An Analysis of Oscillometric Pulsations

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The absolute lack of correlation of oscillometric pulsations with blood flow through vessels is demonstrated. The pulsations obtained are shown to depend primarily on the operation of simple hydrodynamic laws. A modified technic for oscillometric examination which gives a qualitative measure of normal blood flow through vessels is suggested.

The oscillometer has been utilized for several decades for the determination of the arterial blood pressure and for the assay of the vascular efficiency of the extremities. Its use in the measurement of the blood pressure has declined because of the greater simplicity and accuracy of the auscultatory method of Korotkoff.

The oscillometer has been reported to be helpful in ascertaining the level of arterial occlusion and in determining the site of arteriovenous fistulas. A diminished oscillometric reading is said to indicate a disturbance of arterial inflow. In some instances, however, an increase in oscillometric readings may occur in the presence of a decrease in arterial flow. Moreover, strikingly diminished oscillometric readings do not necessarily imply that the local blood flow is markedly impaired. In fact, the reverse may be true. Thus the oscillations sometimes are negligible in cases in which the circulation of the extremities has been found to be good.

Because of these contradictory findings the practical application of the oscillometer for the purpose of estimating the "vascular efficiency" in peripheral arteriosclerotic disease has often proved disappointing. Simple palpation and inspection of the extremities often give more adequate and reliable information than can be obtained from the instrument.

Data obtained in the course of our recent hydrodynamic studies suggested an explanation for these paradoxical relationships between blood flow into an extremity and the amplitude of pulsation. Studies on man were undertaken to establish whether these hydrodynamic principles could be applied to the analysis of oscillometric pulsations.

Methods

Studies were made on 25 unselected patients in the wards of the Michael Reese Hospital. The oscillometer cuff was placed over the proximal portion of the upper arm. The cuff pressure was raised to a level above the systolic pressure and then lowered by increments of 10 mm. Hg. Oscillations of the indicator needle were noted and recorded at each step. Then reactive hyperemia was induced and the observations repeated. Finally the flow of blood distal to the cuff was obstructed by a tourniquet cuff and the observations again repeated.

Results

1. Control Study

Oscillations were minimal when the oscillometric cuff pressure was above systolic pressure. They increased progressively as the cuff pressure fell, becoming maximal at about 20 mm. Hg above the diastolic pressure as determined by the auscultatory technic (fig. 1); the pulsations then diminished and, at a level below diastolic pressure, they became indiscernible. These findings are in accord with previous reports by others.

2. Reactive Hyperemia

In this series, the pressure in the oscillometric cuff was raised initially to 250 mm. Hg. The patient was then instructed to open and close the fist of this arm 50 times in 35 seconds. At the conclusion of this exercise the pressure in the cuff was dropped progressively as in the control readings. Under these circumstances
the oscillations were essentially of the same order as those observed during the control period (fig. 2).

It is generally accepted that immediately after a period of occlusion of the blood supply to an extremity, associated with exercise, a marked increase in blood flow through the part is seen. Despite this, the oscillations were affected little if at all. These results demonstrate clearly that there is no simple relationship between oscillometric pulsations and blood flow through the arterial segment under the cuff.

3. Tourniquet

In this series the oscillometric cuff was in place as in the experiments reported above. A second tourniquet cuff was placed on the arm immediately distal to the oscillometric cuff. This tourniquet cuff was inflated to 250 mm. Hg and maintained at this level during the entire oscillometric recording. Under these circumstances of limited peripheral flow, the pulsations were found to be on the average somewhat greater than when the onward flow of blood could occur (figs. 1 and 2).

These experiments support the concept that the amplitude of the oscillometric pulsations may be entirely unrelated to the amount of blood flowing through the vessels under the cuff. In fact it would appear that under certain conditions of occlusion of the distal vessels there is actually an inverse relationship. This paradoxic effect appears to be due to the operation of physical laws governing flow through elastic tubes, as will be discussed below.

