Effect of Hypervolemia on Ratio of Pulmonary to Systemic Vascular Volume.*† (28627)

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The vascular bed of each tissue and organ of the body, especially the postcapillary portion, can be said to constitute a reservoir for blood. Certain vascular beds have been thought to function more specifically as reservoirs, where blood can be pooled and as circumstances demand be made available to the general circulation. The present experiments were designed to test the concept that the lungs might function as such a specific reservoir(1).

Methods. Observations were made on 19 dogs weighing 12 to 23 kg. Fifteen dogs were anesthetized with sodium pentobarbital (25 mg/kg) and 4 dogs were not anesthetized. The combined blood volume for the lungs and the left side of the heart was determined by the indicator-dilution technic. To do this, one catheter was placed with its tip just distal to the pulmonary valve and another with its tip just distal to the aortic valve. Indocyanine green was injected via the catheter into the pulmonary artery by means of a pneumatic syringe capable of delivering 1 ml in 0.1 second. A linear potentiometer linked to the syringe piston recorded the instant and magnitude of each injection. Changes in concentration of dye at the root of the aorta were recorded continuously by a densitometer attached to the aortic catheter. The densitometer was calibrated with known concentrations of dye in aliquots of the dog's own blood.

Volume of blood in the lungs and the left side of the heart (L.L.H.V.) was calculated as the product of cardiac output and mean transit time of the indicator between the sites of injection and sampling(2). Mean transit time was determined from the recorded dilution curve and was corrected for delay due to the sampling system, according to the method described by Fox and co-workers(3).

Total blood volume was derived from the plasma volume, measured with radio-iodinated serum albumin as described by Beierwaltes and co-workers(4), and the hematocrit. These measurements were obtained at the same time as those for determination of L.L.H.V.

Seven anesthetized dogs were made hypervolemic by transfusions of 250-ml aliquots of fresh blood obtained from other dogs. To reduce the amounts of vasoactive substances which might be liberated by the decrease in arterial pressure, each donor dog was immediately transfused after each bleeding with an amount of stored blood equal to the amount removed.

All bleeding and transfusions were made through wide-bore tubing to minimize trauma to the blood. Transfusions were given intra-arterially during a 5-minute period, and measurements for the L.L.H.V. were made 15 minutes after completion of each transfusion. A total of 1000 ml was transfused. At the time of the last measurement to determine the L.L.H.V. for each dog, measurements for determining total blood volume were again made. For this, an arterial blood sample was first withdrawn to determine the residual radioactivity, then 4 times the initial dose of tracer was injected. In some dogs, intermediate determinations of total blood volume were obtained after transfusion of 500 ml of blood.

In 5 dogs, dextran, 6% in normal saline, was used instead of blood to increase the blood volume.

The four conscious dogs also were made hypervolemic with transfusions of fresh blood. After each 250-ml transfusion, measurements for L.L.H.V. were obtained at rest and during graded exercise on a treadmill. The dogs tolerated the transfusion well and were able to exercise without difficulty.

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Results. The L.L.H.V. of the 15 anesthetized dogs averaged 12 ml per kilo of body weight (S.D. 3 ml; range 8 to 17 ml). The total blood volume averaged 96 ml per kilo (S.D. 18 ml; range 74 to 145 ml). The L.L.H.V. averaged 12.5% (S.D. 3.5%; range 9.4 to 17.4%) of total blood volume. These percentages were determined for the dogs individually; that the average percentage agrees with the per cent of the averages is simply a coincidence.

After transfusion of blood to 7 of the dogs, which increased the total blood volume from an average of 92 ml per kilo (range 73 to 106) to an average of 134 ml per kilo (range 116 to 166), the L.L.H.V. increased from an average of 12.0 ml per kilo (range 8 to 16) to an average 16.5 ml per kilo (range 10 to 28). The L.L.H.V. averaged 12.1% (range 9 to 16.5%) of total blood volume with the hypervolemia, compared with an average of 12.9% (range 8.5 to 15.0%) when these 7 dogs were normovolemic; values for individual dogs gave similar results. Thus there was little change in the proportion of L.L.H.V. to total blood volume when the total volume was increased by an average of 46% (range 30 to 58%). This was also true when similar calculations were made after smaller increments in total blood volume. When dextran was used to increase the blood volume the results were similar in that L.L.H.V. and total blood volume increased in the same proportions (14.5 to 20.5 ml per kilo and 105 to 150 ml per kilo, respectively). In 3 of the 4 unanesthetized dogs, the percentage of L.L.H.V. to total blood volume was similar before and after transfusion of 1000 ml of blood (12.8% and 14.4%, respectively). Total blood volume after transfusion was not available for the fourth dog.

