuff corresponded exactly in plan to that of von Recklinghausen except that it was 2.5 cm. wide and about 5 cm. long. The cuff was connected by pressure tubing to a mercury manometer as in the von Recklinghausen plan. The pressure in this system was raised with a pump after the finger was blanched by the rubber ring. The ring was then removed and the pressure in the manometer cuff system

[4] This point is described in our report, *J. Exp. Med.*, 1918, xxvii, 505.

allowed to fall gradually and regularly.[5] When the pressure in this system falls to the level of the blood pressure, blood begins to flow into the finger distal to the cuff and is recognized by the return of color in the finger. After a little practice there is no difficulty in recognizing the return of color. It is important to make the estimations with north light. We have been aided in seeing the return of color, even in the very anemic, by laying the finger and hand to be examined on a dark, blue-gray cloth, to provide a proper contrast. It was the custom to read the pressure in each case 10 times and to average the readings. Of 153 determinations the range was 1 to 5 mm. in 11 determinations; 6 to 8 mm. in 69; 9 to 10 mm. in 35; 11 to 15 mm. in 27; 16 to 30 mm. in 7; 21 to 25 mm. in 2; and 26 to 30 mm. in 2. That is, the range was below 10 mm. in 75 per cent of the determinations. In many instances both observers made independent readings. When that was done, we compared the averages in twenty-six instances and found a difference of 2 to 4 mm. Twice the averages differed by 5 mm.; twice by 6 mm.; once by 7 mm.; twice by 8 mm.; once by 9 mm.; and once by 11 mm. The differences in range are greater than were found in the estimation of brachial pressure by Kilgore and his associates (5) but not so great as to render the method unserviceable. As an example of the method followed, we cite the figures of one patient, Case 2334 (Tables I and II), made by two observers.

Studies of blood pressure by Gaertner's method have been made with the view of comparing the readings found at the digital, with those taken at the brachial artery.

Hayashi (6), in Strümpell's clinic, found a difference of about 20 mm. between the readings taken of these two arteries whether they were made in children, men, or women, in infections, or in cardiac, vascular, or renal diseases. There were fluctuations in his figures but these were not of sufficient importance to alter the conclusion that the fall in pressure from the brachial to the digital vessels was about 20 mm. Doleschal (7) compared the pressure in the radial artery

[5] We provided for the gradual and regular fall in pressure by placing the rubber bulb which served as a pump between the jaws of a wooden vice. The distance between the jaws was regulated by a screw turned by a long shank; the use of a long shank permits more uniform motion. As the screw was released, the jaws of the vice were separated by springs properly placed.

TABLE I.

March 26, 1917.

Tonometer readings.	
No. 1.	No. 2.
mm. Hg	*mm. Hg*
93	93
89	95
92	95
88	95
87	93
91	93
94	92
95	93
94	95
93	92
Average...........91.6 = 92^{+3}_{-4}	93.6 = 94^{+1}_{-2}

TABLE II.

Blood pressure by the fractional method.			
Auscultation.		Palpation.	
Pressure.	No. of beats heard	No. of beats felt.	Pressure.
mm. Hg			*mm. Hg*
140	0	0	
130	31	20	130 × 20 = 2,600
120	25	22	120 × 2 = 240
110	9	26	110 × 4 = 440
100	9	61	100 × 35 = 3,500
			6,780
90	21	59	
80	18	61	
70	7	58	
60	2	60	$\frac{6780}{62} = 109$
50	0	56	
Average pressure...............130		109	
Radial rate.................. 62			
Apical " 62			

taken by means of von Basch's sphygmomanometer with that taken by Gaertner's tonometer and found uniformly that the tonometer readings were lower than those taken with von Basch's instrument. These results were naturally to be expected, and show that even where the pressure differences are probably small, as in the case of the radial and digital arteries, the tonometer readings, as we anticipate, are lower. Of 200 cases, for instance, the readings showed differences up to 5 mm. in 89, to 10 mm. in 80, to 15 mm. in 19, to 20 mm. in 6, and from 20 to 40 mm. in 6.

