THE AUGMENTATION OF PERIPHERAL ARTERIAL BLOOD FLOW BY THE USE OF A VALVE*

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The modern era in the quantitative measurement of phasic blood flow patterns may be said to have begun with the development of the differential pressure recorders. Of these, the orifice meter has, perhaps, been used most extensively by investigators.[1, 2] In 1943, Shipley, Gregg, and Schroeder reported their studies of blood flow patterns in peripheral arteries using this instrument.[2] They and other investigators have shown that in many of the larger vessels such as the common carotid, axillary, coronary, and femoral arteries there is a significant backflow which occurs in the latter part of systole.[2-5]

Figure 1 is a reconstruction of the femoral arterial pressure pulse, *P*, and the flow pattern, *F*, in the femoral artery of an anesthetized dog. The flow

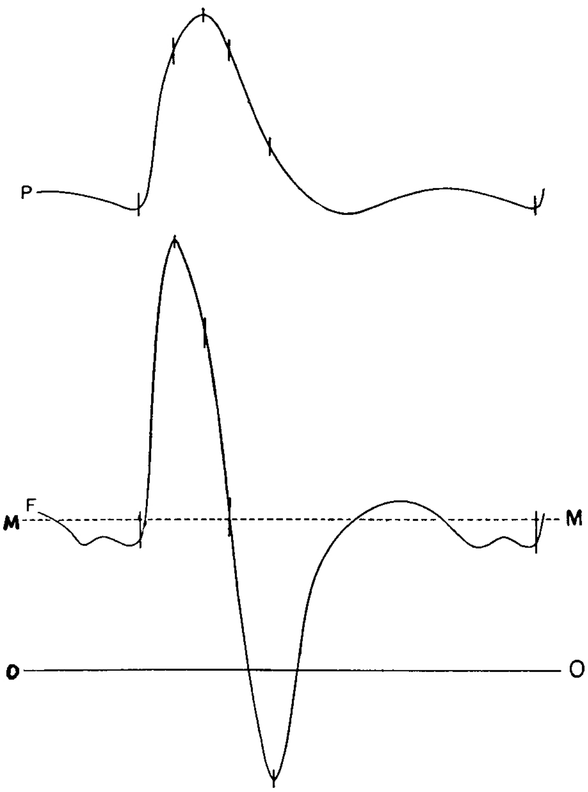

Fig. 1. Simultaneous pressure and flow curves from a dog's femoral artery. *P*, Arterial pressure; *F*, arterial flow; dotted line *MM*, mean flow; line *OO*, zero flow. After Shipley, Gregg, and Schroeder.[2]

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pattern represents the direction and velocity with which blood passes a point in the femoral artery. The dotted line, *MM*, represents the mean flow and line *OO* represents 0 flow. The pressure and flow start to rise simultaneously. The flow reaches its maximum forward velocity before the pressure reaches its peak. Then the forward velocity of the flow begins to decrease. After the peak in pressure has been reached and begins to fall, the forward velocity of the blood flow continues to fall rapidly until it reaches zero. It then reverses its direction, and during the latter part of systole and the beginning of diastole, the blood flows toward the heart in this artery. In the early part of diastole, this backward flow is reversed and the blood again resumes its forward direction, i.e., away from the heart. What this means essentially is that during the early part of systole, when the pressure is rising very rapidly in the proximal portions of the femoral artery, more blood is forced into the arterial system of the leg than can run off peripherally through the capillary bed. Therefore, during the latter part of systole when the pressure is dropping centrally some blood must reflux back up into the abdominal aorta.

It occurred to one of us (A.K.) that if it would be possible to eliminate or, at least, reduce this backflow without affecting the forward flow appreciably, the mean forward flow would be increased. If the blood were to be trapped by some sort of a check valve in the distended femoral arterial system, after it had flowed in under this high pressure, the total mean forward flow should be increased by the amount that was trapped and would normally reflux centrally. If the valve were to close during the latter part of systole, when the pressure is falling rapidly (owing to the reflux of blood centrally), one would expect that the diastolic pressure would be maintained. This would be similar to what happens at the aortic valve when the diastolic pressure in the aorta is maintained at higher levels than that in the left ventricle. If the diastolic pressure were maintained, then the mean pressure would be increased. From Poiseuille's law[6] one would expect that if the mean pressure in the leg were maintained at a higher level, then the mean flow should be greater.

