The George E. Brown Memorial Lecture

Digital Rheoplethysmography

By G. E. Burch, M.D.

T is indeed a great honor to deliver this George Brown Lecture of the American Heart Association. I wish to express my appreciation to the Chairman, other officers, and members of the Section on Circulation for this opportunity. Dr. Brown was responsible in large part for organization of this Section, the oldest and most protein in its interests, covering all phases of science of the circulation regardless of discipline. I have selected to discuss recent studies in rheoplethysmography, firstly, in honor and memory of Dr. Brown, whose main interests were in the peripheral circulation, and, secondly, because the approach is new, the observations, applications and concepts are thought provoking, and, as in any new scientific approach, many problems remain to be solved.

The rate of blood flow to organs and local tissues has interested many investigators for many years. Although methods for measuring the rate of circulation of blood through organs and tissues have varied, the fundamental and standard approach has been that introduced by Brodie and Russell1 and Hewlett and Van Zwaluwenburg.2 These investigators showed that the rate of blood flow to a part, such as the hand, foot, or segment of a limb, or to an organ, such as the kidney, may be recorded by enclosing the part in a rigid plethysmographic chamber connected by rigid tubing to a flexible bellows, which activates a wooden or light lever to record movements on smoked or photographic paper (fig. 1). Any change in volume of the part displaces air or water within the plethysmographic chamber, which, in turn, displaces the flexible bellows an equal volume, and produces a deflection on the recording paper.

This principle of plethysmography has been in use in physiology for many years. These investigators1,2 showed that if venous outflow to the part enclosed in the plethysmographic chamber were suddenly obstructed by a pressure lower than the diastolic arterial blood pressure, the part would increase in volume due to inflowing blood. Since the moving paper records lapse in time and since the linear deflection produced by the recording lever is calibrated in volume change, a volume-time cartesian-type graph is automatically charted. From such a completed record it is possible to obtain the rate of volume change of the part or the rate of inflow of blood to the part (fig. 2). It has been customary to draw a straight line tangentially to the trace and to determine from its slope the mean rate of blood flow to the part. This method of venous occlusion for

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Aided by grants from the U. S. Public Health Service (H143) and the Upjohn Company, Kalamazoo, Mich.


measuring blood flow to a part has been modified considerably during the past 50 years to satisfy various experimental requirements, but all measurements have been limited to estimates of mean rate of inflow of blood to the part. It continues to serve physiologic purposes well and is still considered the procedure by which all other methods are standardized.

Unfortunately, this method has not received critical evaluation; its validity has been mainly inferred. No satisfactory method has yet been devised for its adequate evaluation under the conditions of animal research. In spite of these deficiencies, it can provide useful information concerning the peripheral circulation. Some of the problems inherent in the venous occlusive plethysmographic method have been discussed briefly elsewhere and will not be reiterated here. The magnitude and significance of the problems must be known to the investigator for proper evaluation of his data. Some of the difficulties are evident in published data and reflect errors of variable significance. These and other problems have been considered in these rheoplethysmographic studies and many have been eliminated or controlled. Those that remain require continued attack if the rheoplethysmographic method is to become fully developed and accurate. The main source of difficulty is the volume artifact previously discussed.11

It is not the intention of this report to review historically the technic of venous occlusive plethysmography or to discuss its problems but merely to present the rheoplethysmographic method and to indicate some of its qualitative and quantitative potentialities for the study of the peripheral circulation. The present discussion is limited to the human digit, since the method has been developed and used primarily for the digits of intact man; with relatively simple modifications it can be applied to other organs.

The Rheoplethysmograph

A digital plethysmograph sensitive to a volume change of 0.1 mm. or less and with satisfactory physical characteristics to record volume change accurately has been developed. Many of the problems of leakage, difficulties in usage, and other complications have been eliminated, and the recordings are now technically satisfactory. In addition, a simple electronic method has been designed to occlude digital venous outflow automatically at any preselected period in the pulse cycle for any preselected duration. The rheoplethysmographic apparatus and method from the point of view of the instrument are satisfactory.11

Theoretic Concept

If a digit is enclosed in a lightweight, properly fitted plethysmographic cup (fig. 3) connected to a suitable plethysmograph and if obstruction to venous outflow is suddenly produced, the recording camera being set at a fairly rapid speed to reveal detailed changes, a plethysmogram (fig. 4) will be recorded that presents detailed information not obtainable from the conventional plethysmogram.