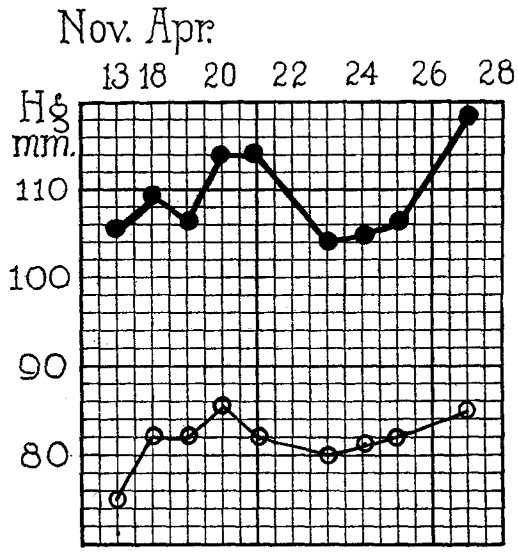
Our experience corresponds closely with that of Hayashi and Doleschal, for we have found uniformly that the tonometer readings at the digital arteries are always lower than the brachial readings. In eight normal individuals we found the average difference to be 20 (19.8) mm., the maximum being 30 mm., the minimum 5 mm. (Table III).

TABLE III.

No. of individual.	Brachial systolic pressure by auscultation.	Tonometer.	Difference.
	mm. Hg	*mm. Hg*	*mm. Hg*
1	110	96	14
2	120	92	28
3	116	97	19
4	119	98	21
5	110	96	14
6	114	109	5
7	120	90	30
8	109	81	28
Average............			19.8

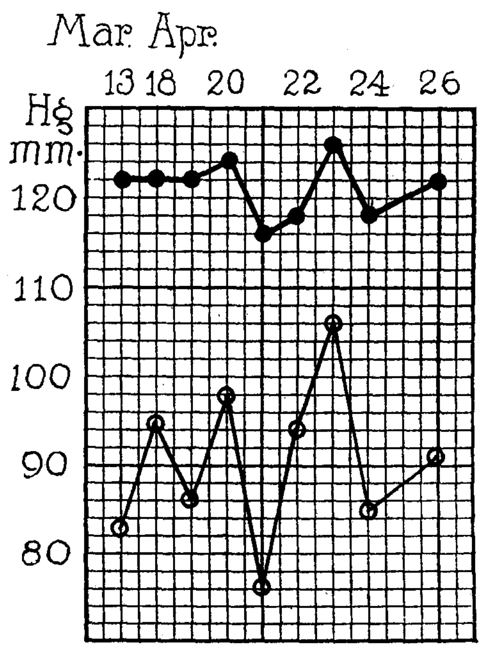
In the patients suffering from chronic heart disease and chronic nephritis (Table IV), in whom the mechanism of the heart beat was normal, the average difference between the two was 25 mm. in all cases, the range being from 6 to 80. If two cases (Nos. 10 and 12), suffering from complete heart block, are omitted, the average is 18 and the range 6 to 30. These values do not differ from normal.

If the cases are arranged according to the height of the brachial pressure, no correspondence between this and digital pressure is observed. The reason probably depends on the instability known to exist in the vasomotor mechanism in different individuals. It is pre-



——— Brachial pressure estimated by the method of auscultation.
— — — Brachial pressure estimated by palpation.
——— Digital pressure.

TEXT-FIG. 1. Curves of the brachial and digital pressure of an individual in whom the circulation was normal.



