CLINICAL STUDIES ON THE VELOCITY OF BLOOD FLOW

X. The Relation Between the Velocity of Blood Flow, the Venous Pressure and the Vital Capacity of the Lungs in Fifty Patients with Cardiovascular Disease Compared With Similar Measurements in Fifty Normal Persons[1]

By HERRMANN L. BLUMGART and SOMA WEISS

(From the Thorndike Memorial Laboratory, Boston City Hospital, and the Department of Medicine, Harvard Medical School)

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In preceding papers, particular attention has been directed to the relation in a given individual or in a group of individuals between the clinical findings and the measurements of the velocity of blood flow, the venous pressure, and the vital capacity of the lungs. In the following, more general treatment of the data, an attempt will be made to learn the extent and frequency of changes in these measurements in all subjects with cardiovascular disease compared with similar measurements in normal persons.

Changes in the venous pressure, in the velocity of blood flow, and in the vital capacity of the lungs can be compared with each other only if obtained in the same subjects. Such comparison would be almost certainly erroneous, if, for example, variations of venous pressures of some patients with cardiovascular disease were compared with variations of the vital capacities of other patients with cardiovascular disease, for it would be impossible to be certain that such different groups showed exactly the same degree of cardiovascular damage. Consequently, we have included here only those patients in whom all three measurements were obtained. Duplicate measurements in the same subject have been excluded in order not to weight some of the results unduly. Fortunately, the three measurements in all but four patients with cardiovascular disease, and the data in

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all but twelve normal individuals are available. The fifty normal persons are those presented in the study of the normal pulmonary circulation time (1); the fifty patients with cardiovascular disease are those included in the preceding communication (2).

Since measurements of the velocity of blood flow, of the venous pressure, and of the vital capacity of the lungs are expressed in such dissimilar units as seconds, centimeters of water, and cubic centimeters of air per square meter of body surface; since the order of magnitude of the measurements differs widely; and since, moreover, the vital capacity diminishes, the venous pressure rises, and the pulmonary circulation time and the arm to heart time becomes greater in circulatory insufficiency, comparison of such unlike quantities is difficult. All measurements have, therefore, been reduced to a common basis by expressing them in terms of percentage variation from their normal average. In all diagrams (see fig. 1) the measurements have been classified in 10 per cent groups. The shaded columns, for example, between +5 and −5 indicate the number of subjects in whom the measurements were found to be within the limits of +5 and −5 per cent of the average of the entire normal group. Vital capacity measurements were first expressed in the number of cubic centimeters per square meter of body surface. The percentage of the normal average was then calculated. If, for example, the vital capacity of a given individual was 1782 cc. per square meter of body surface, and the normal average 2376 cc. per square meter of body surface, the vital capacity observed would be 75 per cent of the normal, or, as we have charted it, a percentage deviation from the normal of −25 per cent. Similarly, the actual venous pressure has been calculated in terms of percentage of the average normal and the variation of this percentage from the normal charted.

Expression of the pulmonary circulation time and of the arm to heart time in terms of actual velocity presented a somewhat different problem. The "circulation time" denotes the time necessary for a substance to travel between two arbitrarily fixed points; the longer the time necessary, the slower is the speed of the substance. To express this inverse relation between circulation time and velocity it has been necessary to divide the average normal pulmonary circulation time by the one observed in order to secure an estimate of the speed in terms of the normal percentage. The normal average pulmonary circulation time is eleven seconds, and if, for example, the observed time in a patient with cardiovascular disease were twenty-two seconds, the doubling of the circulation time denotes a slowing of the blood stream to one-half the normal average velocity. A circulation time of twenty-two seconds would therefore be charted as −50 per cent. The data relating to the arm to heart times have been similarly treated.