As indicated previously, the pressure in the occluding cuff obstructing venous outflow should not interfere with inflow, but, unfortunately, it does to a slight, although probably negligible, extent. Venous occlusion is produced by inflation of a flexible rubber digital
occluding cuff to a pressure of 60 mm. of Hg. Preferably, the occluding pressure should be varied to meet the specific needs of the circulation at the moment of occlusion, but in these experiments a pressure of 60 mm. was used except as indicated.11 With the subject resting quietly in a hospital-type bed in the comfortable atmosphere of a specially designed room11,12 and with the digits resting at heart level on an arm rest, venous outflow in 2RF was suddenly occluded. The completed rhexo-plethysmogram (RPG), as shown in figure 4, reveals simultaneous recordings for the second right fingertip (2RF) and third right fingertip (3RF). The sudden rise in the volume trace for 2RF (fig. 4) was produced by two factors: (1) accumulation of inflowing blood \((I_v)\) within the digit enclosed in the plethysmographic cup and (2) an artifact \((A_v)\). Since the traces for 3RF and 2RF were simultaneously recorded,

any volume change in 2RF can be readily timed in the pulse cycle.

The volume of inflow is obtained by subtracting the volume change produced by the volume artifact \((A_v)\) from the recorded trace for 2RF. This is done by obtaining the curve of the volume-time course of the artifact under the same circumstances as those that existed when the inflow trace for 2RF was recorded. The volume-time course of the artifact is recorded in the following way. The circulation to the arm is arrested by sudden inflation of a blood pressure cuff applied to the brachium with a pressure well in excess of systolic arterial pressure. When the circulation in the digit becomes stabilized, the venous occlusive cuff on the digit is suddenly inflated to a pressure of 60 mm. Hg, and the volume-time course of the artifact \((A_v)\) is recorded (fig. 5). This curve is then subtracted from the volume trace, as

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**Fig. 3.** The plastic, transparent, and lightweight plethysmographic cup and the venous occlusive, or collecting, cuff are shown mounted on the terminal portion of the index finger. The finger or toe tip is defined as that portion of the digit distal to a plane in which lie the major dorsal and palmar or plantar creases in the region of the distal interphalangeal articulation. The digital circulation is diagrammatically shown. When the venous occlusive cuff is suddenly inflated to a pressure less than diastolic arterial blood pressure, inflowing blood is trapped distal to the occluded digital veins within the vessels of that portion of the digit enclosed in the plethysmographic cup, in which the increase in volume of the part is recorded by the plethysmograph.

**Fig. 4.** A rheoplethysmogram showing the simultaneously recorded curves of the volume-time course for the second right fingertip (2RF) and the third right fingertip (3RF) of a normal subject resting in bed in a comfortable atmosphere with the digits at heart level. The recordings are shown at slow and fast camera speeds. The venous occlusive cuff was suddenly inflated to 60 mm. Hg pressure at the arrow 0. The resultant collection of blood in the vessels distal to the occluded digital veins caused 2 RF to increase in volume as indicated by the trace. This \(I_v\) curve actually includes the artifact curve, \(A_v\) (see figs. 5 and 6).
Fig. 5. The artifact volume curve \( A_V \) was obtained by first arresting the circulation to the digits under study by inflation of a blood pressure cuff applied to the arm (brachium), followed by sudden inflation (at arrow 0) of the digital venous occlusive cuff to the same pressure and under the same experimental conditions as existed for the recording of digital blood flow in figure 4. The return of the \( A_V \) curve toward its former level occurred with sudden release of the pressure in the venous occlusive cuff.