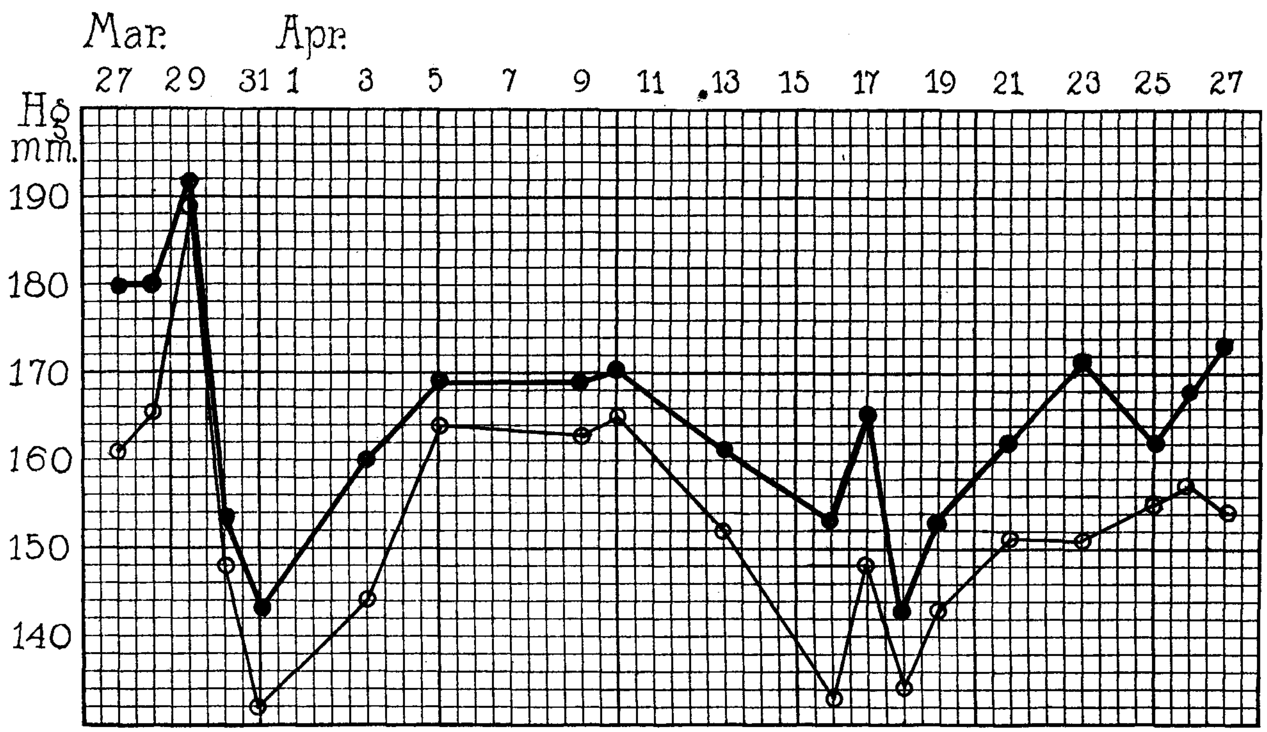
TEXT-FIG. 2. Curves of the brachial and digital pressure of an individual in whom the circulation was normal.

cisely in the smaller vessels that lability is observed, so that fluctuation is expected in the digital rather than in the brachial artery. It is for this reason that the readings in the two arteries are not parallel. In some respects the violent fluctuations in digital pressure present difficulties, so that as a guide for comparison pressure in the digital artery is unsatisfactory. The question arises, however, whether the difficulty which is found is not of clinical importance, and whether it ought not to be emphasized rather than evaded entirely as is now done in estimating pressure only at a point such as the brachial artery where the least variation is found. We recall that the method of Gaertner was practically abandoned because of the fluctuations inherent not so much in the technique as in the artery itself. Furthermore, the matter is important on account of questions associated with fluctuations in oxygen unsaturation in the venous blood of the arm such as Lundsgaard (8) has found. These phenomena may find their explanation, in part, in facts like those which are shown here.

TABLE IV.

