Rationale of Venous Occlusion Plethysmography

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The experimental evidence reported here supports the validity of venous occlusion plethysmography.

Since Hewlett and van Zwaluwenburg modified the technic of Brodie, venous occlusion plethysmography has been widely employed to estimate blood flow in fingers, toes, and limbs. Several excellent comprehensive reviews of the technical pitfalls of the method are available. The validity of the venous occlusion technic of plethysmography rests upon four basic assumptions: (1) that the application of the pneumatic collecting cuff pressure does not affect arterial pressure or inflow, (2) that complete venous tamponade is effected for a finite period, (3) that the resulting increase in venous pressure does not initially reduce the rate of arterial inflow, and (4) that the impounded blood causes the segment under study to swell proportionally to the rate of arterial inflow without significant displacement of tissue or body fluids from the plethysmograph. Adequate evidence exists concerning the first point. The studies to be described were designed to test the other three points.

Methods

A water displacement plethysmograph with a strain gage sensing unit was used for the measurement of segmental forearm blood flow in human subjects, all of whom were adult males without evidence of cardiovascular disease. A PE50 catheter was inserted through a thin-walled no. 18 needle into the brachial artery of the forearm under study. Another PE50 catheter was similarly introduced into a superficial vein of the forearm segment. Simultaneously with the plethysmogram brachial artery and venous pressures were measured with Statham strain gages and recorded on a Sanborn multichannel recorder.

For the purpose of testing the competence of the collecting cuff, the leakage of an indicator substance past the cuff was correlated with simultaneously recorded venous pressure in the obstructed area of forearm. For this purpose 20-40 μc. of I\textsuperscript{131} human serum albumin were injected into a dorsal hand vein following which the collecting cuff was suddenly inflated. On one occasion the I\textsuperscript{131} injection was made into the radial artery. The forearm below the collecting cuff was carefully screened by means of several layers of \(\frac{1}{2}\)" lead sheeting. Preliminary phlebograms using Diodrast and the Fairchild camera demonstrated that injection into a superficial hand vein results in deep vein filling and that the earliest evidence of gross leakage is in the basilic vein. Accordingly, a scintillation counter was placed over the confluence of the cubital and basilic veins in such a position that it would monitor the entire cross-section of the arm just proximal to the pneumatic cuff. Counting was recorded through a TMG decade scaler on the Sanborn recorder.

The relationship between the volume of the arterial inflow and the degree of recorded swelling was tested in experiments on two 20 Kg. mongrel dogs. The hind legs were completely disarticulated at the hip with the exception of the femoral artery and vein. All branches of the femoral artery proximal to the segment to be measured were interrupted. The animal was heparinized in a dosage of 4 mg./Kg. of body weight. A T-cannula was inserted into the artery and connected to a burette of 0.8 mm. internal diameter. A strain gage sensing unit was affixed to the bottom of the burette and calibrated to provide a flow meter which would accurately record the loss in hydrostatic pressure as blood flowed out of the burette. Blood was introduced into this flow meter from the dog's circulation. With the cardiac side of the femoral artery clamped, it was possible to perfuse the leg at a known rate of blood flow and at a constant pressure. This measurement was correlated with simultaneously recorded plethysmographic measurement of flow. The same plethysmographic equipment was used as in the human experiments and the pneumatic cuffs were placed about the dogs' legs in the same fashion.

Results

Eight injections of 20-40 μc. of I\textsuperscript{131} human serum albumin were made into the dorsal hand veins of 6 subjects. An injection of 20 μc. was made into the radial artery of another subject.
Background activity was recorded for several minutes prior to the injection of the radioactive indicator. Venous leakage was indicated by an abrupt increase in radioactivity over the background level. In no instance could venous leakage past the occluding cuff be detected.

![Figure 1](image1)

**Fig. 1.** Incidence of scintillation counts (X10) (upper line) following injection of 20 μg. I\(^{131}\) human serum albumin into a dorsal hand vein at A, in relation to rise of venous pressure following application of pneumatic cuff pressure at B. Note that venous leakage occurs when venous pressure equilibrates with cuff pressure. *Ordinate*, venous pressure in mm. Hg; *abscissa*, time in seconds.

