Hemorrhage Without Hypotension: *

An Experimental Study of Aortic Flow Redistribution Following *Minor* Hemorrhage

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PROBABLY THE COMMONEST clinical hemorrhage problem faced by the surgeon is the loss of a substantial, but unknown, quantity of blood resulting in a transitory drop in arterial pressure which is restored to, or toward, normal spontaneously in a short period of time. This experimental study was aimed at determining alterations of blood flow occurring in response to blood loss of such magnitude that arterial blood pressure was rapidly returned to or near pre-hemorrhage levels without any treatment.

Methods

Thoracic Aortic Flow Distribution. Left thoracotomy was performed in ten mongrel dogs under light intravenous sodium pentobarbital anesthesia. Ventilation was accomplished by use of a piston type positive-negative ventilator. The ascending aorta, brachiocephalic artery, left subclavian artery, descending aorta just distal to the subclavian, and the left circumflex coronary artery were isolated and suitable electromagnetic flow probes** positioned on them. Details of this regional flow measurement technic are described in detail elsewhere.[4] Arterial pressure was recorded continuously from a carotid artery via an inlying catheter attached to an inductance type pressure transducer.

Abdominal Aortic Flow Distribution. Under conditions of anesthesia and ventilation identical to those described above, the abdominal aorta was exposed retroperitoneally in another group of ten dogs through a left flank incision excising the lower one or two ribs. All branches of the abdominal aorta were ligated and divided saving only the celiac axis, the superior mesenteric artery, both renal arteries, and the aortic trifurcation. Electromagnetic flow probes were placed about the aorta at three levels:

A. Above the celiac axis
B. Below superior mesenteric artery but above both renal arteries
C. Below both renal arteries

From measurements using these flow probes it will be apparent that:

A = abdominal aortic inflow
$A–B$ = splanchnic flow exclusive of renal
$B–C$ = renal flow
C = somatic flow to lower extremities

While there are obviously other sources of inflow to each of these areas, except possibly the renal, the flows recorded represent a major portion to each area designated. This technic is also described in detail elsewhere.[4]

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** Electromagnetic Probe Co., Winston-Salem, N. C.

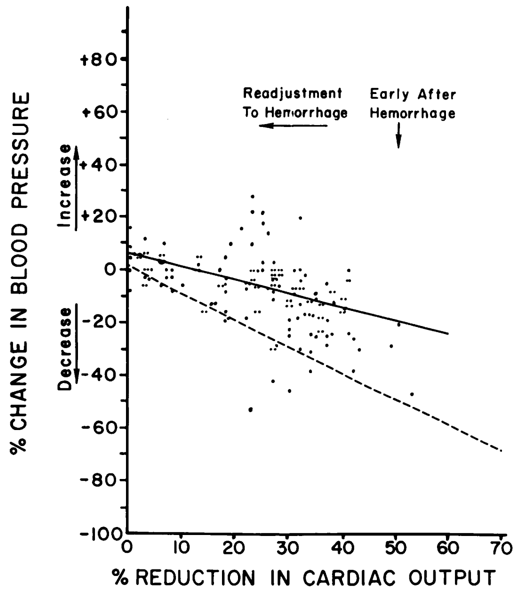

FIG. 1. Alteration in cardiac output plotted against change in arterial blood pressure. Solid line is calculated linear regression line. Cardiac output fall proportionately much more than arterial pressure.

Flow measurements were made from the five probes placed in the thorax or three probes placed in the abdomen in rapid sequence by use of a special probe switching unit*** and a squarewave electromagnetic flowmeter.*** Using this technic it was possible to complete a full set of thoracic measurements in approximately one minute.

Following three to five sets of control measurements each animal was bled 15 cc./Kg. body weight rapidly from a femoral artery. A set of flow measurements as described above and recording of arterial pressure were performed every five minutes for one hour. Eight hundred separate flow measurements were thus performed. Data analysis was carried out by using a polynomial curve fitting program based on the least squares method and performed on the IBM 1620 digital computer. In no instance did higher order polynomials prove a significantly better curve fit than the linear regression line which is shown in the figures.