Case No.	Hospital No.	Rate.	Brachial systolic pressure.	Tonometer.	Difference.
			mm. Hg	*mm. Hg*	*mm. Hg*
1	587	80	84	65	19
2	2915	86	100	84	16
3	2069	109	103	73	30
4	2681	96	145	126	19
5	2867	83	134	106	28
6	2862	82	145	128	17
7	2961	90	153	147	6
8	2907	82	160	139	21
9	2336	85	176	169	7
10	1266	30	176	135	41
11	2992	92	180	162	18
12	2833	30	250	170	80
Average........					25.1

Curves of the brachial and digital pressure of two individuals in both of whom the circulation was normal illustrate these points. In the first instance (Text-fig. 1) the pressure in the brachial artery fluctuated within the usual narrow limits from 104 to 118 mm., a range of



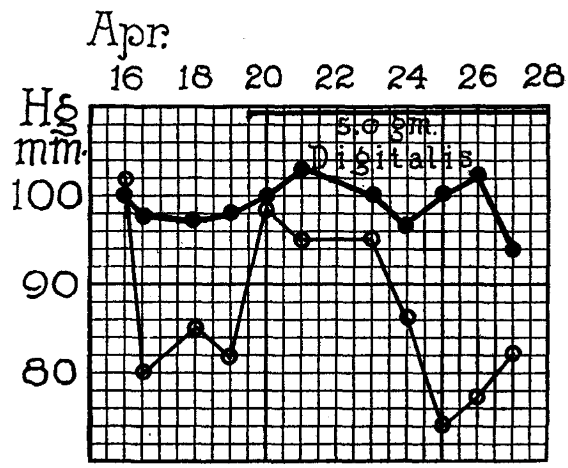
TEXT-FIG. 3. Curves of the brachial and digital pressure of a patient suffering from chronic nephritis and heart failure.

14 mm. Parallel digital pressure fluctuated between 75 and 85 mm., a range of 10 mm. The digital pressure was more constant than the brachial. In the second instance (Text-fig. 2) the brachial pressure fluctuated between 116 and 126 mm., a range of 10 mm., while the digital pressure fluctuated between 76 and 106 mm., a range of 30 mm., or three times as great as the brachial pressure. We expected the peripheral circulation of the first individual to be stable, but in the second we anticipated, because of the frequent rapid alterations of vasomotor tone seen in phenomena like dermatographia, that it was labile. Studies of blood flow, or oxygen unsaturation, already mentioned, had indicated that phenomena of the nature we are now emphasizing, existed to explain the obscure facts relating to flow. There is reason, therefore, to think that in studies like this, facts of importance may be found.

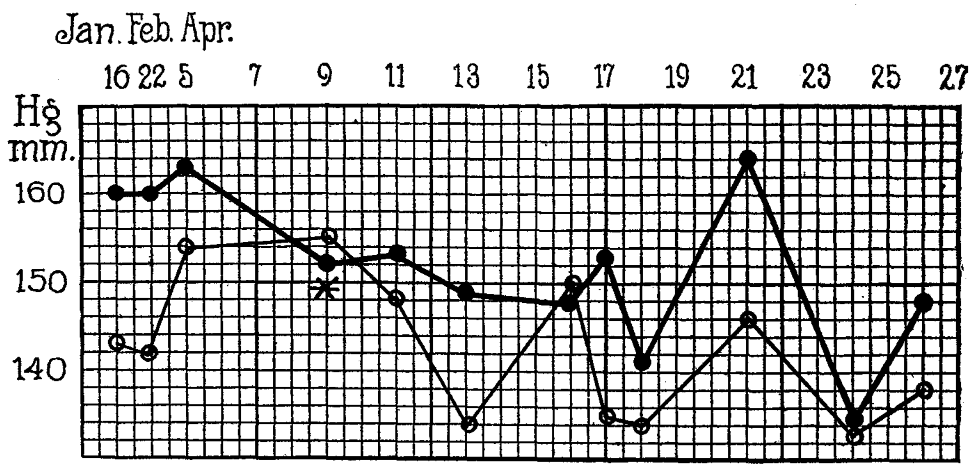
In this connection a consideration of the records of a patient (Text-fig. 3) are important. This individual suffered from chronic nephritis and heart failure; he was at first edematous and orthopneic and had a high pressure and an alternating pulse. The digital pressure fluctuated between 132 and 189 mm., a range of 57 mm. But the brachial systolic pressure fluctuated almost as violently between 143 and 192 mm., a range of 49 mm. In this instance the fluctuations are almost parallel and indicate that they depend on alterations in the functional state of the heart rather than on fluctuations in vasomotor tone. These three cases show that there are instances in which simultaneous brachial and digital readings are of value. But we have cited them in addition to show that of the two arteries, the blood pressure is uniformly higher in the one more centrally placed; the curves of the two do not cross.

