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THE PULSE-FLOW IN THE BRACHIAL ARTERY

IV. REFLECTIONS OF THE PRIMARY WAVE IN DICROTIC AND MONOCROTIC PULSE-FORMS *

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It is well known that in most tracings from the peripheral arteries various secondary waves follow the principal or primary wave on the descending limb of the pulse. The chief of these is usually spoken of as the dicrotic wave; and when this wave can be distinctly felt by the palpating finger on the radial artery, the pulse is described as dicrotic. The typical dicrotic pulse is relatively common in typhoid fever, but it occurs not infrequently in all types of infection. It is also occasionally encountered in other conditions, as, for example in cardiac patients with badly broken compensation. Marked instances of dicrotism are frequently but not invariably associated with low blood-pressure. On the other hand, equally low blood-pressures occur without marked dicrotism. In this as in many other conditions the relation between blood-pressure, whether systolic or diastolic, and pulse form is but a loose one. Pulse form does not depend directly on blood-pressure, though the two are controlled by many factors in common.

During the past year I have studied the brachial flow in seven patients who presented definitely palpable dicrotic pulses. In all of these cases the records obtained showed characteristic variations from the usual pulse-flow in the brachial artery (Figs. 1 and 2). Instead of the step-like entrance of blood most commonly seen in normal tracings, the primary wave was immediately followed by a marked retrograde movement of blood in the artery, and this in turn was followed by a forward movement of blood due to the dicrotic wave. The smaller secondary waves so frequently seen on the normal pulse were absent. The tracings showed many points in common with those obtained from normal individuals who have taken nitroglycerin. The marked backflow in the brachial artery which occurs just after the entrance of the primary wave is present in both, and is, I believe, due

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to a reflection of the primary pulse-wave in the vessels of the arm. Certain differences between the nitroglycerin pulse and the dicrotic pulse of fever will be discussed later.

One of the characteristic features of sphygmographic radial tracings of the dicrotic pulse is the marked fall in the pressure-curve between the primary and the dicrotic waves, which may be so great that the tracing descends nearly as low as and occasionally even lower

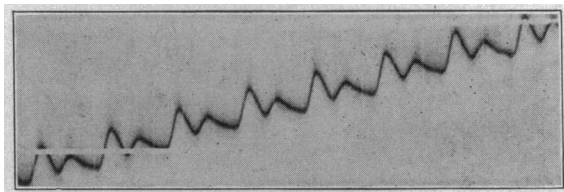


Fig. 1.—Common type of pulse flow in a palpable dicrotic pulse. The horizontal lines represent a difference in volume of 2 c.c. Vertical interruptions, $\frac{1}{4}$ second. Rate of flow, 2.1 c.c. per hundred c.c. arm substance per minute. Height of primary wave above the average rate of flow, 0.5 c.c.

than it does at the end of the pulse-cycle. Our records show that this fall of pressure is associated with a backflow in the brachial artery. Hirschfelder¹ has based his classification of pulse-form on the degree of this fall after the primary pulse-wave, and Marey apparently assumes a similar classification. According to this view, all pulses which show a marked fall in the late systolic portion of sphygmo-

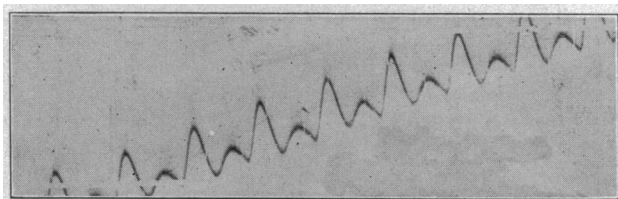


Fig. 2.—Unusually large primary wave (0.8 c.c.) with unusually marked backflow after this wave in a patient with dicrotic pulse. Rate of blood flow, 2.2 c.c.

