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THE RELATIONSHIP BETWEEN PULSE VOLUME AND BLOOD FLOW IN THE FINGER*

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Accurate measurement of digital blood flow by plethysmography requires considerable attention to technical detail. Determination of digital pulse volume, on the other hand, is less difficult, and there are many sensing and recording devices available for this.[1-5] In order to use pulse volume measurement as a routine laboratory procedure in the differential diagnosis of digital ischemia, however, it is necessary to know the correlation between pulse volume and flow in both the normal and the diseased finger under differing states of vasomotor tone. Investigation of this problem has been limited.[6, 7]

APPARATUS

The digital plethysmograph consisted of a cup, covering the distal two phalanges and forming an airtight seal with the skin by a plastic material, Plethysmoseal.† The chamber was connected by stiff vinyl tubing to a sensitive differential pressure transducer (Statham PM5, 350 ± 0.2). This was connected to a chopper amplifier and polygraph.‡ The system was calibrated by the introduction of 0.015 ml of air through a vent at the tip of the plethysmograph from an automatically adjusted syringe.

For occlusion of arterial inflow or venous outflow from the finger, a small pneumatic cuff was positioned around the proximal phalanx, immediately adjacent to the seal of the plethysmograph. The cuff was connected to a pressure tank through a solenoid valve system, so that cuff pressures could be preset, and filling was rapid.

METHOD

Studies were performed in a temperature-controlled room. Patients were examined in the recumbent position, with their arms positioned comfortably

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away from their sides on foam rubber bolsters, and with their hands at heart level. The middle fingers of both hands were studied simultaneously.

Both pulse amplitude and blood flow were determined. Flow was measured by the venous occlusion technique essentially as described by Burton,[6] utilizing four cuff collecting pressures (40, 60, 80 and 100 mm Hg) to determine the optimal one for recording. Systemic blood pressure was determined for each set of pulse and flow measurements by the auscultatory method, with a sphygmomanometer on the right upper arm. Studies were carried out under four different conditions.

Casual. The room temperature was 75° F and the patient was lightly covered. Pulse and flow measurements were made after 15 min. of recumbency.

Cool. The room temperatures was 65° F and the patient was lightly covered. Pulse and flow measurements were made after 30 min. of recumbency.

Heated. The room temperature was 80° F. Pulse and flow measurements were made after direct body heating (two heating pads beneath and three on top of the trunk and the patient covered from neck to toes with woolen blankets) until the oral temperature had risen at least 0.5° F. This procedure is believed to reduce sympathetic tone to a minimum.[8, 9]

Maximum dilatation. The conditions were as outlined above under "*heated.*" Pulse measurements were made after 10 min. of direct warming of the hands with heating pads and 5 min. of ischemia of the finger, produced by raising the pressure in the collecting cuff to 250 mm Hg. This procedure aims to reduce vascular tone to a minimum and hence to reflect the structural capacity of the vascular bed.

The volume of finger enclosed in the plethysmograph was determined at the conclusion of each experiment by a displacement technique.

Calculations. Pulse volume was corrected for a unit of 5 ml finger volume and for pulse pressure.

$$\text{Pulse volume (ml/5 ml finger/mm Hg pulse pressure)} = \frac{\text{(pulse deflection)(calibration factor)}}{\text{(finger volume/5)(pulse pressure)}}$$

Pulse deflection was obtained by averaging 10 consecutive pulse-height measurements. The final result was multiplied by 10^{-5} to provide manageable numbers.

Finger flow per unit of time was determined by drawing a line in the conventional manner along the rising volume curve which follows venous occlusion. A mean of two to four such collection periods was used for each determination. Flow was adjusted for finger volume.

$$\text{Finger flow (ml/min/5 ml finger)} = \frac{\text{(deflection/min)(calibration factor)}}{\text{(finger volume/5)}}$$

Subjects. Ten student volunteers with no clinical evidence of circulatory difficulty, and ten patients with scleroderma and Raynaud's phenomenon were studied. Investigations under cool conditions were omitted in the latter group.

RESULTS

Pulse Volume

Tracings of pulse volume and blood flow in one normal subject as he was taken from the constricted (cooled) to the maximally dilated state are illustrated in figure 1. Mean values and variability in pulse volume at each stage of the test for both groups are given in table 1. Pulse volume was smaller in the patients than in the normal subjects, under all conditions.