OBSERVATIONS.

Our especial interest was directed to the study of the relation of digital to brachial pressures in individuals suffering from fibrillation of the auricles. We studied four patients in detail. The pressure curves made by the tonometer method are not remarkably different from those found when the mechanism of the heart beat is normal. But when the digital pressure curves are compared with the brachial pressures obtained by the method of fractional readings devised by



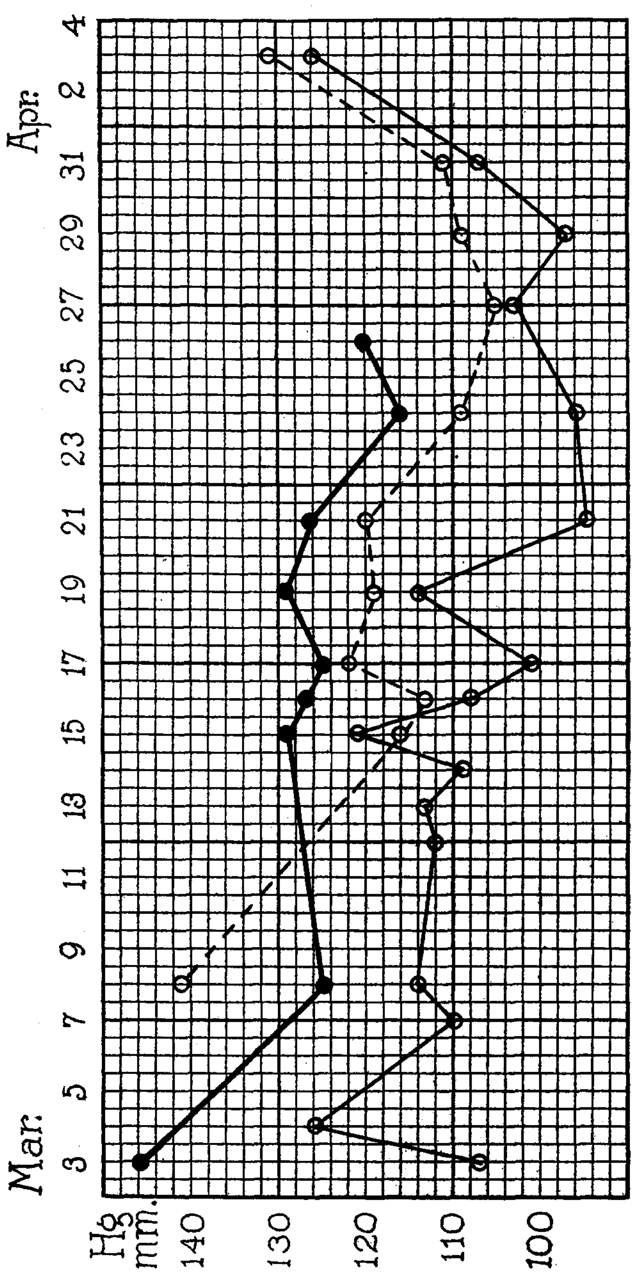
TEXT-FIG. 4. Curves of the brachial and digital pressure of an individual in whom the auricles were fibrillating. The curves cross once.