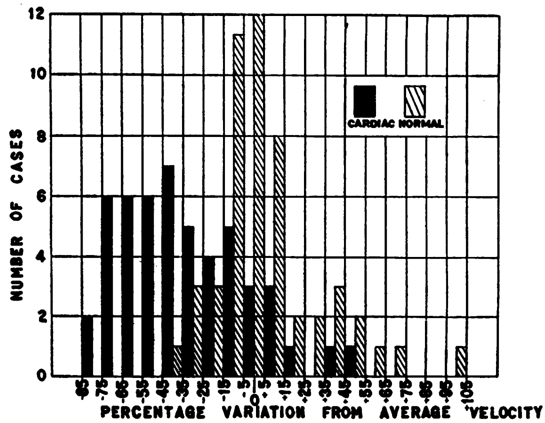

FIG. 1. PULMONARY CIRCULATION TIMES (CRUDE) OF NORMAL AND CARDIAC SUBJECTS

In these diagrams the normal measurements are those obtained in the fifty subjects we personally studied, and the data in patients with cardiovascular disease are those presented in the preceding communication. The methods employed and the conditions of the tests were consequently similar. The group of patients with cardiovascular disease includes those whose circulation was compensated, as well as those whose circulation was insufficient. The patient with cardiovascular disease in whom the velocity of blood flow (plus 47 per cent) was swiftest, for instance, showed essential hypertension and had never experienced symptoms or signs of circulatory insufficiency.

The frequency distribution of the pulmonary circulation time (crude)

The diagram (fig. 1) shows the degree and frequency of variations in the pulmonary circulation times in fifty patients with cardiovascular disease compared with the findings in fifty normal persons. A frequency distribution diagram such as the one presented is of value in showing the degree and incidence of variations in the velocity of blood flow in cardiovascular disease compared to the normal. For purpose of diagnosis, the ideal test would be one according to which all results in diseased states differed from any found in normal subjects. The degree to which a test approaches this ideal is one measure of its diagnostic importance. It is consequently of interest that of the fifty patients with cardiovascular disease, twenty showed more marked diminution in the velocity of pulmonary blood flow than that found in any single normal subject of this series.

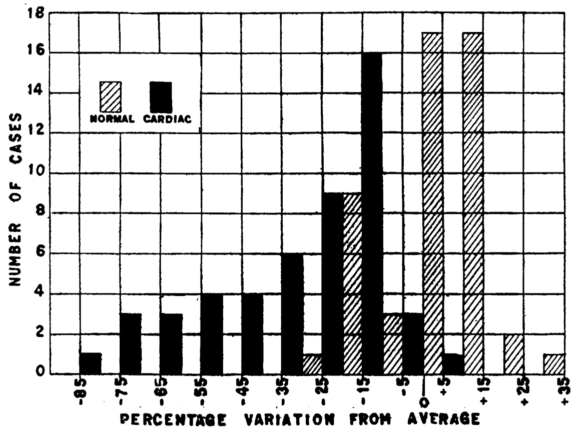

FIG. 2. COMPARISON OF THE VITAL CAPACITIES OF CARDIAC AND NORMAL SUBJECTS

The frequency distribution of the vital capacity of the lungs (per square meter of body surface)

The percentage variation in the normal subjects and in patients with cardiovascular disease has been charted (fig. 2). In the normal subjects the range of their vital capacity variations is less than that of their pulmonary circulation times, but it should be noted that in the cardiovascular patients likewise there is a similar relation; the deviation from the normal average pulmonary circulation time is correspondingly less striking. Although twenty cardiac patients showed more marked diminution in the velocity of pulmonary blood flow than that found in the lowest normal subject (fig. 1); in the vital capacity, only fifteen patients showed more marked diminution than the lowest normal.