![Calculated Volume (I_v) and Rate (I_R) of Inflow](image)

Fig. 6. Method for converting manually the recorded plethysmographic curve of the volume-time course of 2RF, which contains \( I_V \) and \( A_V \), to volume inflow \( I_V \) by subtracting from it the volume artifact curve, \( A_V \). The curve of the recorded rate of inflow \( I_V \) is the first derivative of the \( I_V \) curve. The gradual decline in rate of inflow for the second pulse cycle is due to leakage past the venous occlusive cuff, to a decline in A-V pressure gradient produced by the blood collecting in the digital vessels, or to both these factors.

FIG. 7. This volume pulse wave is the same one shown in figure 6 for 2RF immediately prior to digital venous occlusion. This volume curve represents the time course of the difference \( D_V \) between volume of inflow \( I_V \) and volume of outflow \( O_V \). The pulse wave recorded simultaneously for 3RF, after correction for size of the digit, can be employed interchangeably in these analyses with the pulse wave recorded for 2RF. The similarity of these pulse curves is evident from figure 6.

![Volume-time graph](image)

The result curve representing the volume-time course of inflow \( I_V \) (fig. 6).

Obviously, the accuracy of the \( I_V \) curve depends upon the accuracy of the artifact curve, still a minor problem in the method, discussed more fully elsewhere. If the procedure is employed carefully, the artifact can be fairly accurately recorded and subtracted, especially if the first 0.20 second after application of the digital occluding pressure is disregarded and only the remainder of the trace is employed.

Since the volume pulse wave (fig. 7) is recorded simultaneously with the inflow trace \( I_V \) and represents the time course of the difference \( D_V \) between the volume of inflow \( I_V \) and volume of outflow \( O_V \), then:

\[
D_V = I_V - O_V. \tag{1}
\]

Since \( D_V \) and \( I_V \) are actually recorded, the time course of the volume of outflow \( O_V \) is obtained by subtracting \( D_V \) from \( I_V \), or:

\[
O_V = I_V - D_V. \tag{2}
\]

\( D_V \) is recorded for 3RF simultaneously with the time course of inflow \( I_V \) for 2RF. If it is assumed that \( D_V \) of 3RF, after correction for size of the digit, is the same as for 2RF, then \( D_V \) for 3RF may be subtracted from \( I_V \) for 2RF to obtain \( O_V \) for 2RF. Or, if a suitable \( D_V \) trace recorded for 2RF for the pulse cycle immediately preceding occlusion to venous outflow may be used to obtain \( O_V \) for 2RF. No significant difference was observed in these two methods when they were properly used. In these experiments the \( D_V \) curve for the same digit recorded just before venous occlusion was used to obtain the \( O_V \) curve for that digit. Thus, whereas in the strict sense the \( I_V \), \( O_V \), and \( D_V \) curves so obtained are not simultaneously recorded, they may be so considered under proper conditions. Three such volume curves are shown in figure 8. This venous occlusive plethysmographic method for obtaining continuous volume inflow and outflow curves for a single pulse cycle has been called plethysmography.
example, since they are continuous throughout the pulse cycle and since the volume pulse wave \( D_V \) is recorded simultaneously, any phase of inflow or outflow may be related to any moment in the pulse cycle and, in turn, to the corresponding cardiac cycle. Furthermore, changes in inflow can be related to outflow and changes in outflow to inflow.

Since inflow occurs by way of the arteries supplying the part, the inflow curves reflect the behavior of the arterial side of the circulation, and since outflow occurs by way of the veins, the curves of outflow reflect the behavior of the venous side of the circulation. By integration of such principles with others in rheoplethysmography and plethysmography, these approaches can be extended much further to the understanding of the peripheral circulation. Some of these applications to normal and abnormal physiologic processes in the peripheral circulation are presented in this lecture.
primarily to illustrate the potentialities of this method in the study of the intact circulation in an organ such as the digit rather than to define aspects of the circulation for any particular circulatory state.