graphic tracings are grouped together, irrespective of the size of the dicrotic waves. In the present paper I shall designate as monocrotic a pulse which shows this marked fall of pressure in late systole without the presence of a prominent dicrotic wave. That this sudden fall of pressure is of greater importance than is the size of the dicrotic elevation is shown by the fact that variations in the latter often occur while the former remains constant. Thus von Kries² found that during

1. Hirschfelder, A. D., *Diseases of the Heart and Aorta*, 1910, p. 44.

2. Von Kries: *Studien zur Pulsehere*, Freiburg, 1892.

the height of amyl nitrite action, the radial pulse was monocrotic and that the dicrotic wave appeared and became more marked as the action of the drug wore off. Febrile patients may also show great variations in the size of the dicrotic wave while preserving the marked systolic fall, as may be seen in tracings published in Marey's "Circulation du sang" (Fig. 274). Further evidence of the intimate relationship which exists between the monocrotic pulse as above defined and the dicrotic pulse is also obtained by records of the brachial pulse flow. A typical monocrotic pulse is shown in Figure 3, and it will be seen that like the dicrotic pulse there is a very marked backward movement of the blood in the brachial artery just after the entrance of the primary pulse-wave. This record was obtained from a typhoid fever patient who, on other occasions, showed a typical dicrotic pulse. Nitroglycerin will produce in some individuals a monocrotic pulse, in others a dicrotic pulse. In still others the typical monocrotic flow pulse present at the height of the action later becomes a dicrotic pulse as the effect of the

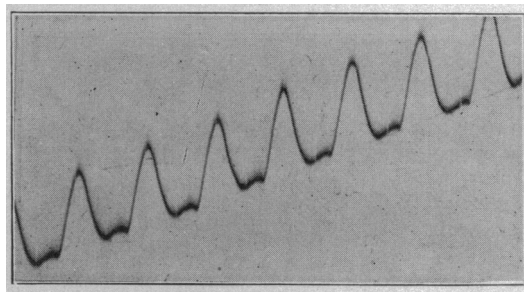


Fig. 3.—Marked monocrotic pulse.

drug wears off, an observation analogous to that of von Kries on the effect of amyl nitrite on radial tracings. It is, I believe, quite certain that the typical dicrotic pulse and the typical monocrotic pulse (as above defined) are but subvarieties of a more general type in which the primary pulse-wave has a pointed form on account of the marked fall in the pressure tracing just after its entrance. This fall is accompanied by the exit of a considerable amount of blood from the larger arteries of the arm owing to a local reflection of the primary pulse-wave.

In a previous paper³ it was shown that nitroglycerin produces a marked backward movement of the blood in the brachial artery just after the entrance of the primary pulse-wave, and my collaborators and I have endeavored to explain this backward movement solely from the point of view of the changed conditions in the local vascular

3. Hewlett, A. W.: Van Zwaluwenburg, J. G., and Agnew, J. H.: The Pulse Flow in the Brachial Artery, *THE ARCHIVES INT. MED.*, 1913, xii, 13.

apparatus of the arm. It was assumed that a relaxed condition of the larger vessels of the arm allowed an unusually large primary wave to enter this region, and that the reflection of this wave by the relatively constricted finer arterioles was a sufficient explanation of the backward movement of blood in the brachial artery just after the entrance of the primary wave. An attempt to apply this explanation to the dicrotic pulse of fever encounters certain difficulties. In the accompanying table I have given the records from our seven febrile patients who presented definitely palpable dicrotic pulses. In addition to the brachial flow records, which give the average rate of blood-flow in the arm and the height of the primary wave above this average flow, I have determined the velocity with which the pulse wave moved down the arm, by making simultaneous pressure tracings of the radial and of the carotid or brachial pulse-curves. The blood-pressure records in the table were in most but not in all instances taken at the same time as the other records.