*** Carolina Medical Electronics, Winston-Salem, N. C.

Results

While it is not possible to include the time parameter in the figures to be presented, in general the points to the far right in each illustration represent values obtained early after hemorrhage. As homeostatic readjustments came into play, the distribution of values shifted toward the left. In each illustration the broken line shows for visual comparative purposes the line of direct proportionality; that is the line on which all points would fall if the one parameter were reduced in direct proportion to the other. The solid line is the calculated linear regression line which represents the best statistical evaluation of the behavior of the entire group of data points.

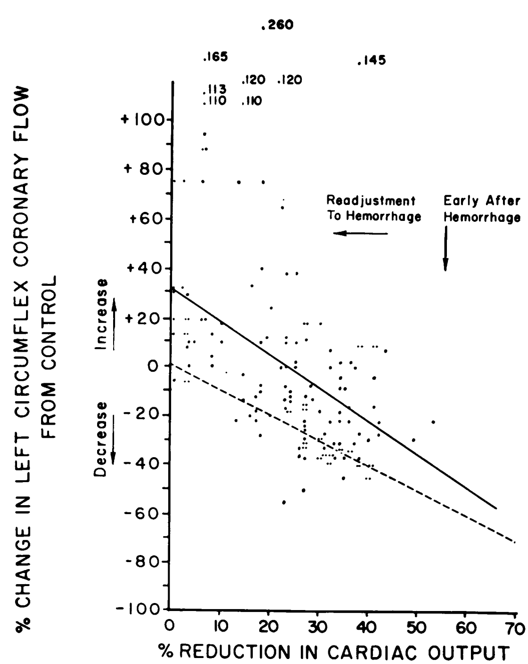

FIG. 2. Alteration in left circumflex coronary artery flow plotted against change in cardiac output. Preferential flow redistribution toward this vessel is evident.

Thoracic Aortic Distribution

1. *Cardiac Output.* Reduction in cardiac output is plotted as a function of change in arterial blood pressure in Figure 1. It will be noted that the regression line is closer to horizontal than to the line of direct proportionality, indicating that cardiac output is reduced by the hemorrhagic episode to a much greater extent than blood pressure. When cardiac output was reduced 40 per cent, as a group, the blood pressure values were only reduced 10 per cent. One-third of the entire group of arterial blood pressure determinations were equal to or exceeded the control value even though the output was reduced up to 40 per cent below the control value.

2. *Coronary Flow.* Alteration in left circumflex coronary artery flow is plotted as a function of reduction in cardiac output in Figure 2. If no alteration in *distribution* of aortic blood flow occurred, all values would fall along the broken line of direct

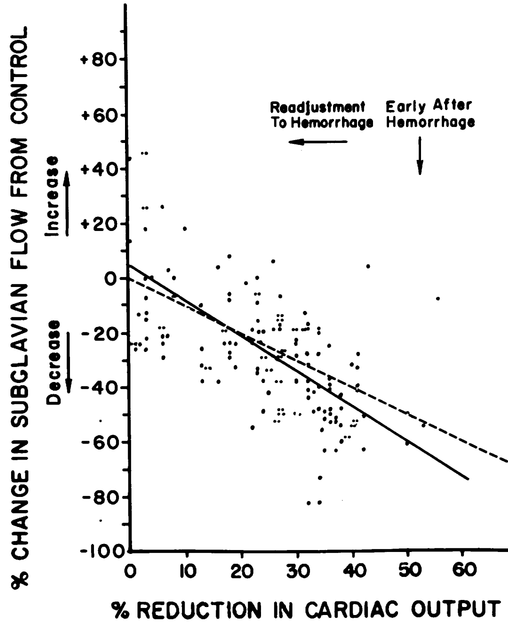

FIG. 4. Alteration in left subclavian artery flow plotted against change in cardiac output. No redistribution to this vessel occurred.