In association with Mr. J. A. Cronvich, a new electric type of rheoplethysmograph (fig. 11) was developed\textsuperscript{15} that makes it possible, by means of transducers,\textsuperscript{*} suitable circuits, and a group of nine galvanometers,\textsuperscript{†} to record simultaneously and automatically the rheoplethys-

\* Two pressure transducers, model PT-5, of high sensitivity for digital plethysmography, each with 2 and 10 mm.\textsuperscript{3} volume calibration plugs, obtained from the Grass Instrument Company, Quincy, Mass.

\textsuperscript{†} Nine type 7-288 galvanometers, natural frequency, 150 c.p.s., 1 type 5-116P4-9 recording oscillograph, 9 trace capacity for operation from 115 v., 60 cycle source, obtained from CEC Instruments, Inc., Pasadena, Calif.

mographic volume ($R_v$) and rate curves ($R_r$). A typical record is shown in figure 12. All rheoplethysmograms presented in this report were obtained with this recorder. Methods for obtaining the dimensions of the digits, standardizing the galvanometers, correcting for size of the digit and converting the data to proper units have been discussed in detail elsewhere.\textsuperscript{11, 14}

**Selected Applications of Digital Rheoplethysmography**

**Basal Component of Digital Flow**

It has been of interest for some time to know the basal component of the rate of the pulsating digital blood flow, upon which is superimposed the complemental pulsating increases in flow in association with the heart beat. The basal component in figure 9, for example, is obtained simply by noting the rate of flow at $t_s$ or onset of the pulse cycle in the $I_r$ curve (30 cu. mm./5 ml. part/sec.). Upon this basal rate of flow is superimposed the complemental pulsatile and more rapid rate produced by the heart beat (figs. 13 and 14). The relative roles of the energy from the heart and from the recoil of the vascular walls require study. It has been found that the basal rate of flow is high when the subject is in a hot and humid atmosphere, tends to be low in aortic insufficiency, falls below that at heart level when the part is ele-
Fig. 12. A normal rheoplethysmogram recorded with the new electrorheoplethysmograph. The volume and rate curves and changes in the total or over-all volumes of the two digits are recorded automatically and simultaneously. The scales for the volume (Rv) and rate curves (Rf) are shown; the ordinate values of rates are 10 times the ordinate values of volume. The ordinate values of the traces of total volume of the digits are one fifth that of the volume pulse traces. By proper standardization of the recording galvanometers, to correct for volume of the part, the linear deflection represents changes in volume directly in cu.mm./5 ml part and changes in rate directly in cu. mm./5 ml part/sec.

Fig. 13. Curve of the rate of inflow for a normal resting subject. The pulsatile flow is readily divided into the basal component and the complemental component. The slightly lower level for the rate of inflow at the end of the pulse cycle is due to error caused by leakage past the venous occlusive cuff or a decline in A-V pressure gradient resulting from the blood collected in the digital vessels or both these factors.

Fig. 14. Curve of the rate of inflow for the same normal resting subject shown in figure 13, in whom vasoconstriction of the digital vessels was produced by sound of a bell. Comparison of the curve with that in figure 13 shows a decline in rate throughout the pulse cycle, involving both the complemental and basal components of the rate curve or pulsatile flow.

vated 45 cm., is low in Raynaud's disease but high with respect to the maximal rate of flow attained during the systolic phase of the pulse cycle and is decreased by deep inspiration or vasoconstriction produced by psychogenic and neurogenic stimuli, noradrenaline or cold.11, 16-20

The basal rate of flow of the rheoplethysmogram should be studied further for various
normal and abnormal physiologic states of the central and peripheral circulation.

**Mean Rates of Digital Flow**

The mean rates of inflow throughout the pulse cycle are easily determined from the

**TABLE 1.—Clinical and Quantitative Rheoplethysmographic Data of One Normal Subject Studied**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Duration (sec.)</th>
<th>Inflow % Total vol.</th>
<th>Mean rate (cu. mm./5 ml. part/sec.)</th>
<th>Outflow % Total vol.</th>
<th>Mean rate (cu. mm./5 ml. part/sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systole</td>
<td>0.33</td>
<td>60.9</td>
<td>67.6</td>
<td>49.5</td>
<td>54.8</td>
</tr>
<tr>
<td>Diastole</td>
<td>0.52</td>
<td>39.1</td>
<td>27.5</td>
<td>50.5</td>
<td>35.6</td>
</tr>
</tbody>
</table>

**Age** 30 yrs.
**Blood pressure** 90/48
**Finger volume** 3.67 ml.
**Soft tissue volume** 3.14 ml.
**Bone volume** 0.53 ml.
**Surface area** 10.05 cm.