PALPABLE DICROTIC PULSE

Patient	Diagnosis	Rate of Blood Flow per 100 c.c. Arm Substance per Minute, c.c.	Height of Primary Wave Above Average Inflow, c.c.	Velocity of Pulse Wave, cm.	Blood-Pressure	
					Max.	Min.
Mor.	Typhoid....	2.5	0.5	840	120	76
Bus.	Typhoid....	2.5-4	0.35-0.5	650	112	
V. H.	Typhoid....	2.2	0.8	650	115	90
Barn.	Tuberculosis	2.5	0.45	750	130	
Mered.	Tuberculosis	2.0	110	72
O'L.	Tuberculosis	2.5	0.6	830	95	
Bo.	Pneumonia..	1.7	0.4	870	108	57

It will be seen from this table that in all of the cases studied the average rates of blood-flow in the arm during marked dicrotism approached the lower level of the normal, which, by the method used, usually lies between 2 and 8 c.c. of blood per hundred c.c. of arm substance per minute. It is evident, therefore, that in cases of marked dicrotism there is no increased blood-flow in the arm, and consequently no marked dilatation of the finer arterioles in this vascular area. It cannot, of course, be inferred that there is likewise no vasodilatation of the arterioles in other important vascular areas and especially in the splanchnic region, for we know that an antagonism frequently exists between these vessels and those of the extremities.

It is likewise apparent from the table that the size of the primary pulse wave in the exquisite type of dicrotic pulse here studied is if anything less than the average. Thus in a series of twenty-five individuals showing various clinical conditions, exclusive of aortic insufficiency, the size of the primary pulse-wave as measured above the average rate of inflow varied from 0.4 to 1.1 c.c. with an average of

0.63 c.c.; while in our dicrotic pulses the primary wave varied from 0.35 to 0.8 c.c., with an average of 0.51 c.c. In this respect, therefore, the brachial flow in the dicrotic pulse differs from that present after the administration of nitroglycerin, for in the latter the size of the primary wave is almost invariably considerably larger than what was normal for the individual studied. It is thus evident that in the dicrotic pulse of fever with its close resemblance to the nitroglycerin pulse we lack one of the features which led us to attribute the latter chiefly to changes in the local blood-vessels of the arm itself. In the dicrotic pulse the primary wave which enters the arm is not unusually large.

The condition of the arteries of the arm is not easily determined, but from palpation one gets the impression that in the dicrotic pulse of fever the size of these vessels does not differ greatly from the normal. Furthermore, the rate of propagation of the pulse-wave is not markedly or constantly changed from the normal, which varies from about 670 to 1,000 cm. per second, with an average of about 825 cm.⁴ Since the rate of propagation depends largely on the elastic coefficient of the arterial walls, it would appear that a marked reduction in the elastic coefficient of the larger vessels of the arm is not a constant and essential factor in the production of the dicrotic pulse of fever.

Our records indicate, therefore, that marked instances of the febrile dicrotic pulse are associated with moderate to marked constriction of the finer arterioles in the arm and with the entrance into the arm of primary waves of normal or subnormal size. So far as we can judge, there are no marked and constant changes in the condition of the larger arteries of the arm. It seems difficult to explain the marked oscillations in the brachial column of blood from these data alone and we are inclined to refer the dicrotic pulse of fever, in part at least, to cardiovascular changes outside of the arm. Before discussing the character of these changes, however, we wish to bring further evidence in favor of the view that a reflection of the primary pulse-wave in the arm is an important factor in the production of the pointed primary wave, which is such a prominent feature of dicrotic and monocrotic pulse-forms.

RELATION OF POINTED PULSE-FORMS TO REFLECTIONS OF THE PRIMARY PULSE-WAVE IN THE ARM

The view that dicrotism is associated with marked reflection of the primary pulse-wave in the arm stands in apparent contradiction to the commonly accepted view that dicrotism is most frequently encountered in conditions of vascular relaxation. According to this view, as

4. Friberger, R.: Ueber die Pulswellengeschwindigkeit bei Arterien mit fühlbarer Wandverdickung, *Deutsch. Arch. f. klin. Med.*, 1912, cvii, 280.

described for example by Hirschfelder, the flow of blood through the arterioles is so rapid that a very marked fall of arterial pressure occurs even during the systolic portion of the pulse. Our records show that so far as the arm is concerned no such rapid flow of blood is present.