TEXT-FIG. 5. Curves of the brachial and digital pressure of an individual in whom the auricles were fibrillating. The curves cross twice. The upper curve represents pressure in the brachial artery determined by the method of auscultation, except where indicated by an asterisk. The lower curve represents digital pressure taken by Gaertner's method.

James and Hart, difficulties occur. In the first place, the taking of readings requires as many minutes or half minutes as there are levels at which pressure is read. During this time the state of the vessels does not remain the same, the number of sounds heard or beats felt at one level may, after 3, 4, or 5 minutes, alter appreciably; sometimes, indeed, no reliable count is possible. To avoid continuous pressure, we invariably reduced the pressure to zero, for at least 1 minute between successive readings, although the length of the examination was thereby doubled. The procedure, however, did not remove the difficulty. The explanation for this may depend on a number of causes related to the auscultatory method, possibly to the formation of the sounds. But another cause also deserves consideration. Compression of the brachial vessels for so long a time may alter the partition of the blood stream so that an increasing fraction passes, uncompressed by the cuff, in the medullary vessels of the bone or in vessels protected by the grooves on its surface. This explanation implies a rapid increase in the area of the collateral vessels, but there is reason for believing that it may take place. It has, on the other hand, been observed that the difficulty may develop gradually. If absent at first, it increases as the daily examinations proceed. The establishment of the collateral circulation need, therefore, not be abrupt. The factors involved in the production of the sounds, whether produced by the mechanism of the water-hammer or otherwise, may also change. Whether these are the occurrences which actually take place and are the ones responsible for the difficulty we are considering, is of secondary importance. The sounds in any event do not remain sufficiently distinct in many individuals to make auscultation reliable as the basis of the fractional method. For the reasons stated, counting the beats by palpating the radial artery also offers difficulties. We have, therefore, in two cases counted the rate in the radial artery by palpation as well as in the brachial by auscultation. In one case in which it was satisfactory, we used the auscultatory method alone.

A second difficulty is that the curve of average brachial pressure occasionally crosses and is lower than the level of digital pressure taken on the same day. A crossing of the two curves had not been observed by others and was not seen in our studies of individuals the



TEXT-FIG. 6. Curves of the brachial and digital pressure of an individual in whom the auricles were fibrillating. The curves cross once when the fractional pressure by palpation is considered.

mechanism of whose hearts was normal. The crossing of the curves is, moreover, inconceivable. In Case 13 (Table V) crossing was observed once in eleven observations (Text-fig. 4); in Case 14 (Text-fig. 5) twice in twelve observations; in Case 15 (Text-fig. 6) once in seventeen observations when the fractional pressure was taken by palpation, but not if taken by auscultation; in Case 16 (Text-fig. 7) thirteen times (in two they were equal) in nineteen observations if taken by palpation, and five times in twenty observations if taken by auscultation.