<table>
<thead>
<tr>
<th>Volume inflow per pulse cycle</th>
<th>36.6 cu. mm./5 ml. part</th>
</tr>
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<tbody>
<tr>
<td>Basal rate of digital flow</td>
<td>29.4 cu. mm./5 ml. part</td>
</tr>
<tr>
<td>Mean rate of inflow</td>
<td>43.1 cu. mm./5 ml. part</td>
</tr>
<tr>
<td>Rate of turnover of digital volume at mean rate of inflow</td>
<td>116.0 sec</td>
</tr>
</tbody>
</table>

**Normal, 2RF**

![Graph](http://circ.ahajournals.org/)

**FIG. 15.** Various curves obtained from analyses of the rheoplethysmogram of a normal resting subject.
Vasoconstriction produced by fright, orienting reflex, noradrenalin, or cold reduces inflow to a degree directly related to the intensity of the stimulus. Rates of digital flow too low to record have been produced by exposure of the subject to a cool environment of 12 C. Vasodilatation, accompanied by an increase in rate of digital flow, was produced by a hot and humid environmental atmosphere, reflex vasodilatation to heat, sympathectomy or procaine interruption of the sympathetic nerve supply to the digit, pentapyrrolidinium, or hexamethonium. The mean rate of flow was reduced by the presence of Raynaud's disease, crises of Raynaud's phenomenon, severe congestive heart failure, arteriosclerotic obliterative endarteritis and arterial thrombosis, Leriche's syndrome, scleroderma, and other arterial disease states.

**Complemental Pulsatile Component of Digital Flow**

Superimposed upon an essentially basal rate are the surges in flow that accompany the heart beat, as illustrated in figures 13 and 14. The rheoplethysmogram reveals the time course of these variations and the quantitative and temporal relationships of the $I$, $O$ and $D$ components throughout the course of the pulse cycle. The configurations of these curves varied considerably under various normal and abnormal physiologic states. These relations not only reflect the normal or diseased physio-

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**Fig. 16A.**

**Leriche Syndrome, 2LT**

Before bifurcation graft

<table>
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<th>%</th>
<th>0</th>
<th>50</th>
<th>100</th>
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<tr>
<td>0.4</td>
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<td></td>
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<tr>
<td>0.6</td>
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<td></td>
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<tr>
<td>0.8</td>
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</table>

<table>
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<th>Seconds</th>
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<th>0.4</th>
<th>0.6</th>
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<tbody>
<tr>
<td>$I_V$ (cu.mm./5 cc.part)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_V$ (cu.mm./5 cc.part)</td>
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<td></td>
<td></td>
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<tr>
<td>$D_V$ (cu.mm./5 cc.part)</td>
<td></td>
<td></td>
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</table>

**Fig. 16B.**

**Leriche Syndrome, 2LT**

After bifurcation graft

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<tr>
<th>Seconds</th>
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<tr>
<td>$I_V$ (cu.mm./5 cc.part)</td>
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<tr>
<td>$O_V$ (cu.mm./5 cc.part)</td>
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</tr>
<tr>
<td>$D_V$ (cu.mm./5 cc.part)</td>
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Fig. 16. Various rheoplethysmographic curves for the second toe tip of a subject with the Leriche syndrome (A) before and (B) after graft of aortic bifurcation.
logic state of the circulation but also provide information concerning circulatory function.\textsuperscript{18, 19} A study of these rheoplethysmograms can yield interesting data about the central and peripheral portions of the cardiovascular system, including the result of medical and surgical therapeutic procedures employed in the management of disease states of the cardiovascular system (figs. 15, 16A and B). As stated previously, the associated quantitative changes in the basal and mean rates of flow are revealed in the rheoplethysmograms.