Indeed, if the arterioles of the arm are markedly dilated and the local blood-flow is very fast, the pulse tends to lose its dicrotic character. Very rapid local flows in the arm can be produced by having an

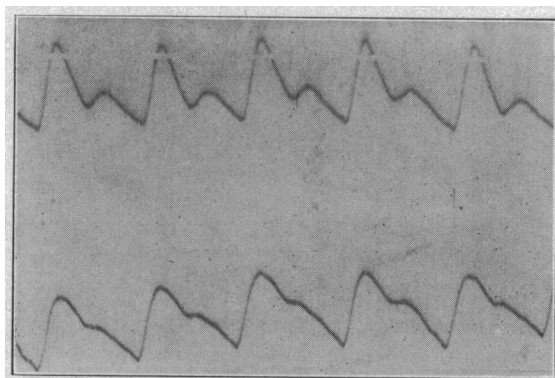


Fig. 4.—Volume pulse of the arm. Effect of constricting the arteries at the wrist after taking a very hot bath. Lower tracing without constriction, upper with constriction.

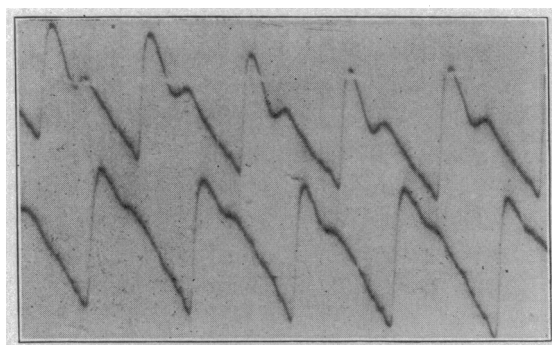


Fig. 5.—Volume pulse of the arm. Effect of constricting the arteries at the wrist after taking a very hot bath. Lower line without constriction, upper with constriction.

individual remain in a tub of very hot water until free perspiration is established and the body temperature is slightly elevated. The volume pulse then assumes the form shown in the lower curves of Figures 4 and 5. It is characterized by a gradual fall in the tracing and by a dicrotic wave which occurs relatively high on the tracing, both being characteristics opposite to those which are present in typical dicrotism.

Veiel⁵ observed similar changes in the radial pressure pulse after a hot bath.

According to Stewart,⁶ a compression of the radial pulse below the sphygmograph will cause the typical pulse of aortic insufficiency to lose its collapsing character. According to Marey (Fig. 138), on the other hand, such a compression may increase the dicrotism of a normal pulse. It is well known that sphygmographic tracings are liable to be influenced by gross technical errors, and we have therefore sought to make similar observations on the volume pulse of the arm when the arteries about the wrist were compressed. This was accomplished by placing a pressure cuff about the wrist within the plethysmograph and applying pressures of 200 mm. or more of mercury. The rubber tube to the pressure cuff was carried out of the plethysmograph, and it was therefore possible to obtain alternate tracings of the volume pulse or of the brachial flow when the wrist arteries were compressed and when they were left open.

The effect of obstructing the arteries at the wrist varied in different individuals and in the same individual at different times. In many cases the compression of the wrist produced little effect on the form of the volume curve; but in no case have we encountered any marked tendency toward diminished dicrotism as a result of such pressure. On the other hand, a number of records were obtained in which an increased dicrotism appeared when the wrist arteries were compressed. This effect was obtained with considerable regularity when the very rapid blood-flow after a hot bath was obstructed at the wrist by a pressure cuff (Figs. 4 and 5). One of our typhoid fever patients who had shown a typical dicrotic pulse on several occasions showed on one examination a rapid blood-flow through the arm (10 c.c. per hundred c.c. of arm substance per minute) and a pulse that was not definitely dicrotic. Compression of the wrist arteries slowed the blood-flow to 3 c.c., and at the same time the pulse took on a dicrotic character (Fig. 6).

