BLOOD VOLUME - BLOOD REPLACEMENT

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Maintenance of a stable circulating blood volume in the pump and in the patient was a real problem in the early days of perfusion and cardiac surgery and continues to plague us today, especially during the extracorporeal management of infants. Various rather complex systems have evolved, aiming to equilibrate venous return with arterial inflow. One such system is the use of paired pumps, one on the arterial side, the other on the venous line, to insure that no more is pumped out than is pumped in. Another system is designed around scales under the venous reservoirs and oxygenator, with servomechanisms monitoring the flow. All these systems work, after a fashion; they are, however, complex and expensive.

Much investigative effort has gone into the problems of venous return and blood volume maintenance during perfusion. In 1958, Dr. Stanley Giannelli, my colleague at the St. Vincent's Hospital, published his studies of hemodynamic mechanisms which tend to maintain a constant blood volume during cardiopulmonary bypass. He found that, providing that the venous pressure is kept below 10cm. of water, the blood volume of the perfused animal increased as the perfusion rate increased, and for each perfusion rate in a given animal under these conditions, there was a relatively constant blood volume.

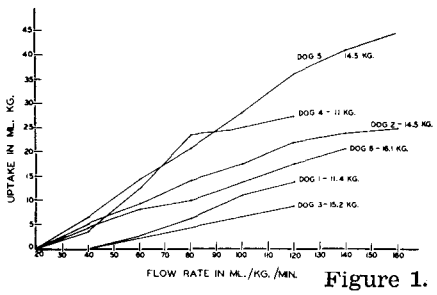

Figure 1.

This is one of his studies illustrating this point (figure 1). Given a low venous pressure by appropriate adjustment of reservoir levels below the level of the right atrium and using large bore tubing on the venous side, it is possible to maintain a reasonably constant blood volume by gravity flow alone. In other words, for a given arterial inflow, blood volume and venous return tend to level out at relatively constant values provided that there is no obstruction to venous return and venous pressure is kept low. This particular study was done on the dog, and I shall have more to say about some modern refinements of it later.

Studies such as these have resulted in the design of many perfusion systems, including our own, around gravity siphonage of venous return, usually into a reservoir so that the levels in the oxygenator can be kept constant. A popular accessory is a blood level sensor system connected to the arterial pump to guard against violent swings in the oxygenator levels, as occasionally results from sudden hemorrage into the field.

The development of open-heart surgery is held up by many, as the shining example of fruitful collaboration between the laboratory worker and the clinician. Most of the early laboratory work was carried out in the dog, and extrapolated from there into the human. As clinical experience along these lines accumulated, it became apparent that much of the early perfusion data was obtained from the wrong animal; that a great deal of information gained from the dog was was just not applicable to the human. The dog does not take perfusion well; this led to much frustration in the design of perfusion systems. The opinion has been voiced that man's best friend probably has delayed the progress of open heart surgery by at least 10 years.

One of the dog's little eccentricities while on bypass is the closing of various sphincters in the hepatic veins within minutes after the start of perfusion. This leads to marked splanchnic and liver engorgement and congestion with loss of circulating volume. The triggering of these hepatic sphincters is thought to be the result of an anaphylactic reaction to homogolous blood. This unfortunate reaction in the dog makes interpretation of perfusion data obtained from the animal difficult. It is clear that in many studies on perfusion using this animal, such data is at best only a guide.

With this in mind, we have been repeated some of the earlier studies using patients undergoing heart surgery on cardioplmonary bypass. Perfusion spaces and perfusion volumes have been measured employing the techniques of dye dilution. Dye dilution studies are commonly employed during cardiac catheterization across the pulmonic circulation to measure output and to detect

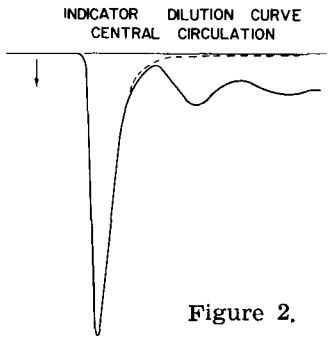

Figure 2.

shunts (figure 2, normal dye dilution curve). The method depends upon the calculation of the area under the first circulation curve after

$$\text{FLOW RATE} = \frac{\text{AMOUNT INDICATOR INJECTED}}{\text{AREA UNDER CURVE}}$$

$$\text{VOLUME} = \text{FLOW RATE} \times \text{MEAN TRANSIT TIME}$$

Figure 3.

the downslope has been extrapolated to zero (figure 3, dye curve calculations).