**Selected Quantitative Analyses**

Since the curves of the rheoplethysmogram are continuous, they are obviously subject to many different types of analyses, some of which have only academic interest, whereas others have, in addition, physiologic significance. No effort is made in this lecture to present a complete series of such analyses, only a selected few being included to illustrate possible approaches.

**Time Course of Accumulated Inflow and Outflow as Percentage of Total Digital Inflow and Outflow, Respectively**

The time courses during the pulse cycle of the successive accumulated volumes of inflow and outflow at times $t$ can be expressed as percentages of total volumes of inflow and outflow merely by changing the value of the ordinate of the volume-time course curves ($I_v$ and $O_v$). This is expressed for inflow by the formula:

$$\frac{I_{v_{t}}}{\text{Total } I_{v}} \times 100,$$

where $I_{v_{t}}$ is the accumulated inflow at any time $t$ in the pulse cycle and total $I_{v}$ is the total accumulated volume of inflow during the entire pulse cycle. The same type of formula may be applied to volume of outflow ($O_v$). These curves make it possible to know at a glance the percentage of total digital inflow or outflow that occurred during systole or during diastole or the moment-to-moment course of flow in detail (fig. 15). Their characteristics vary with physiologic variations, being especially different in some subjects with aortic valvular insufficiency, for example.\textsuperscript{16}

**Time Course of Rate of “Turnover” of Digital Blood**

An estimate of the rate of digital blood flow can be expressed as the time required for a volume of blood to flow through the digit that is equal to the total volume of the digit, volume of the digital soft tissue, or volume of the digital bone for the mean rate of flow or for the rate of flow that prevails at any moment during the pulse cycle (fig. 17). This method of expression emphasizes further the rapid rates of digital flow. It is evident from figure 17 that if the maximal rate of flow in that particular pulse cycle were to prevail constantly, a volume of blood equal to the volume of the entire fingertip would circulate through the fingertip in 50 seconds. If the minimal rate of inflow were to prevail, however, 175 seconds would be required for a volume of blood equal to the digital volume to circulate through the digit. Inspection of the curves in figure 17 reveals other interesting details. The higher values at the end of the pulse cycle than at the beginning are the result of a decline in the A-V pressure gradient and possibly leakage past the occluding cuff, factors discussed earlier in this presentation.

Such curves reveal great differences in the peripheral circulation in the normal and various disease states, too numerous to illustrate here. These curves should make possible an approach
to estimation of the state of digital circulatory reserve.

**Time Course of Inflow Remaining as Percentage of Accumulated Blood Flowing in at any Moment in the Pulse Cycle**

The time course of the percentage of accumulated inflowing blood that remains in the digit at any time \( t \) can be calculated from the equation:

\[
\text{% } I_v \text{ remaining} = \frac{I_{v,t} - O_{v,t}}{I_{v,t}} \times 100 = \frac{D_{v,t} \times 100}{I_{v,t}}.
\]  

\( I_{v,t} \text{ and } O_{v,t} \) may be measured at successive 0.05 second periods of time throughout the pulse cycle to produce a satisfactory curve (fig. 15). This curve may serve as a rough index of the duration of time that blood remains in the tissues for purposes of chemical and thermal exchange, but, unfortunately, the blood escaping is not a portion of that entering at the same moment. For example, early in the pulse cycle the subject with aortic insufficiency often retained almost 100 per cent of the inflow, a situation not yet observed in normal man under comparable experimental conditions. These relations between inflow and outflow are considered to represent effects of the critical closing and opening phenomena described by Burton.\(^\text{21}\)

**Time Course of Change in Volume Inflow as Percentage of Total Volume Inflow**

The changes in volume of inflow from one 0.05 second period to the next during a single pulse cycle may be expressed as percentage of total digital inflow during the pulse cycle to learn the time course of the change in volume inflow as percentage of total volume inflow. The values were derived from the expression:

\[
\frac{I_{v_2} - I_{v_1}}{\text{Total } I_v} \times 100, \tag{5}
\]

where \( I_{v_2} - I_{v_1} \) is the inflow from \( t_1 \) to \( t_2 \), measured at 0.05-second intervals in the pulse cycle, and total \( I_v \) is total inflow for the entire pulse cycle.