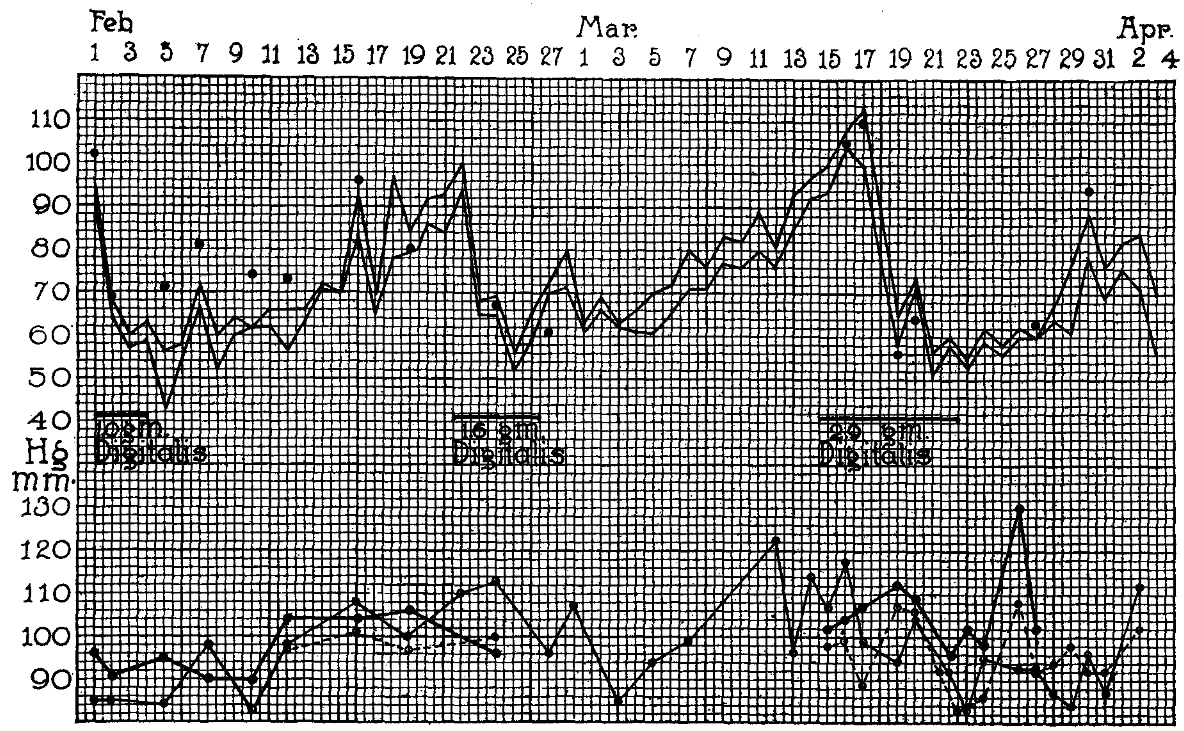
TABLE V.

Case No.	Hospital No.	No. of observations.	Crossing.	
			Observed by method of palpation.	Observed by method of auscultation.
13	3007	11		1
14	2548	12	1	1
15	2683	17	1	
16	2334	19	13	
		20		5

Although the number of patients studied is not large, the fact that in each of them the fractional method of estimating pressure gave readings for the brachial artery lower than for the digital is important. The finding makes it desirable to review the opportunities for error.

An average pressure can no doubt be obtained by the fractional method. But even if the result is obtained free from the technical errors already discussed, and from one other now to be considered, it would probably be incorrect because it is not possible to regard the circulation as is usual in physical phenomena. In order to do this the value of one cycle ought to be directly comparable with another in terms of its numerical equivalent.[6] To regard it in this manner is, however, impossible. If, for instance, a ventricular cycle is unable to lift the aortic valves, this cycle is of no importance in increasing or even in maintaining the pressure in the arterial reservoir. It has no functional value and ought not to be included in calculating the average pressure; it tends merely to lower the value. The only

[6] Kilgore has considered this matter in a similar manner.



TEXT-FIG. 7. Curves of the brachial and digital pressure of an individual in whom the auricles were fibrillating. The curves cross thirteen times in nineteen observations if taken by palpation, and five times in twenty observations if taken by auscultation. In the upper set of curves the upper line represents the average ventricular rate for the day, the lower one, the average radial rate. The dots indicate the ventricular rate at the time of blood pressure determination. In the lower set of curves the brachial pressure by the auscultatory method is represented by the heavy line; brachial pressure by the method of palpation is represented by the broken line. Digital pressure taken by the method of Gaertner is represented by the light line.