Flow

Mean values and variability in flow for both groups are given in table 2. Flow measurements could not be obtained under conditions of maximal dilatation, because at very high flow rates, the venous bed filled within one to two beats and a straight line on the volume displacement curve could not be drawn. Even in the heated condition, this was only just possible (fig. 1).

Relation Between Pulse Amplitude and Flow

Within individual subjects. In order to evaluate the correlation between pulse amplitude and blood flow, values obtained under the various environmental conditions were plotted against each other. The slope and intercept of linear regressions of blood flow on pulse volume were calculated. Scattergrams of the results obtained in two normal subjects are illustrated in figure

TABLE 1

Conditions	Pulse Volume	
	Normal subjects	Patients
	ml/5 ml/mm Hg	*ml/5 ml/mm Hg*
Cool	5.1 ± 2.1	
Casual	14.1 ± 6.8	5.0 ± 3.9
Heated	21.3 ± 7.9	7.0 ± 2.9
Maximum	23.7 ± 7.0	9.4 ± 4.5

TABLE 2

Conditions	Blood Flow	
	Normal subjects	Patients
	ml/5 ml/min	*ml/5 ml/min*
Cool	0.67 ± 0.56	
Casual	1.11 ± 0.84	0.35 ± 0.21
Heated	2.16 ± 0.66	0.75 ± 0.42

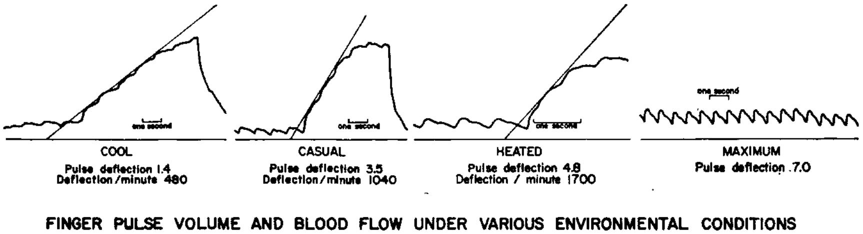

Fig. 1. Finger pulse volume and blood flow under various environmental conditions in one subject. Note the progressive increase of pulse deflection from coolness through maximal dilation, produced by direct and indirect heating plus reactive hyperemia. Flow increases in parallel to pulse amplitude. The more rapid paper speed during the "heated" observation should be noted.

2. Correlations of high statistical significance were obtained (by the t-test the regression slope for each individual was significantly different from 0 at the $p = 0.005$ level, while the intercepts did not differ significantly from 0).

In some subjects, there was a difference in regression slopes between hands, however, the differences between subjects were significantly greater than those found between hands in single subjects.

Between individuals. Substantial differences between subjects in the slopes of regression lines of pulse volume to blood flow was apparent, and figure 2 illustrates the extremes of this. Regression lines for all the individuals in the normal and abnormal groups are illustrated in figure 3. Values ranged from 0.044 to 0.176 ml per min per ml pulse volume among the normals, the mean for this group being 0.106 ± S.D. 0.076. An even wider range of regression slope was found in the patient group (0.012 to 0.285 ml per min per ml pulse volume) but the mean, 0.120 (± S.D. 0.121), was quite similar to that observed in normal subjects.

DISCUSSION

Measurement of pulse amplitude and blood flow in the finger from vasoconstriction through vasodilatation has been readily accomplished with this plethysmographic technique. Absolute values for flow during reflex heat dilatation (mean = 2.2 ± S.D. 0.66 ml/5 ml of finger/min) were in reasonable agreement with maximum values obtained after indirect heating by Burton[6] (90 ml/100 ml/min), and by Greenfield et al.[10] (53 ml/100 ml/min). In an individual subject changes in finger blood flow were found to be directly paralleled by the size of the finger pulse volume, over a wide range of environmental conditions. This finding is also in agreement with Burton,[6] who demonstrated a high correlation between pulse and flow in one subject. Burch[7] obtained similar results with subjects in the resting state. However, he predicted that this correlation would not hold under physiologic conditions producing extremes in flow and/or in disease states. Our results do not bear this out. While the degree of alteration in pulse volume per unit change in flow has been observed to vary greatly from individual to individual, this relationship