Since the pressure curves from arteries in the arm follow nearly the same course as do the volume curves, it seems probable that similar changes in the pressure curves were present. These observations furnish further evidence in support of the view that one of the important factors favoring the production of a sharp fall in the volume (and pressure) tracings immediately after the primary wave

5. Veiel, E.: Ueber die Bedeutung der Pulsform, *Deutsch. Arch. f. klin. Med.*, 1912, v, 249.

6. Stewart, H. A.: Experimental and Clinical Investigation of the Pulse and Pressure Changes in Aortic Insufficiency, *THE ARCHIVES INT. MED.*, 1908, i, 102.

is a constriction of the finer arterioles of the arm which tends to cause a reflection of the primary wave in this region.

THEORIES OF THE POINTED CHARACTER OF THE PRIMARY WAVE IN DICROTIC AND MONOCROTIC PULSE FORMS

We have seen that the common and probably the most important feature of the dicrotic and monocrotic pulse-forms is the marked backward movement of blood in the brachial artery just after the primary pulse-wave, which movement gives rise to a pointed form of this wave in both volume and pressure records. Although present data hardly permit a satisfactory explanation of this pointed type of pulse, it may be of interest to review certain theories in the light of our observations and to suggest possible explanations for this type of pulse. I have shown previously that in the nitroglycerin pulse the marked backward movement of blood in the brachial artery during late systole could not be attributed solely to a settling back of the blood-

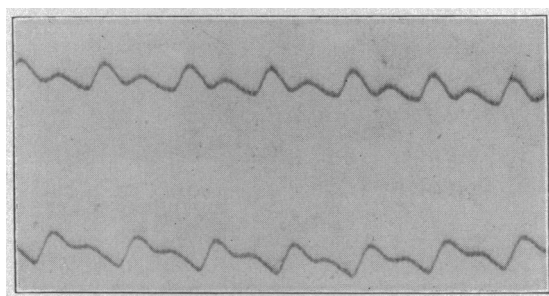


Fig. 6.—Volume pulse of the arm. Effect of constricting the arteries at the wrist in a patient with typhoid fever. The lower curve without constriction. Blood flow, 10 c.c. The upper tracing with constriction. Flow reduced to about 3 c.c.

column against the aortic valves. In that type of pulse as well as in those discussed in the present paper, the movement backward in the brachial artery is altogether too great to be accounted for in this manner. The only explanation which seems possible for this backward movement is that it is due to a reflection of the primary wave in the arm. New evidence in favor of this view is given in the present paper, and it is supported by a comparison of volume curves from the arm and from the hand, which are published elsewhere.⁷

In the nitroglycerin pulse an unusually large primary wave enters the arm, and in a previous paper I sought to explain that type of pulse solely on the basis of changes in the arm vessels. In the dicrotic pulse

7. Hewlett, A. W.: Reflexionen der primären Pulswelle im menschlichen Arme, *Deutsch. Arch. f. klin. Med.*, 1914, cxvi, 237.

of fever, however, such an explanation encounters the difficulty that the primary wave may be unusually small and yet the backflow in the brachial artery may be relatively large. For this and other reasons it does not seem possible to account for the peculiar features of the dicrotic pulse solely on the basis of circulatory changes within the arm. It seems to us necessary to assume that changes in the cardiac or vascular mechanism outside of the arm play an important part both in the production of the backward movement of late systole and in the size and time of onset of the dicrotic wave.

Just what these conditions are is difficult to determine. Since the primary wave entering the arm interferes to a greater or lesser extent with its own reflection, a separation of these two in point of time would tend to make the reflected wave more evident on our tracings. Such a separation might be produced by a relatively slow rate of propagation of the pulse wave in the arm; but this, as we have seen, does not appear to be a constant finding in the types of pulse here studied. A short primary wave due to a rapid systolic emptying of the heart would also diminish this interference, and in cases of tachycardia as well as certain extrasystoles the frequently observed pointed character of the pulse may be due to this cause. Whether or not this factor plays a part in the backflows here described we do not know.