The frequency distribution of the arm to heart times

The diagram (fig. 3) shows the degree and frequency of variation in the arm to heart times in fifty patients with cardiovascular

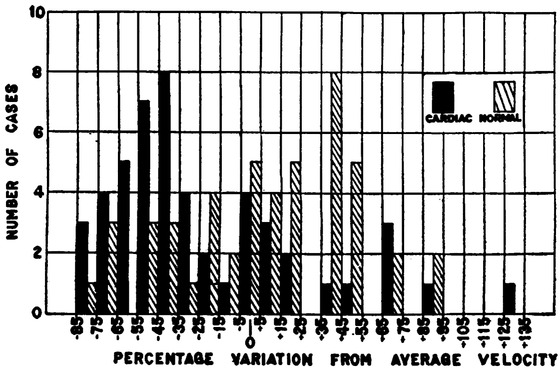

FIG. 3. COMPARISON OF ARM TO HEART TIMES OF CARDIAC AND NORMAL SUBJECTS

disease compared with the findings in fifty normal persons. In contrast to the measurements of the vital capacity and of the pulmonary circulation times, the normal arm to heart times show a much greater variation (fig. 3). While the normal vital capacities of the lungs per square meter varied over a range of 70 per cent and the pulmonary circulation times, with one exception, over 120 per cent, the arm to heart times of normal persons varied over a range of 180 per cent. Not only is the spontaneous variation of the arm to heart time in normal subjects great, but the variation in cardiovascular subjects is practically identical except that the incidence of the increased times (diminished velocity) is somewhat greater in cardiovascular disease. This finding of such great difference in the normal arm to heart time is in harmony with the studies of G. N. Stewart (3), and Hewlett and Van Zwaluwenburg (4) who observed that the volume flow of the arm varied considerably.

The frequency distribution of the venous pressure

Inspection of the chart (fig. 4) which compares the venous pressures of the fifty patients with cardiovascular disease with the venous pressures in normal persons shows that in both groups of subjects the

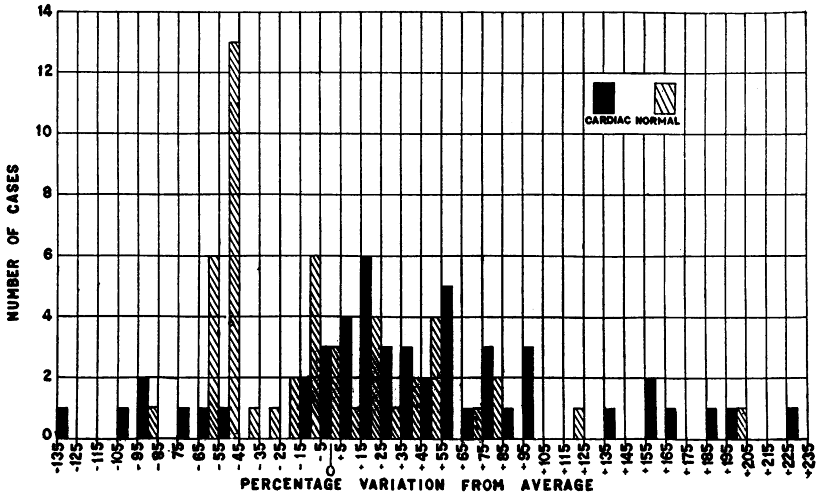

FIG. 4. COMPARISON OF VENOUS PRESSURES OF CARDIAC AND NORMAL SUBJECTS

.variability is far greater than that shown by the other measurements The venous pressure in cardiovascular disease varied over a range of some 360 per cent; in normal subjects over some 300 per cent. Of the fifty normal subjects, thirty showed a venous pressure below the average; twenty, a venous pressure above the average. In cardiovascular disease twelve measurements were below the average; thirty-eight above the average. Analysis of these findings confirms our general impression that the stage of congestive failure is attended by a significant rise in venous pressure, but that this rise cannot be interpreted as diagnostic because of the great variability shown by normal persons.