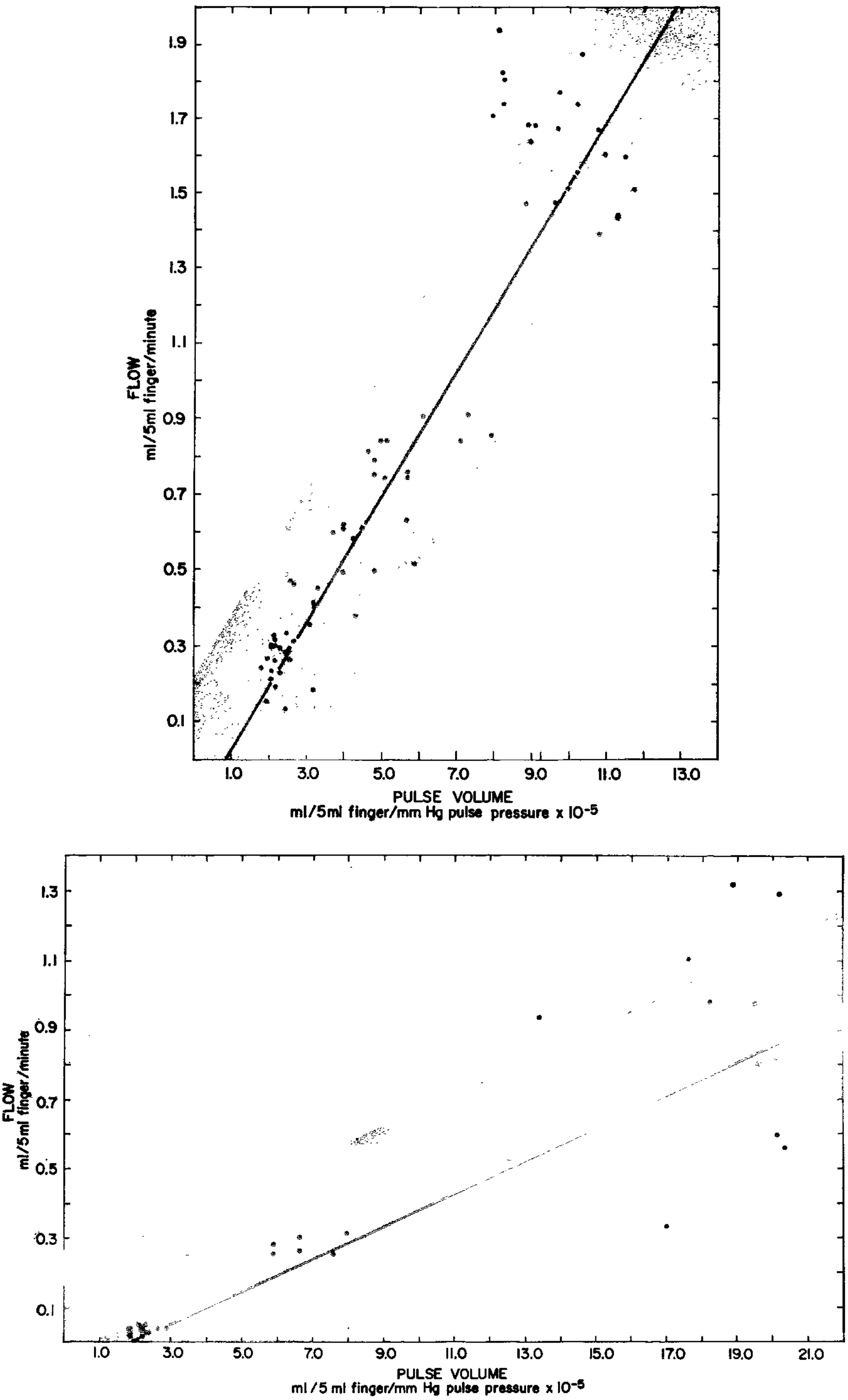

FIG. 2. Scattergrams with regression lines in two normal subjects. This demonstrates the close correlation between finger blood flow and pulse volume. These particular examples were selected also to demonstrate the extremes in the relationship between pulse volume and blood flow. The *shaded area* represents one standard deviation above and below the mean.