The known facts in regard to these pulse-forms may also be explained in accordance with the views of von Kries. This author concluded from theoretical studies on wave motion in elastic tubes and from comparisons of the pressure pulse and the tachogram of the arm of man that reflections of the primary pulse waves usually take place in the arm. My tracings show that under certain conditions such reflections produce well-marked backflows just after the entrance of the primary pulse wave. It is highly probable that similar reflections occur at numerous other points in the vascular tree and that these complicated systems of reflected waves return to the aorta and may then be propagated as centrifugal waves into various arteries. Under normal conditions these numerous and complicated systems of reflected waves tend to neutralize one another by interference, and the pulse approaches the type produced by the intermittent expulsion of fluid into an elastic bag with a narrow outlet. Von Kries explained the changes in pulse form produced by amyl nitrite by assuming that, owing to vascular dilatations in parts of the body other than the arm, certain of these reflected waves were absent and that the absence of these reflected waves which would otherwise have entered the arm between the primary and the dicrotic waves was the cause of the marked fall in pressure after the primary wave.

A similar explanation may be given for the pointed character of the primary wave in the dicrotic and monocrotic pulse-forms of fever, and it may well play an important part in the production of other pointed pulse-forms. A vasodilatation of certain vascular areas outside of the arm may diminish or eliminate certain reflected waves which would otherwise enter the arm between the primary and the dicrotic waves. This would allow the reflection of the primary wave in the arm to become apparent on our tracings as a negative blood-flow in the brachial artery. Knowing the rate of propagation of waves in the arterial system it is possible to estimate the distance which must be traveled in order that waves reflected from other parts of the vascular apparatus should enter the arm shortly after the primary wave. Such a calculation shows that these waves would be reflected from points lying in the neighborhood of 35 to 60 cm. beyond the points of origin of the subclavian arteries. The most important vascular areas lying at about this distance are the abdominal vessels. It is possible, therefore, that the pointed form of the primary wave in the dicrotic and monocrotic pulse of fever may be due in part at least to an unusual dilatation of the splanchnic vessels. This hypothesis is in accord with many statements concerning the conditions which produce these pulse-forms. Thus Cushny⁸ states that amyl nitrite produces a more marked dilatation of the vessels in the head and the abdomen than in those of the extremities. Fever is likewise generally supposed to cause a dilatation of the splanchnic vessels. The frequent but not invariable association between low blood-pressure and dicrotism may be due to the fact that while dilatation of the splanchnic vessels frequently lowers the blood-pressure it may fail to do so owing to the constriction of vessels in other parts of the body. A constriction of the arterioles in the arm would tend to maintain the blood-pressure and at the same time it would increase the local reflection, provided the larger arteries of the arm were not correspondingly constricted.³

CONCLUSIONS

1. In febrile patients showing palpable types of the dicrotic pulse, the brachial flow curves show characteristic changes. These consist in a marked backflow in the brachial artery just after the entrance of the primary pulse-wave and in an inflow and outflow with the dicrotic wave.

2. In the form of pulse here described as monocrotic there is also a marked outflow just after the primary pulse-wave, but no marked dicrotic wave follows. This type of pulse is closely related to the

8. Cushny, A. R.: *Pharmacology and Therapeutics*, 1906, p. 465.

typical dicrotic pulse. The primary wave in each has a pointed character.

3. Other things being equal, the pointed character of the pulse in the arm is increased by vasoconstriction of the arm arterioles and is diminished by their relaxation.

4. We have been unable to explain all forms of the pointed pulse satisfactorily solely on the basis of local vascular changes in the arm; that is, constriction of the arterioles and relaxation of the larger arteries. In many, if not in all cases, factors outside of the arm play a part in their production.

5. Among such possible factors are (1) a brief systolic output from the heart and (2) a dilatation of certain vascular areas outside of the arm, the most important being the splanchnic vessels.