The relation of the pulmonary circulation time (crude) to the weight and height

In the foregoing discussion of the vital capacity of the lungs and of the crude pulmonary circulation time, the former has been reduced to the number of cubic centimeters per square meter of body surface, whereas the crude pulmonary circulation time used in the computations has been the one actually observed at the time of test. In order to learn whether the pulmonary circulation time in normal persons varies according to the weight or to the height, diagrams have been made (fig. 5, fig. 6). According to these diagrams the variation in the crude pulmonary circulation time is as great when referred to weight or height, as when the actual observed time is charted. The

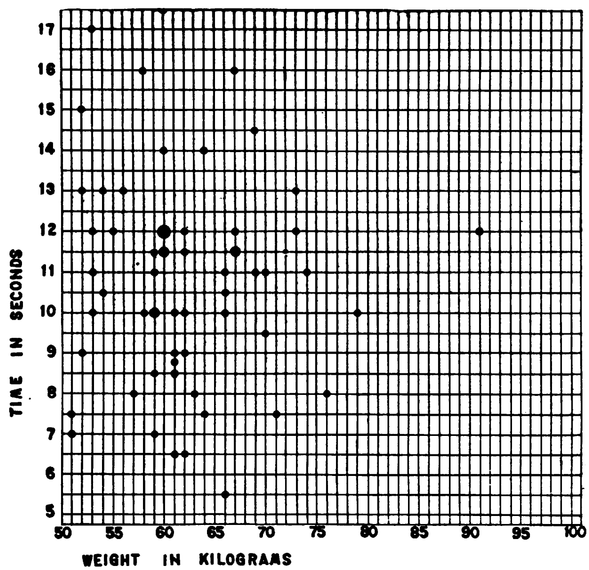

Fig. 5

circulation time as used in this connection refers to the time necessary for the radium active deposit to travel from the right auricle to the left antebrachial artery. That the time of transit is essentially the same in all individuals regardless of height or weight indicates that the velocity of blood flow in different sized individuals varies in such a way as to maintain in general the same time of transport.

The relation of the crude pulmonary circulation time to the vital capacity of the lungs in normal persons and in patients with cardiovascular disease

The frequency distribution of the vital capacity and of the crude pulmonary circulation time discussed earlier in this communication

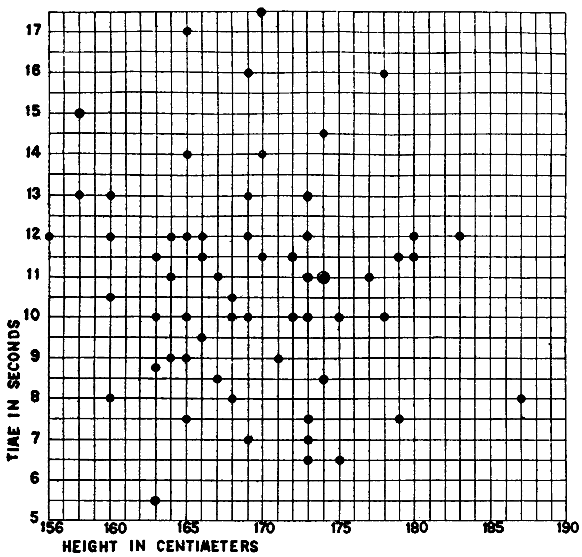

Fig. 6

does not indicate whether those individuals who showed a lower vital capacity tended to show a greater pulmonary circulation time (decreased velocity). To study the relationship between the pulmonary circulation time and the vital capacity of the lungs more clearly, a diagram (fig. 7) has been constructed. The chart is divided into four parts by a vertical and a horizontal line. The horizontal line represents the average normal pulmonary circulation time. The vertical line represents the average normal vital capacity found in our fifty normal persons. Group 1 consists of individuals in each of whom a low pulmonary circulation time was associated with an increased vital capacity; group 2, of persons in each of whom a low pulmonary circulation time was associated with a lowered vital capacity; group 3, of persons in whom a prolonged pulmonary circulation time was associated with an increased vital capacity; and group 4, of persons in whom a diminished vital capacity was associated with a prolonged pulmonary circulation time (decreased velocity). The normal subjects of each group are included in the smaller squares; the subjects with cardiovascular disease, in the larger squares. The normal subjects are distributed fairly evenly into the four groups so that the probability of a given normal individual being in any one group is about equal. Quite the reverse is true of patients with cardiovascular disease. They show a striking tendency to be in group 4 (prolonged pulmonary circulation time and decreased vital capacity).