METHOD

A series of acute experiments was done in anesthetized adult mongrel dogs in order to test the validity of this hypothesis. The experimental setup is diagrammatically illustrated in Figure 2. The left femoral artery was dissected free for a length of about 5 cm. in the groin. The artery was then severed and 2 cannulae were inserted: one in the proximal end of the artery in such a position as to receive all of the blood from the femoral artery; the other in the distal segment of the artery in such a position as to deliver all of the blood to the peripheral portion of the animal's leg. From the proximal cannula the blood was led to a Y-tube. In one limb of the Y-tube, a fast-acting valve was inserted in such a fashion so as to permit blood to flow only in the direction toward the periphery; that is, it did not permit any backflow. The other limb of the Y-tube contained a stopcock arranged so it was possible to shut it off at will. A second Y-tube rejoined the streams and the blood was led to an orifice meter. At this point the pressures and the flows were recorded. From the orifice meter, the blood was returned to the distal cannula and continued on its way peripherally to the tissues of the leg. By leaving the stopcock open in limb 2, it was possible to study the normal pressures and flows in the dog's femoral artery, as others have done. By closing the stopcock in limb 2, the blood circuit was made to pass through the check valve. This afforded us an opportunity to record and compare the pressures and flows through the dog's femoral artery, with and without a valve in the circuit. The experimental and control observations were made

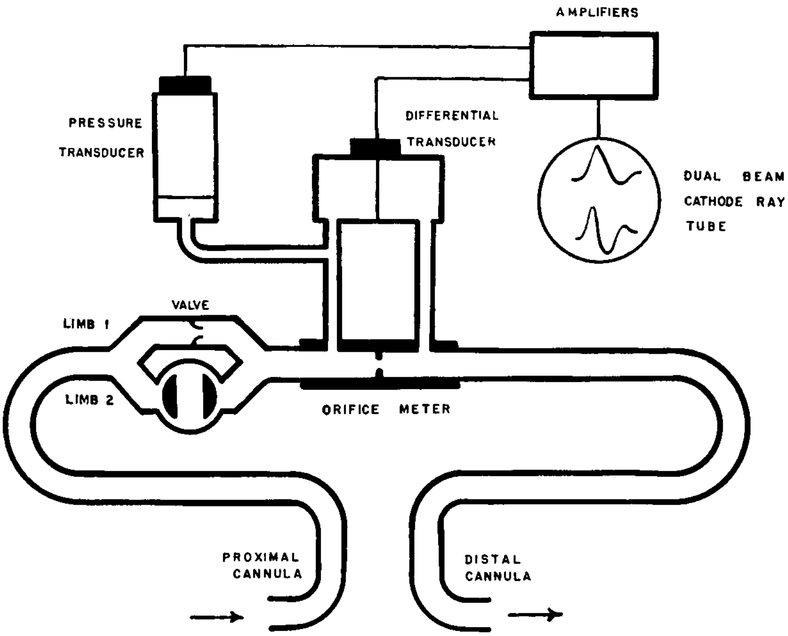

Fig. 2. Diagram of experimental setup for femoral arterial inflow studies (see text).

a few seconds apart. Thus, it was possible to compare the flows through the dog's leg with a valve in the femoral artery, to the flow without a valve, in the same animal under almost identical conditions.

RESULTS

It was possible to make 47 separate, controlled observations in these animals. In all cases, the mean flow was greater into the dog's leg with the valve in place, as compared to the control observations when the valve was not in place. Sections of a typical record of one of these experiments, using this setup, are shown here in Figure 3. The upper curves depict the femoral artery pressures. The middle curves are the recorded flows in cc. per minute, and the lower curves are reconstructions of the recorded flow on linear coordinates. Section *A* shows the simultaneous pressure and flow curves under the control conditions. Section *B* shows the simultaneous pressure and flow curves with the valve in place. Section *B* was recorded 7 seconds after section *A*. The mean pressure in section *A* is 94 mm. Hg. The mean pressure in section *B* is 117 mm. Hg, an increase of 24 per cent. The mean flow in section *A* was 25 cc. per minute, and the mean flow in section *B* was 38 cc. per minute, an increase of 52 per cent. One can see in section *B*, where the valve is in place, that the valve closes about halfway down on the falling limb of the pressure curve, and following this, it maintains the diastolic pressure at a higher level throughout the rest of diastole than in the control curve. In the flow curve, this has the consequence of decreasing considerably the backflow region and the over-all effect of increasing the mean forward flow.

