REGIONAL BLOOD FLOW
DURING EXTRACORPOREAL CIRCULATION


Studies of the distribution of total blood flow at varying total flow rates are of interest in both the intact individual in whom total flow represents cardiac output, and in the patient during cardiopulmonary bypass when total flow represents pump-oxygenator output. In the intact individual such information should be helpful in understanding the phenomena associated with hemorrhage, shock, heart failure, and other conditions characterized by low cardiac output. Objective studies of distribution of flow at varying rates of cardiac output in the intact individual are lacking because of difficulty in experimental control of cardiac output. The development of satisfactory pump-oxygenator systems has made available a relatively simple technique for maintaining total flow at accurately determined rates for sufficient time to permit measurement of regional flow rates. Such data are important in determining optimum total flow rates and in understanding the changes observed in patients during and after cardiopulmonary bypass. Furthermore, if the cardiovascular response to changes in total flow rate is similar in intact and perfused animals, data obtained during perfusion are applicable to the intact animal with varied cardiac output.

In the present studies, blood flow through the femoral, superior mesenteric, and left renal vessels was studied during cardiopulmonary bypass in the dog.

MATERIALS AND METHODS

Twelve healthy mongrel dogs, weighing from 6 to 15 kilograms, were anesthetized with intravenous Nembutal, intubated intratraecheally, and maintained on a mechanical piston respirator. Through a right fourth interspace thoracotomy, the azygos vein was ligated and tapes passed about both venae cavae. Caval cannulas, about two thirds the diameter of the vessels, were inserted through the right atrial wall and connected to the oxygenator. Oxygenated blood was returned to the animal through a femoral artery cannula. The animals were heparinized prior to cannulation. The pump oxygenator used was a...

*Markle Scholar in Medical Sciences.
Kay-Cross rotating disc oxygenator with roller pumps, and was primed with heparinized blood obtained from 2 donor animals on the day of each experimental preparation.

In 4 animals, femoral venous return was studied by inserting a T-shaped glass cannula, as nearly as possible approximating the size of the common femoral vein, on the side opposite the femoral arterial cannula and is held in place by ligatures. A proximal loop ligature, when tightened, permitted diversion of all flow to the side arm which was kept clamped except during periods of collection (Fig. 1).

Fig. 1.—Diagram which shows method of cannulation of veins and collection of venous flow during study periods.

In the superior mesenteric flow study, a similar side arm glass cannula was inserted into the superior mesenteric vein through a midline abdominal incision in 4 animals. The proximal loop ligature to occlude temporarily the superior mesenteric vein during periods of collection was placed just distal to the formation of the portal vein from the superior mesenteric and splenic veins.

In studies of renal flow the left renal vein was exposed through a midline abdominal incision and cannulated with a T-shaped glass cannula approximating closely the size of the vein itself. During insertion of the venous cannula, the renal artery was occluded temporarily and the venous cannulation was performed as quickly as possible to avoid damage to the kidney. A proximal ligature which was used to occlude the vein during periods of collection was placed at the caval junction with the left renal vein.

In all experiments, after satisfactory preparation of the vessels, cardiopulmonary bypass was begun, and the respirator was turned off after the tapes about the caval cannulas were tightened. It was found necessary to withdraw one caval cannula so that a single side opening lay on the atrial side of the caval ligature to prevent overdistention of the heart during prolonged periods of total bypass. Isothermal temperatures were maintained, using a heating coil about the oxygenator jacket. In most experiments, temperature fell 2° to 3° C. during the experiment, and in one instance fell 6° C. Arterial blood pressures closely were obtained.

Blood was added to the oxygenator output in order to prevent stabilization. A arterial pump was calibrated at least
ips, and was primed with

\[ \text{Total Body Flow Ml/Kg/m/Min} \]

\[ \text{Femoral Flow ML/Min} \]

\[ \text{Figure 2.} \]

were monitored using a Statham pressure transducer and Sanborn direct-writing recorder. Measurement of outflow through the individual vessel to be studied was obtained after stabilization of perfusion at 80 to 100 c.c. per kilogram per minute by opening the side arm and simultaneously tightening the ligature about the vessel proximal to the cannula. Measurements were obtained over a 30-second interval and blood was returned to the oxygenator reservoir. During collection of venous blood the tip of the side arm was held at the level of the vein being studied during periods of collection. Care was taken that this level be constant for each preparation. At least two determinations which agreed closely were obtained at each flow level. The total flow rate of the pump oxygenator was then changed and venous flows studied at varying levels of pump-oxygenator output. These levels were not changed in a stepwise direction in order to prevent a prolonged period of low-flow perfusion. About 5 minutes of stabilization was allowed after instituting new flow rates before measurement. Blood was added from the venous reservoir if necessary to maintain the oxygenator level. Animals were sacrificed at the end of each experiment. The arterial pump was adjusted to be occlusive before each experiment and was calibrated at least once for each two experiments.
RESULTS

Femoral Vein Flow.—Data obtained from 4 animals are shown in Figs. 2 and 3. All blood flows are expressed in absolute values of total flow (ml./min.), not in milliliters per kilogram per minute. The increase in flow recoverable from the femoral vein with increase in total body flow is roughly linear. In Fig. 3 the percentage of total flow recoverable from the femoral vein is plotted against total flow. One of the four experiments suggests a fall in percentage of total flow recoverable from the femoral vein as total body flow decreases.