This ratio is concerned with inflow only and is not influenced by simultaneous outflow. These curves (fig. 15) reveal the time course of the variation in total inflow delivered to the digit during successive intervals in the pulse cycle. For example, during one 0.05-second period almost 10 per cent of the total inflow occurred, whereas less than 5 per cent occurred during most of the other 0.05-second intervals of the pulse cycle. The importance of these quantitative variations in inflow upon the rate of metabolism in the tissues is unknown. The metabolic rate may oscillate in some way with respect to the rate of inflow.

The remarkable aspect of these curves is their striking similarity in magnitude and configuration despite wide variations in normal and abnormal physiologic states, for example, vasoconstriction, vasodilatation, and disease of the cardiovascular system. Apparently the moment-to-moment percentage of total volume of blood flowing into the fingertip during a pulse cycle is fairly constant even in the presence of large variations in peripheral and central circulation.\(^\text{20}\) One of the main exceptions to this general rule was observed in the curves of a patient with aortic insufficiency,\(^\text{19}\) but surely other exceptions exist. Although the maximal value during the pulse cycle was approximately 10 per cent of total inflow for most pulse waves studied and the magnitude of the percentage values was remarkably similar during the same relative moments in the pulse cycle, the maximal value in some subjects with aortic insufficiency was as high as 20 per cent. Many more records must be carefully analyzed to define consistencies and peculiarities in this type of curve.

**General Discussion**

Many other relations and analyses, which may elucidate cardiovascular physiologic phenomena and reveal early pathologic activity, are available in the continuous curves of the rheoplethysmograms (RPG). These simultaneous time-course curves permit a study of temporal interrelations during a pulse cycle, in which the functions of the arterial and venous sides of the digital vascular bed may be differentiated to some extent. Events in inflow
and outflow may be simultaneously correlated at any moment during the pulse cycle. Since the RPG shows the rate of outflow to fluctuate considerably, the venous side of the digital vessels must pulsate correspondingly. These curves readily reveal mean rates and wide variations in basal rates of flow under normal and abnormal physiologic variations, the magnitude of which has been unknown and only conjectured.

The RPG readily shows when leakage past the occluding cuff occurs or when changes in the A-V pressure gradient produce definite errors in measurements of flow, important information for proper quantitative evaluation of the data. The mean rates of digital flow, as measured rheoplethysmographically, are higher than those generally reported by other methods, probably due to elimination of errors caused by leakage past the occluding cuff, decline in the A-V pressure gradient and other factors.

The average rate of flow for the finger of normal man at rest was compared with that for equal volumes of vital organs with known high rates of blood flow (fig. 18) and, under comfortable environmental conditions, was found to be of about the same magnitude as that for the liver, brain, and myocardium of the left ventricle and to be several times the average flow for the whole body. Reasons for this high rate of digital flow are unknown but may be related to thermal regulation, repair of digital tissue, which is almost constantly subjected to physical trauma, and to the large blood supply necessary for tactile sensory function. These sensitive organs may require a rich supply of blood for highly discriminatory function in touch, the fifth sense, so important to man's daily life. The high rate of digital flow varies considerably, practically reaching zero levels when the subject is in a cool atmosphere and rising to high levels when the subject is in a hot and humid environment. Paresthesia of the fingertips in cold environment indicates the importance of adequate circulation to the digits. The "hunting phenomenon," described by Sir Thomas Lewis for cold digits, may reflect an effort to maintain adequate circulation to the digital tactile organs with minimal thermal loss. Such problems require study.

The rheoplethysmographic method requires further development, especially that involving the problem of the artifact and the capacity of the reservoir vessels. It can be of value not only in a study of physiologic phenomena but also in evaluation of drugs and therapeutic procedures concerned with the circulation. By this method actions upon the arterial and venous segments of the circulation can be approached in the intact circulation of man and other animals.