This method is normally not applicable to studies over the peri-

pheral circulation because of the differences in recirculation time across the various visceral capillary bed renders impossible the necessary extrapolation of the slope surve and hence ruins the calculations (figure 4, differential caval traces in the dog).

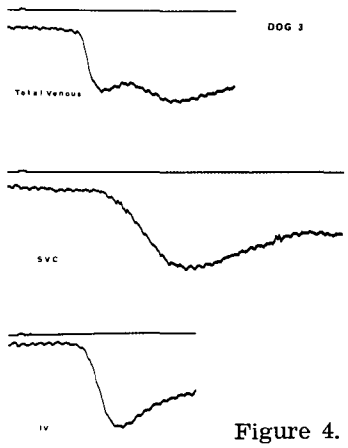

Figure 4.

Cardiopulmonary bypass provides the necessary circumstances for dye dilution studies across the peripheral circulation. The cardiac output is equal to the pump output, and recirculation can be delayed by adding extra tubing to the pump circuit. Injection is made into the arterial line proximal to the filter, thus insuring mixing, and sampling is done from the venous line.

These studies are still in progress. The difference in "perfusion space" is measured by dye dilution studies employing red cells tagged with Cr51 and serum albumin tagged with I 125 (figure 5).

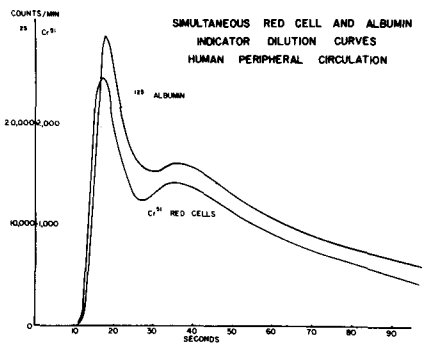

Figure 5.

It is evident that the difference in area under the two curves is about 10%, and that the mean transit time of the tagged cells is faster than the tagged albumin.

The tagged plasma protein fraction traverses or perfuses a larger space and a different area than the tagged red cells. This suggests an extravascular position for the albumin, and raises the interesting question of just what we measure with blood volume studies employing tagged albumin.

We have compared the output as calculated from the dye curves with the known pump output. The agreement is close; the method appears to give valid data. Serial curves done in the course of a single perfusion have not shown a progressive gain in circulating volume. Hepatic vein wedge pressure has been measured in man during bypass, and found to be stable. These studies have been carried out with 100% whole blood primes without hemodilution. So far, we have not observed clinically nor have any experimental measurements to support the concept of a homologous blood reaction in the human similar to that described in the dog.

We are now endeavoring to equate these dye curves with the clinical state of the patient; to see, in other words, whether the perfusion volumes of the red cells and the serum proteins are affected by the hemodynamic state of the patient. Other studies will include the effect of varying the molecular weight of the tagged element on "perfusion space" as defined by this method.

These studies and others have raised doubt in our minds concerning the validity of blood volume measurements and especially the value of such measurements in the management of the cardiac surgical patient. Our preoperative workup used to include a blood volume determination as measured by I131 and we followed these patients with serial determinations in the immediate postoperative period. We did not find this information of much practical value. The measurement of blood volume in the intact normal human can be estimated within an error of about 5%. In the postoperative heart case, such measurements are complicated by, among other factors, vasoconstriction, A-V shunts, low cardiac output with visceral capillary bed stagnation; we believe the error to be much greater.

We currently rely on a continuous dynamic measurement of effective circulatory volume, the central venous pressure, rather than on static measurements of an imponderable space, the blood volume. We employ the central venous pressure as our guide to the adjustment of circulating volume as bypass is discontinued and, together with the measured blood loss, as a monitor of postoperative blood replacement. Reviewing the charts of those patients studied with pre and postoperative blood volumes, I cannot say that we were seriously misled by blood volume determination. We have abandoned it in the ordinary clinical situation for what we believe to be a simpler, cheaper and more reliable guide to effective circulatory blood volume, the central venous pressure.

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There is a pride which incites a man to override his inferiors, while it does not hinder his crawling at the feet of those who are above him. It is a peculiarity this vice, which is based neither on personal merit nor virtue, but on riches, place, influence, and useless knowledge, that it renders man equally apt to look with contempt upon persons who do not share with him those advantages, and to think too highly of those who are more largely endowed with them than himself.

La Bruyere