A second series of experiments was done in 3 dogs in order to be certain that not only is the arterial inflow into the leg increased by inserting a valve into the artery, but that the venous outflow is also increased. To do this, the setup diagrammatically illustrated in Figure 4 was used. It is similar to the arrangement previously used except that the orifice meter and differential transducer were removed and the flow was studied by collecting the blood returning from the leg via the femoral vein. A steel cable tourniquet was applied around the animal's leg in these experiments in such a fashion as to

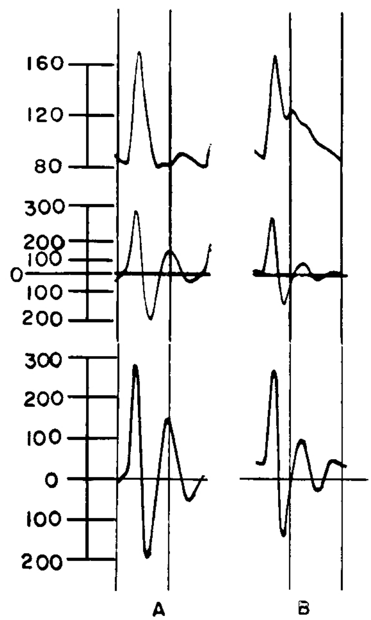

Fig. 3. Segments from record in dog No. 6-20. Upper curves represent femoral artery pressures in mm. Hg; middle curves, phasic flow as recorded with an orifice meter in cc. per minute; lower curves, reconstructions of phasic flow curves on linear ordinates. Section *A* is control flow; section *B* is flow with valve in femoral artery circuit. Time lines represent 0.02 seconds. Flow is 52 per cent greater with valve in circuit.

assure that all blood entered the leg through the femoral artery and external blood circuit and, after passing through the leg, was able to leave only through the femoral vein which was cannulated. All blood collected by the cannula in the femoral vein was allowed to pour freely into a 25 cc. burette. As the blood level in the burette rose, the pressure on the transducer at the bottom of the burette was increased and this was recorded on the cathode ray tube. The rate of increase of the weight of the blood in the burette was proportional to the rate of flow. At no time was more than 25 cc. of blood removed from the animal. After an observation, all blood collected in the burette was returned to the animal by way of an intravenous infusion in the other leg. It was possible to record pressures, as was done in the previous experiment, by placing a transducer in the external arterial circuit. Again normal flows could be recorded by opening the stopcock, and flows with a valve in place could be recorded by closing that stopcock. Eighteen separate observations were made. Again in all cases, the flow was greater with the valve in place than under the control conditions.

The record of a typical experiment is illustrated in Figure 5. The upper tracings are the pressures in millimeters of mercury. The sloping line across the lower portion of section *B* is the flow curve. Section *A* is the contour of the pressure curve with the valve in place. The point can be observed at which the valve closes with the consequent maintenance of the diastolic pressures at higher levels than the control pressure curve seen in section *C*. Section *B* was recorded at a slower paper speed than that in sections *A* and *C*. In the first half of section *B*, the valve is in place. The valve is removed

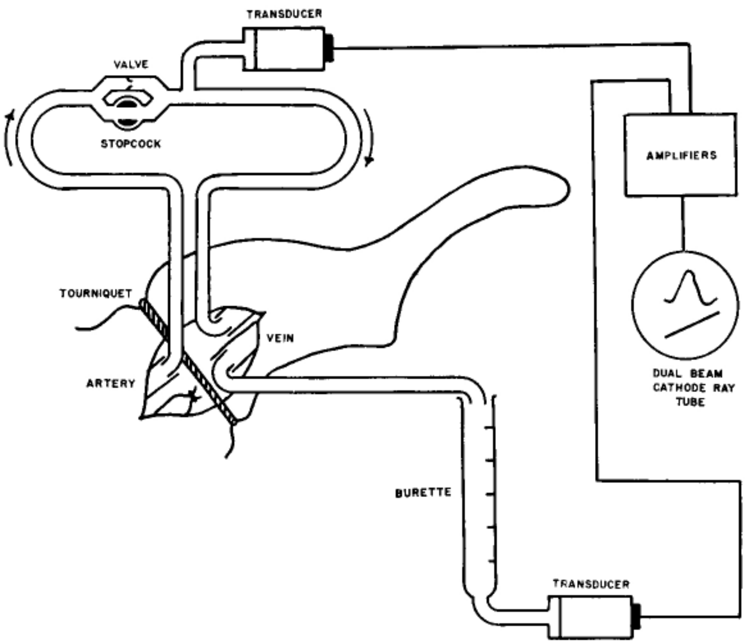

Fig. 4. Diagram of experimental setup for femoral vein outflow studies (see text).