4. Model Experiments

In an effort to determine the effects of flow of fluid through elastic vessels a hydraulic analog was used. This consisted of a segment of soft rubber (Penrose) tubing attached at one end to a column of water (fig. 3). The soft tubing was enclosed in a glass-cylinder plethysmograph so that its volume might be measured. Measurements were made of the volume of the segment under several conditions of pressure and flow.

(a) Static Experiments. Volume measurements were made when the outflow from the

![Figure 1](http://circ.ahajournals.org/)

**FIG. 1.** Oscillometric pulsations obtained in a subject without apparent cardiovascular disease. The continuous line C gives control pulsations in arbitrary units for various levels of cuff pressure. The broken line O gives pulsations obtained when a tourniquet obstructing the flow of blood was placed immediately distal to the oscillometer cuff. Discussed in text.

![Figure 2](http://circ.ahajournals.org/)

**FIG. 2.** Average deviations from control oscillometric readings obtained after exercise or sustained occlusion in 25 unselected subjects. Solid line gives deviations from control after exercise. Broken line gives deviations from control during occlusion by tourniquet. Dots represent actual average values; lines are approximated to the dots.
segment was obstructed by a stopper. Under these static conditions the effect of a rising head of (arterial) pressure, as expected, caused progressive dilation of the segment.

(b) Flow Experiments. Data on the volume of the Penrose tubing were also obtained during conditions of unobstructed flow through the tube. The volume of the segment was found to be less for each level of head of (arterial) pressure than that obtaining when the outflow was obstructed (fig. 4). These experiments illustrate the fact that for a given head of pressure the volume of an elastic vessel is greater when there is no flow through it than when flow is taking place.

**DISCUSSION**

In our approach to the problem of oscillographic pulsations, we have considered the physical laws involved in flow through elastic vessels. In accordance with the principle of conservation of energy (Bernoulli), the force provided by a given head of pressure may be considered to be the sum of two related manifestations of energy (fig. 5). One of these is the lateral pressure energy expanding the walls of the vessels. The second form of energy is that manifested in the movement of fluid through the tube, kinetic energy. When one of these increases for a given head of pressure, the other must decline.

Oclusion of the vessels below the point of measurement reduces the flow through the vessels under the cuff to a minimum. The reduction in the kinetic energy of flow, therefore, results in an increased lateral pressure. This actually occurred during the tourniquet experiments as shown in figures 1 and 2. In figure 1 the increased pulsation is especially notable in the same range in which it is greatest under ordinary control conditions.

In figure 2, the average control values in all 25 subjects are subtracted from those obtained after exercise or during occlusion. As the pressure in the oscillographic cuff is lowered the pulsations in the occlusion experiment become progressively greater than the control values. This finding is in accord with the interpretation that the presence of flow through the part

**Fig. 3.** Schema of model experiment. In the design on the left a constant pressure head maintained in the reservoir causes distention of an elastic tube illustrated as the rounded segment. On the right, the same pressure head is maintained but flow is permitted to take place; the elastic segment is now shown to be less distended or even narrowed by the high velocity of the stream. Discussed in text.

**Fig. 4.** Volume changes in a segment of Penrose tubing produced by flow at various pressure heads. As in figure 2, the values represent the difference between those with flow (control) and those without flow (tourniquet). The abscissa represents multiples of 0.01 cc. Discussed in text.
diminishes the degree of pulsation for a given head of pressure and resistance. At any given pressure head, the arithmetic difference in the degree of pulsations between control and occluded conditions may thus be qualitatively related to the rate of volume flow through the part.

![Diagram](image)

**Fig. 5.** Schema to illustrate principles involved in changes in volume. With normal flow (upper figure) kinetic energy is represented by the long horizontal arrow, while lateral pressure energy is represented by the vertical arrows operating against the wall. Obstruction of flow (middle figure) causes a redistribution of energy so that none is expended in velocity; more energy therefore becomes available as lateral pressure (vertical arrows). The horizontal arrow simply expresses a static pressure exerted against the stopper. Increased flow through the vessel (lower figure) provides a greater total energy. Most of this is utilized in the kinetic energy of flow, illustrated by the two horizontal arrows. The lateral pressure energy component may vary somewhat or even be unchanged (vertical arrows). Discussed in text.