In the 4 dogs exercised on a treadmill after graded transfusion of blood, the initial L.L.H.V. was exceeded after each transfusion. At each stage of volemia, however, there was little change from the resting value during exercise which resulted in a 3-fold increase in cardiac output. The complete observation on one of the dogs is shown in Fig. 1 and is typical of the results obtained in the other 3 animals.

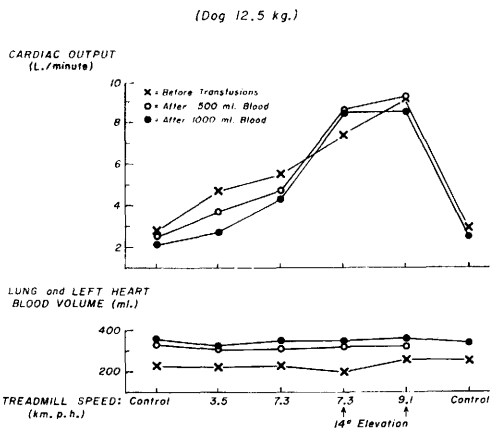

FIG. 1. Changes in cardiac output and in volume of blood in lungs and left side of heart at rest and during exercise, before and after transfusions of blood. To increase the severity of the exercise, the treadmill platform was elevated 14° from the horizontal.

Comment. Measurement of volume of blood in lungs. When the indicator is injected at the pulmonary valve, and blood is sampled at the aortic valve, it is likely that the requirements of the indicator-dilution technic are met for good mixing of indicator with circulating blood(5) and that the L.L.H.V. can be determined with confidence. A disadvantage is that the volume of blood in the lungs alone cannot be computed. In attempts to determine this volume, indicator has been injected into the pulmonary artery and into the left atrium with a continuous recording of the resulting dilution curves from a peripheral artery(6,7). The difference between the 2 volumes calculated from these 2 injection sites should represent the lung volume with an additional but unknown left atrial component. With the object of using this technic in the present experiments, a comparison was made at different degrees of volemia of L.L.H.V. and "lung" volume. The latter volume was obtained by making sequential injections of dye into the pulmonary artery and left atrium and recording the change in indicator concentration at the femoral artery. When successive measurements were made within a few minutes, at each level of volemia, individual values of the L.L.H.V. did not vary by more than 5% from the mean value (22 observations in 2 dogs). In the same 2 dogs, 12 observations of

the "lung" volume were made. A scatter of 18% from the mean was seen for the "lung" volume when observations were repeated at the same volemia. In one of the dogs the value of the "lung" volume was found once to exceed that of the L.L.H.V. In the other dog, the L.L.H.V. increased after transfusion from 95 to 150 ml while the "lung" volume decreased from 85 to 75 ml. Because of the reproducibility of the values of the L.L.H.V., it was decided to determine this volume in the present study.

Measurement of total blood volume. The control values for total blood volume quoted here are in agreement with those reported in the literature(8). The fact that after transfusion the blood volume was significantly less than the sum of the initial and added volumes is in agreement with the results of other studies on the effects of transfusion of blood in dogs(9).

Conclusions. Since the L.L.H.V. remained a relatively constant percentage of total blood volume even when the latter was increased by an average of 46%, there was no selective storage of blood in the lungs. Thus the reservoir function of the lungs is equivalent to that of the systemic vascular bed as a whole. The lungs and the vascular system accommodated this large increase in volume without any evidence of inconvenience to the animal, and the right atrial pressure increased by only 5 mm of mercury (average value) 15 minutes after the last transfusion. This tolerance to hypervolemia was shown especially by the conscious dogs, who performed severe exercise as easily under these conditions as in the control state. Although the dextran infusions increased the L.L.H.V. and the filling pressure of the ventricles as much as blood, cardiac output increased in proportion with the decrease in hematocrit when dextran was used and was little changed when blood was used. Thus increases in L.L.H.V. are not necessarily associated with increases in cardiac output. Also, as the cardiac output increased during exercise (up to 3 times the control value), there was little change in the L.L.H.V. from the initial value when the animal was at rest, regardless of the amount of initial volume.

Summary. The volume of blood in the lungs and the left side of the heart (L.L.H.V.) and total blood volume were determined in 15 anesthetized dogs. L.L.H.V. averaged 12 ml per kilo of body weight or 12.5% of total blood volume. Infusion of fresh blood or of dextran, 6%, produced hypervolemia sufficient to increase the total blood volume by an average of 46%. During the hypervolemia, the proportion of L.L.H.V. to total volume was essentially unchanged. This was also true in 3 conscious dogs. Thus there was no evidence from these observations of a specific reservoir function of the lungs. In 4 conscious dogs, the L.L.H.V. was measured at rest and during exercise at different degrees of hypervolemia. Regardless of the initial L.L.H.V. there was little change from this initial value as cardiac output increased up to 3-fold with exercise.

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