ventricular cycles which can have an influence on the pressure in the arteries are those the systolic value of which is greater than diastolic pressure. But as far as maintaining the driving force of the circulation is concerned, that is the head of pressure represented by the difference between systolic and diastolic pressure, not all the cycles having a systolic value above diastolic pressure are equal. Many having a low value need have no significance in maintaining the effective pressure. In cases where the rate is low, and where there is no pulse deficit, whether the rhythm is regular or irregular, both a high systolic and a high diastolic level can be maintained. This is observed in cases of complete heart block. Of two such cases studied, the brachial systolic pressure in one was 250, the diastolic 90, and the digital pressure 170; and in the other the systolic pressure was 176, the diastolic 63, and the digital pressure 164. It is apparent that additional ventricular beats, if they are ineffective, whether able to lift the aortic valves or not, would have no significant influence on these figures. The rate in both cases was about 30. A few cycles of great power can therefore maintain a high head of pressure. We infer from this that 30 to 40 beats at a given pressure, 130 mm. for instance, are sufficient to maintain effective pressure close to this level. If additional 40 to 60 beats having low systolic pressure values are introduced into the calculation the numerical value given to the pressure is merely reduced and no added light is thrown on the actual circulatory condition. And if ventricular cycles that do not even develop force sufficient to open the aortic valves are included, the average pressure is still further depressed.

In estimating the systolic pressure in fibrillation of the auricles, therefore, the fractional method is defective. A substitute is readily found in the use of the tonometer method of Gaertner. By its means satisfactory readings are possible. One should remember, however, that the readings so obtained tend to be about 20 mm. lower than the pressure in the brachial artery. As a rough method for estimating the pressure in fibrillation, it appears to us to be sufficient to find rapidly the level of pressure in the brachial artery at which about 40 beats per minute occur; this point is not far removed from the effective pressure about which information is actually required. It avoids, furthermore, the appearance of numerical accuracy, where accuracy, as Mackenzie pointed out, is impossible.

In two patients (Nos. 13 and 16), the subjects of fibrillation of the auricles, we were able to study the effect of digitalis on the brachial and digital pressures. In the first, after giving digitalis for about 8 days, there was a slight lowering of the digital curve (Text-fig. 4) from 97 to 74 mm. But in the period before this, readings of 80 to 85 mm. were recorded and a reading of 84 was found later in the treatment. The influence of digitalis in this instance cannot, therefore, be called striking. In the second case (Text-fig. 7) there were three digitalis periods separated by 14 or more days during which 1, 1.6, and 2.9 gm. were given. In each digitalis period the digital pressure fell, rising again during the intervals between administrations. In the first interval the pressure rose from 83 to 108 mm.; in the second interval from 85 to 122 mm.; in the third interval from 83 to 112 mm. It is the usual experience, when the mechanism of the heart is normal, to find little or no alteration in brachial blood pressure during digitalis administration. Whether this is true when the auricles are fibrillating, is unknown. The fractional blood pressure curve in this patient taken either by palpation or auscultation is unsatisfactory, so that the record of its behavior is not valuable. Nor is it possible to construct a brachial curve based on the levels at which about 40 beats were heard or felt because the counts due to the long examination made necessary by the fractional method are inaccurate. These observations permit us to state merely that we observed not a rise but actually a fall in digital pressure during digitalis administration. The subject requires further study.

SUMMARY.

The function of the arteries as an elastic reservoir between the heart and the capillaries is reviewed. The appropriateness of selecting the exit from this reservoir as the point for estimating its effective pressure is shown. The technique for taking the pressure here by the method of Gaertner is described and its advantage and certain apparent disadvantages are indicated.

The technique of Gaertner is shown to be especially applicable to the study of the blood pressure in fibrillation of the auricles. The use of this technique has brought out a defect in the so called fractional method of taking the pressure in this condition; the brachial and digital curves cross.

Taking pressure of both brachial and digital arteries has shown that certain different types exist; first, that in which both central and peripheral pressures are stable; second, that in which the more central pressure is stable and the peripheral pressure fluctuates; and third, that in which both pressures fluctuate together.

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