![Figure 2](image2)

**Fig. 2.** The relation of flow in ml./min. (*ordinate*) to decrements in mean arteriovenous pressure gradient produced by increasing venous pressure (*abscissa*). Note the two distinct phases of the pressure/flow curve.

![Figure 3](image3)

**Fig. 3.** Diagram illustrating maximum error encountered in 8 plethysmographic determinations of flow. Perfusion pressure constant at 100 mm. Hg. One hundred per cent line, metered inflow; broken line, average of 8 plethysmographic estimations of flow.

until the time that venous pressure equilibrated with the effective occluding cuff pressure (fig. 1).

Nine pressure-flow curves were constructed from experimental data obtained from 5 subjects. During the 10–30 sec. required by each observation arterial pressure remained essentially constant. Visual integration of these curves permits estimation of arterial inflow rates for a series of arteriovenous pressure gradients in which all decrements are produced by an increase in venous pressure (fig. 2). The arterial inflow is very little affected until venous pressure has risen from 4–12 mm. Hg over the resting value. There is then a sharp break in the curve which descends steeply in a straight line fashion toward interception of the pressure axis at a positive value between 40 and 85 mm. Hg.

Four determinations of flow were made in each of the two canine hind limbs which were tested. In general the agreement between metered and plethysmographically estimated flows was 96 per cent of the metered inflow. In only one instance did the plethysmograph record more than the actual inflow (+6 per cent). The greatest plethysmographic error was −10 per cent (fig. 3).
DISCUSSION

The I\textsuperscript{21} experiments quite conclusively demonstrate the efficiency of venous tamponade. Although it is not possible to estimate with accuracy the degree of dilution of the indicator by blood, an injection of as little as 0.5 µc. of the indicator into the unoccluded arm was grossly apparent as it passed the counter. Therefore it is quite unlikely that undetected venous leakage occurred.

The pressure-flow curves are of great interest. The initial flat slope shows a decrease in resistance as venous pressure begins to rise. Our data do not demonstrate where or how this comes about. The most likely explanation is that it results from dilatation or distension of the arteriolar bed. However, the straightness of the initial slope of the plethysmogram permits the estimation of preocclusive arterial flow. The second phase of the pressure-flow curve, namely the sharp decline toward the positive pressure axis, demonstrates a marked and progressive increase in peripheral resistance and strongly suggests active arteriolar constriction. The mechanism by which this occurs is not illuminated by our experiments. It could result from a venousvasomotor reflex\textsuperscript{6} or it could be the result of myogenic activity.\textsuperscript{7}

The good agreement of metered and of plethysmographically estimated arterial inflow is gratifying, particularly since great effort was made to reproduce in the animal experiments the conditions under which the plethysmograph is employed in human forearm measurements.

SUMMARY

Three of the 4 basic assumptions of venous occlusion plethysmography have been experimentally validated: Competent venous tamponade is effected by the pneumatic collecting cuff; venous tamponade does not initially decrease the rate of arterial inflow; and directly metered and plethysmographically estimated rates of blood flow agree satisfactorily.

It is the authors’ opinion that venous occlusion plethysmography permits satisfactory estimation of segmental forearm flow under normal hemodynamic conditions.

SUMMARIO IN INTERLINGUA

Tres del 4 premissas fundamental de plethysmographia de occlusion venose esseva confirmate experimentalmente: (1) Competente tamponage es effectuate per le pneumatic manica de collection, (2) tamponage venose non produce initialmente un relentation del influxo arterial, e (3) mesurationes directe e estimationes plethysmographic del fluxo de sanguine es satisfactoriamente de accordo.

Le autores opina que plethysmographia del occlusion venose permitte un estimation satisfactori del fluxo antibrachial segmental sub normal conditiones hemodynamic.

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