These discussions have purposely avoided the presentation of studies of specific disease states, pharmacologic responses in the cardiovascular system, effects of therapeutic procedures on the cardiovascular system, diagnostic procedures and other physiologic reactions of the cardiovascular system reflected in the RPG, but some such studies have already been reported. No attempt has been made to define the variations and limitations of the normal RPG. However, with existing knowledge of digital plethysmography, calorimetry and thermometry, as well as the behavior of the cardiovascular system, more rapid understanding of rheoplethysmography may be obtained.

Although the great reactivity and variability of the digital circulation has been considered objectionable by some for the study of aspects of the peripheral circulation, these are actually favorable factors and should be exploited.

Fig. 18. Rate of digital flow in normal man compared with rates of flow reported in the literature by others for selected vital organs of man.
Simplicity in use of a digit and its lack of muscle, with separate circulation, is an advantage. Furthermore, the tips of the digits are complex organs that reflect vascular disease early and extensively. The methods of digital rheoplethysmography are simple to employ and are dependable, yet disturb the subject relatively little during the period of study.

For simplification, symbols have been introduced in the field of rheoplethysmography that are simple, obvious, and readily learned.\textsuperscript{11, 18-20} With the development of an electrorheoplethysmograph with difference and differentiating circuits, calculations of the various curves have been simplified or eliminated. However, complex apparatus is not essential; ordinary conventional plethysmographic equipment can be adapted for rheoplethysmography. Regardless of the methods used in digital rheoplethysmography, accuracy and methodic, deliberate approaches must be developed and used for satisfactory results. Errors in the methods, extent of the variations, conditions of the subject and his physiologic state, as well as conditions of the environment and the observations, must be considered for adequate evaluation and interpretation of the data.

Plethysmography, and especially rheoplethysmography, like electrocardiography, requires training, knowledge of the subject, and experience. When properly employed, rheoplethysmography has a great deal more to offer in the study of the cardiovascular system than conventionally employed digital plethysmography, but its value in clinical practice has not yet been established. At present it does not supplant simple clinical procedures; it has only supplementary value, if any at all, in a limited number of subjects in the everyday management of cardiovascular diseases. Its potentialities, however, are evident.

**Summary**

This lecture briefly summarizes the principles of digital rheoplethysmography, which records simultaneously the time course of the volume, rate, and acceleration of inflow, outflow, and difference between inflow and outflow for a single pulse cycle, as well as the basal rate of flow. The mean rate of flow during a single pulse cycle is readily obtainable. Although problems remain to be solved, the method introduces a new approach to a quantitative analysis of the peripheral circulation of intact man. A specially constructed electrorheoplethysmograph permits simultaneous recording of nine traces and reduces considerably the need for manual construction of curves and calculation of data.

Rheoplethysmography permits a study of normal and abnormal physiologic states of the peripheral circulation, with its pharmacologic responses, in intact man and makes possible simultaneous study of the arterial and venous sides of the circulation. It can be applied to organs other than the digits of man.

**SUMMARIO IN INTERLINGUA**

Iste discuro summaris brevemente le principios de rheoplethysmographia digital, que registra simultaneemente le curso temporal del volumine, prorata, e acceleration de influxo, effluxo, e diferentia inter influxo e effluxo pro un sol cyclo pulsar como etiam le prorata basal del fluxo. Le prorata median del fluxo durante un sol cyclo pulsar es facilmente obtenibile. Ben que il ha problemas que remane a resolver, le metodo introduce un nove base pro le analyse quantitative del circulation peripheric de humanos intacte. Un specialmente construite electrorheoplethysmographo permette le registration simultanea de 9 traciaimentos e reduce considerablemente le necessitate del construction manual de curvas e del calculation de datos.

Rheoplethysmographia permette le studio de normal e anormal statos physiologic del circulation peripheric (con su responsas pharmacologic) in humanos intacte e rende possibile le studio simultanea del aspectos arterial e venose del circulation. Illo pote esser applicate a organos altere que le digito de humanos.

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Circulation. 1956;13:641-654
doi: 10.1161/01.CIR.13.5.641
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/13/5/641.citation

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