According to the results shown in figure 7, the probability of a given individual with a low vital capacity (groups 2 and 4) having cardiovascular disease could be expressed by

$$\frac{\text{Group 2 cardiovascular plus Group 4 cardiovascular}}{\text{Group 2 normal plus Group 4 normal}}, \text{ or } \frac{45}{21}$$

That is to say, roughly, the probability, regardless of the pulmonary circulation time, would be two to one. Similarly if the pulmonary circulation time were prolonged (groups 3 and 4), indicating a slower velocity of pulmonary blood flow, the probability of the subject having cardiovascular disease regardless of the vital capacity of the lungs would be $\frac{41}{21}$, or again, roughly two to one. If, however, both tests were performed and the pulmonary circulation time were found prolonged and the vital capacity diminished (group 4), the probability of the subject having cardiovascular disease would be expressed by

$$\frac{\text{Group 4 cardiovascular}}{\text{Group 4 normal}}, \text{ or } \frac{40}{9}, \text{ or approximately four to one}$$

This indicates that changes in the pulmonary circulation time occur simultaneously with changes in the vital capacity of the lungs.

The relation of the venous pressure to the crude pulmonary circulation time and to the vital capacity of the lungs

When, in addition to changes in the vital capacity of the lungs and the pulmonary circulation time, alterations of the venous pressure are compared to the other two measurements, a diagram similar to figure 7 can be constructed in which there are eight squares. Figure 8

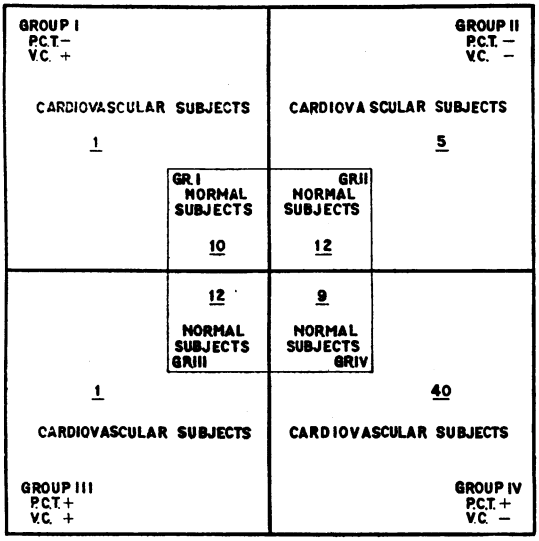

Fig. 7

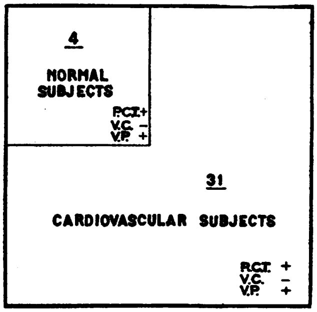

Fig. 8

represents one square in which those persons are found in whom a high venous pressure was associated with a diminished vital capacity of the lungs and a prolonged pulmonary circulation time. This square is analogous to the group 4 square of figure 7. Only four normal subjects satisfy these requirements in contrast to the thirty-one subjects with cardiovascular disease. If, consequently, a given person shows increased pulmonary circulation time, decreased vital capacity of the lungs, and venous pressure above the average normal, the probability of his having cardiovascular disease would be eight to one. It should be noted, however, that although the probability of a person with cardiovascular disease being in the group (group 4, fig. 7) with decreased vital capacity and prolonged pulmonary circulation time would be four out of five, 40/50; the probability of his being in the group (fig. 8) which showed in addition an increased venous pressure would be only three out of five, 31/50. Consequently, if a subject shows such changes (shown in fig. 8) from the normal, the probability is great that he has cardiovascular disease while if he fails to show such changes, the significance is not so great for he may be one of the 40 per cent group of patients with cardiovascular disease that does not show such deviations.