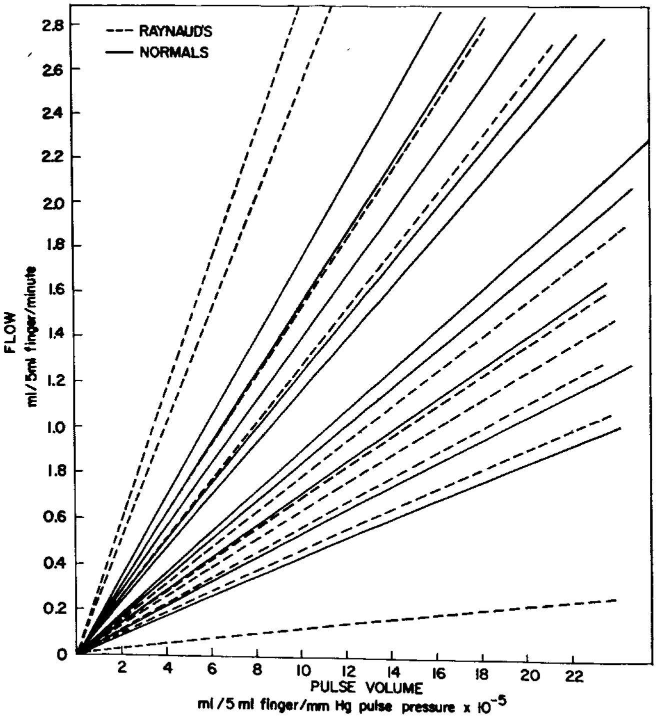

FIG. 3. Regression lines for normals and patients illustrating the wide range of slopes. Note the general similarity between the two groups. These slopes were calculated on the assumption that the intercept was 0 because, as noted in the text, the intercepts did not differ significantly from 0. In fact, slopes obtained in this manner did not differ substantially from those obtained by full linear regression technique which includes the intercept as a parameter.

has not been found to be affected by changes in vasomotor tone or by disease.

The pulse volume and blood flow relationship is determined by the dependence of each upon the physical characteristics of the blood vessels. For the pulse volume, the main contributing feature is the compliance of the vascular bed, and for the blood flow, the major factor is vascular caliber. Both are influenced by structural damage and by vasomotor tone.

In the evaluation of patients with Raynaud's phenomenon, a primary consideration is whether this problem is a "functional" disturbance or whether it is a symptom of obstructive digital artery disease.[11-13] In a careful clinicopathological correlation, Lewis[14] found that those patients with Raynaud's attacks and severe trophic changes have advanced obstructive arterial disease. Lynn et al.[15] reported essentially the same findings, based on an excellent arteriographic investigation. Plethysmography has also been applied to the study of this problem. Peacock[9] and Mendlowitz and Naftchi[16] reported that patients with Raynaud's phenomenon could be divided into two groups based on maximum flow rates obtained in symptomatic hands or digits, and they suggested that those patients with impaired flow during vasodilation had obstructive disease. Others[1-5] also have emphasized the value of plethysmography in the detection of obstructed vessels, but the investigation of patients with vascular disease of the fingers has not been extensive, probably because the technique seemed to be too complex. Our studies show that the pulse volume, which can be measured quite easily even in individuals who have digital vascular disease, is as reliable an indicator of the state of the vascular bed as the blood flow. Furthermore, the digital pulse volume is commonly subnormal in patients with scleroderma and in a variety of other conditions associated with finger blanching on cold exposure. This suggests that structural abnormality of the vascular bed is a frequent underlying factor in Raynaud's phenomenon. Further investigations of patients with this disorder are in progress.

SUMMARY

Studies have been undertaken to determine the relationship between digital blood flow and pulse volume in 10 normal subjects and in 10 patients with scleroderma and Raynaud's phenomenon. Measurements were made as the subjects were taken from cooled to heated conditions induced by direct body heating. The volume flow relationship, however, ranged widely among individuals. Although the scatter for the normals was less than for the patients with Raynaud's phenomenon, there was no evidence of a preferential reduction in the pulse volume or the blood flow in the diseased digits. Pulse volume, therefore, appeared to be as reliable an indicator of the state of the vascular bed as the blood flow.

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