At the upper end of the curve in figure 2, with oscillometric cuff pressure above systolic, the pulsations obtained under conditions of occlusion can be seen to be less than those obtained under control conditions. It is possible that this effect is due to the following circumstances: We have shown that flow through the arteries under the cuff occurs even though the cuff pressure is at or even above systolic pressure. Under control conditions, without the presence of the tourniquet cuff, the blood passing into the vessels under the oscillometric cuff during systole can move on during diastole and leave the vessels relatively empty. With each systolic pulse a small amount of blood enters the vessels and provides a slight pulsation. When a distal tourniquet cuff is in place, it may be assumed that the arteries between the oscillometric cuff and the tourniquet cuff become progressively filled with blood and become turgid due to a "valve action" of the oscillometric cuff. As a result the pulsations become reduced in the arteries under the distal portions of the oscillometric cuff.

Conditions are different when the oscillometric cuff pressure falls below systolic pressure in that the blood passing through to the arteries between it and the tourniquet cuff can spill back during part of the cycle into the arteries under the oscillometric cuff and those central to it. Hence, the turgidity of the vessels, present when the pressure of the oscillometric cuff is higher, is lessened or avoided.

It is of some interest that previous reports have called attention to the paradoxic findings sometimes seen in obliterating arteritis or in arterial embolism. In these, the pulsations of the oscillometer may be greater than the pulsations normally obtained at the same site, or in the normal contralateral limb. These clinical findings bear a striking resemblance to our present studies. They demonstrate that the degree of pulsation is certainly unrelated to the delivery of blood to the more dilated part of the limb.

The situation obtaining in reactive hyperemia is more complex but nevertheless bears on the present argument. Exercise of an occluded extremity causes the local release of vasodilator substances, producing a vasodilation in the part. An augmented flow into the arm may therefore take place even though the arterial pressure remains unchanged. Despite the increased total energy available because of the increased volume of blood passing through the segment of artery, most of this energy is utilized in the increased velocity; the lateral
pressure component may change little if at all (fig. 5). The increased inflow into the arteries under the cuff runs off easily against the reduced resistance in the more distal vessels.

Our results indicate that consideration of hydrodynamic laws may be of value in the analysis and interpretation of oscillometric data. The pulsations of the artery provide an index of the fluctuations of energy available for stretching the walls of the vessel at any given instant. A reduction in velocity, as produced in our tourniquet experiments, permits more energy to become available as lateral pressure and this is expressed as an increase in the degree of the pulsations. The increase in the degree of pulsations is qualitatively related to the normal blood flow through the part. Extension of these findings may make it possible to interpret oscillometric pulsations more satisfactorily and assist in adapting the instrument to the estimation of the volume flow of blood to the extremities.

SUMMARY

Oscillometric pulsations were measured over the upper arm of 25 unselected patients. A tourniquet was then placed immediately distal to the oscillometric cuff. Under these conditions of reduced flow into the arm, the oscillometric pulsations were increased. After the induction of reactive hyperemia with an increased flow of blood through the arm, the pulsations were little affected.

These data are discussed in terms of hydrodynamic laws affecting the partition of the available energy between that producing lateral pressure and that producing movement of the blood. The enhanced pulsations in the tourniquet experiments are seen as a conversion of kinetic energy to lateral pressure.

SUMARIO ESPAÑOL

La absoluta falta de correlación entre pulsaciones oscilométricas y la circulación de sangre por los vasos se demuestra. Las pulsaciones obtenidas se demuestra que dependen principalmente en la operación de sencillas leyes hidrodinámicas. Una técnica modificada para el examen oscilométrico que proporciona una determinación cualitativa de la circulación de la sangre por los vasos se sugiere.

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