Statistical study of data such as is presented in this communication is important in physiological study of the dynamics of the circulation for it throws considerable light on the general relation between the velocity of blood flow, the vital capacity of the lungs and the venous pressure under both normal and pathological conditions. In an individual instance these considerations are of limited interest. It is not for a moment proposed that such formulae should be used in the diagnosis and prognosis of circulatory disease. These will, in fact, usually depend on the physical examination and history. On the other hand, the general knowledge of the velocity of the peripheral and pulmonary blood flow in different types of cardiovascular disease is of considerable value both physiologically and clinically. In certain obscure cases the electrocardiograph and the vital capacity of the lungs give useful information and it is felt that the measurement of the velocity of blood flow may, similarly, be of value since it affords a more direct measurement of the cardiac and vascular response in appropriate pathological conditions. Later communications will show that knowledge of the velocity of blood flow in normal persons and in patients with circulatory insufficiency affords a basis for study of the adaptations of the circulation in conditions such as fever, anemia, hyperthyroidism and myxedema, as well as of the effects of various drugs upon the circulation.

We are indebted to Dr. E. B. Wilson for his assistance in the statistical analysis of the data.

SUMMARY AND CONCLUSIONS

The relation between the pulmonary circulation time, the arm to heart time, the venous pressure, and the vital capacity of the lungs in fifty patients with cardiovascular disease has been compared with similar measurements in fifty normal subjects.

1. All measurements were expressed in terms of the percentage deviation from the normal average. Of the fifty patients with cardiovascular disease, twenty showed more conspicuous slowing of the pulmonary blood flow than that observed in any of the fifty normal subjects, while only fifteen patients showed more marked diminution in the vital capacity of the lungs than that found in any normal subject.

2. The arm to heart times of normal subjects and of patients with cardiovascular disease showed a greater percentage variation (from the normal average) than the vital capacity of the lungs and the pulmonary circulation time. The variations in normal subjects are over the same range as in disease but the incidence of the increased times (diminished velocity) is greater in cardiovascular disease.

3. Of the four measurements, the venous pressure showed the greatest variability both in normal subjects and in patients with cardiovascular disease. The variation in normal subjects was over the same range as in patients with cardiovascular disease although, in general, the stage of congestive failure was attended by a significant rise above the level of normal.

4. Unlike the vital capacity of the lungs, the pulmonary circulation time and the arm to heart times bear no relation to the weight, to the height, or to the surface area of the subjects.

5. In normal subjects the variations in the vital capacity of the lungs

are independent of variations in the pulmonary circulation time so that if the measurements are grouped according to their deviation from the average, the probability of a given normal subject being in any of the four groups is about equal.

6. In cardiovascular disease, however, there is a striking tendency for a decrease in the vital capacity of the lungs to be associated with an increase of the pulmonary circulation time which denotes a slower speed of blood flow through the lungs.

7. Statistical study of our measurements shows that, in a given person, if the vital capacity of the lungs is below the average normal the probability of his having cardiovascular disease is roughly two to one.

8. Statistical study of our measurements shows similarly that in a given person, if the pulmonary circulation time is above the average of normal the probability of his having cardiovascular disease is roughly two to one.

9. If a given individual has both a low vital capacity and an increased pulmonary circulation time, the probability, according to our experience, of his having cardiovascular disease would be four to one.

10. If, in addition to retardation in the pulmonary blood flow (increased pulmonary circulation time) and to diminution in the vital capacity of the lungs, the subjects show venous pressure increased above the normal average, the probability of his having cardiovascular disease is roughly eight to one.

11. It should be noted, however, that whereas the probability that a person with cardiovascular disease is in the group with a decreased vital capacity and increased pulmonary circulation time is four to one, the probability when he shows also increased venous pressure, is but three to one.

12. The value and limitations of the statistical analysis of the data are pointed out.

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