**Fig. 4.**

**Fig. 5.**
animals are shown in Figs. 2 values of total flow (ml./min.), increase in flow recoverable y flow is roughly linear. In m the femoral vein is plotted suggests a fall in percentage of al body flow decreases.

Superior Mesenteric Flow.—Data from 4 additional animals are depicted in Figs. 4 and 5. As total body flow is increased, the rise in mesenteric flow appears to be roughly linear in these experiments. In Fig. 5 it can be seen that the percentage of total flow recoverable from the superior mesenteric vein increases as total body flow is decreased. This relative increase in blood flow to a vital area during increase in total body perfusion has long been suspected and recently has been documented by others.¹

Renal Flow.—In Figs. 6 and 7, data from a third group of 4 dogs are presented. In Fig. 6 it can be seen that under the conditions of these experiments the increase in renal flow as total flow increased was not consistent or marked. There is an over-all increase in renal flow over the range of total flow studied. Fig. 7 demonstrates an increase in the percentage of total flow recoverable from the renal vein as the total body flow decreases. This increase does not appear to be striking until a level lower than 60 c.c. per kilogram per minute is reached. It appears that protection of the kidney by increasing the percentage of cardiac output distributed to it does not occur until a very low rate of flow is present.
There are a number of obvious objections to the experimental methods utilized in obtaining these data. The measurement of arterial flow by collecting venous return is open to criticism because, among other reasons, the insertion of a venous cannula and the position of the side arm influence resistance to flow and, therefore, may affect flow rate. For this reason, only changes in flow rate for each individual animal have been considered significant. An additional objection to this method is the failure to distinguish between total circulating blood volume in the animal and in the pump-oxygenator apparatus. This has been taken into consideration only by allowing the perfusion to stabilize before making individual determinations of flow. Finally the failure to control temperature over a narrow range may be considered an objection although there are, as yet, few data indicating that distribution of flow varies with the temperature in the range encountered in these experiments. This is under investigation at the present time.

DISCUSSION

These studies indicate that, as total body flow rates are decreased during cardiopulmonary bypass, there is selective redistribution of blood flow to vital organ systems. There appears to be a significant increase in the percentage of total body flow recoverable from both the renal and mesenteric veins as total flow is decreased. The protection of renal blood flow by shifting an increasing proportion of total flow to the renal vessels does not seem to become effective until total flow is markedly reduced, but this will require further corroboration using other techniques for measuring renal blood flow.

Several studies of total and regional blood flow and its distribution during extracorporeal circulation have been reported. Our experiments support the conclusions reached by Andersen and co-workers although the method of measuring blood flow reported by Andersen does not separate flow to individual organs. The work of Andersen indicates a proportionate decrease in percentage of total flow going to the lower extremities during cardiopulmonary bypass as the total flow is reduced. Data from the studies reported in this communication do not clearly demonstrate this change. Andersen emphasized that the protection accorded the organism by the selective redistribution of blood flow shown in his experiments is incomplete since absolute values for "vital" organ flow decreased with the total flow rate.

There is considerable evidence that the cardiovascular system in the intact animal responds in a similar fashion to the animal during extracorporeal circulation. If this is accepted, these data support the long-accepted theory that during periods of low cardiac output there is selective distribution of blood flow toward those organs which are vital to survival of the individual.

SUMMARY AND CONCLUSION

1. The amount of blood recovered from the femoral, superior mesenteric, and renal veins has been measured in the dog undergoing cardiopulmonary bypass with the use of a pump oxygenator.
e experimental methods utilizing arterial flow by collecting luer reasons, the insertion of influence resistance to flow in, only changes in flow rate significant. An additional objective is to total circulating blood apparatus. This has been shown to stabilize before making failure to control temperature although there are, varies with the temperature rise is under investigation at rates are decreased during ection of blood flow to vital decrease in the percentage of mesenteric blood flow as total flow by shifting an increasing not seem to become effective require further corroborating and its distribution during our experiments support the thought the method of measuring separate flow to individual sate decrease in percentage cardiopulmonary bypass as stated in this communication emphasized that the probition of blood flow shown uses for "vital" organ flow vascular system in the intact using extracorporeal circulating-accepted theory that during distribution of blood flow to individual.

moral, superior mesenteric, undergoing cardiopulmonary

REFERENCES