(by opening the stopcock) at the point designated by the vertical broken line. It can be seen that the slope of the flow curve changes sharply at this point. In the first part the slope of the flow curve rises rapidly, indicating a greater outflow from the dog's leg with the valve in place. In the second portion of section *B* the slope does not rise as rapidly, indicating a lesser outflow from the dog's leg when the valve is removed. The mean pressure in section *A* is 146 mm. Hg; the mean pressure in section *C* is 126 mm. Hg. The flow in the first portion of section *B* is 53 cc./minute and the flow in the second half of section *B* is 36 cc./minute, an increase of 47 per cent.

DISCUSSION

It may be feasible to apply these findings in the treatment of human peripheral vascular disease where it is felt that the pathologic process, for the most part, involves the main stem arteries and that the smaller branches which are responsible for carrying the collateral supply of blood are often free of disease.[7] If it were possible to place the valve in such a way as to increase the blood flow through the collateral system, then this method might be of some usefulness. Certainly, if one were to place the valve in the common iliac artery above its bifurcation into the hypogastric and the common femoral, one would then be in a position to affect the pressures in most of the collateral vessels in the leg, since they arise from branches below this point. Plethysmographic studies[8] on individuals suffering from arterio-sclerotic peripheral vascular disease suggest that some elasticity still exists in their arterial tree. Indeed, measurable backflow can often be demon-

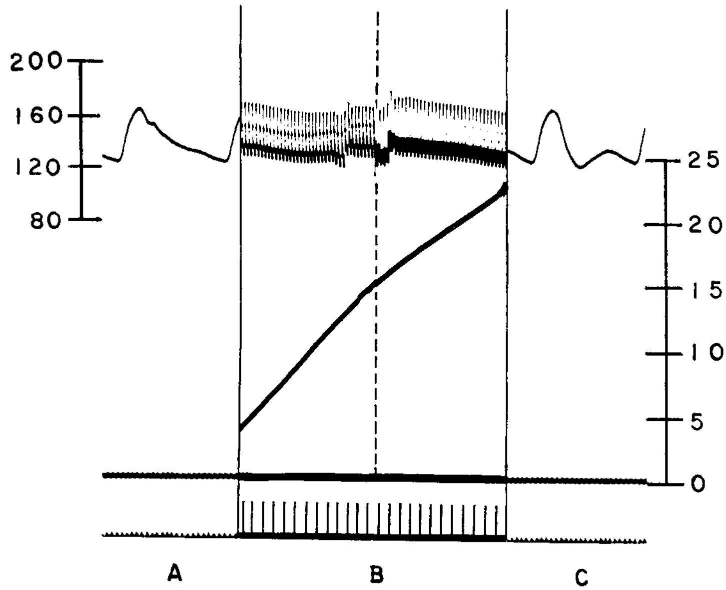

Fig. 5. Segments from record in dog No. 6-23. Upper curves represent femoral artery pressure in mm. Hg; sloping line represents venous outflow in cc. Section *A*, contour of pressure curve with valve in femoral artery circuit; first half of section *B*, valve in femoral artery circuit; second half of section *B*, control flow, valve removed from circuit at point indicated by vertical broken line; section *C*, contour of pressure curve without valve in femoral artery circuit. Time marks in section *B*, 1 second. Flow 47 per cent greater with valve in circuit.

strated. Therefore, one would expect that the human with peripheral vascular disease should not react any differently than the experimental animal when a valve is placed in his femoral artery.

Finally, the observation should be made that if it is possible to improve the blood flow in the legs of individuals with peripheral vascular disease, this same principle may be applicable in other arteries. It is known that back flow exists in such vessels as the common carotid artery, the brachial arteries, the coronary arteries, and some of the visceral arteries in experimental animals. A valve which may have usefulness in human (adult and pediatric) vascular problems is being developed.

SUMMARY

1. Since the development of modern phasic inflow meters, it has been

known that a considerable backflow normally exists in some arteries of the experimental animal.

2. It is suggested that by eliminating the backflow in the femoral artery by means of a check valve, the mean forward flow should be increased.

3. This hypothesis was tested in a series of 23 acute experiments in anesthetized dogs.

4. In 8 dogs, the arterial inflow was studied with and without a valve in site. In 47 separate controlled observations, it was found that the arterial inflow was increased anywhere from 6 to 52 per cent.

5. In 3 other animals, the venous outflow from the dog's leg was studied in 18 separate controlled observations with and without a valve in the femoral artery. Increases of the venous outflow were observed in all cases.

6. Finally, some reasons are presented why this may be of value in the treatment of human peripheral arterial disease.

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