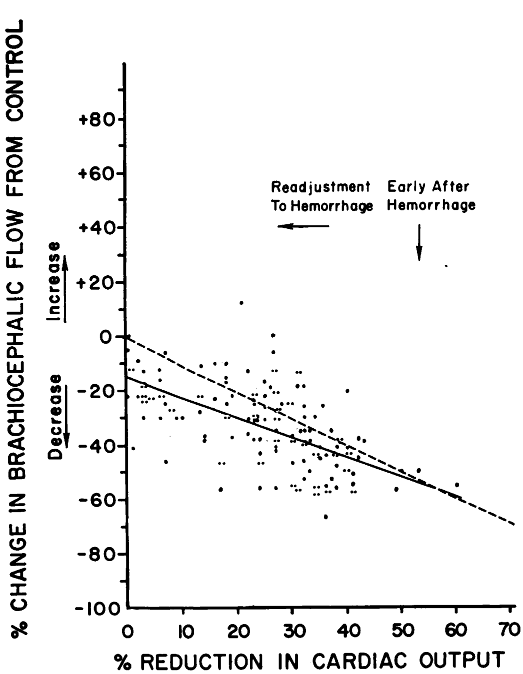

FIG. 3. Alteration in brachiocephalic artery flow plotted against change in cardiac output. With readjustment to hemorrhage, small flow shift away from this vessel is evident.

proportionality in this type of illustration. Data points appearing above the line of direct proportionality indicate a preferential shift of flow toward the individual area being studied while data points below the line of direct proportionality indicate preferential shift away from that area.

It will be seen that most of the data points in Figure 2 fall well above the line of direct proportionality and the calculated regression line falls significantly above it. Statistically, circumflex coronary artery flow remains normal when cardiac output is reduced 30 per cent. Forty per cent of all coronary flow values are equal to or exceed the control values even with reductions in cardiac output up to 40 per cent of the control.

3. *Brachiocephalic Flow.* The response pattern of brachiocephalic flow is shown in Figure 3. The regression line intersects the line of direct proportionality early after hemorrhage, then falls progressively beneath it as readjustment takes a place indi-

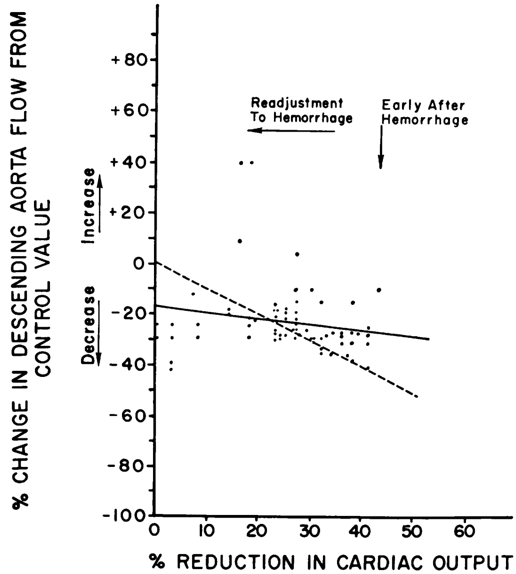

FIG. 5. Alteration in descending aorta flow plotted against change in cardiac output. Flow to this vessel is depressed less immediately after hemorrhage than is cardiac output but shows little tendency to redistribution during recovery.

cating a small but preferential shift away from the brachiocephalic trunk.

4. *Left Subclavian Flow.* From Figure 4 it can be seen that there is no significant difference between the calculated linear regression line and the line of direct proportionality; hence, no distribution shift to the subclavian artery occurred from this hemorrhagic episode or the readjustment to it.

5. *Descending Aorta Flow.* The regression line seen in Figure 5 indicates that the descending aorta flow was reduced about 20 per cent below the control value early after the hemorrhage and changed very little during the succeeding hour of readjustment so that when cardiac output had returned to or near control values descending aorta flow remained reduced roughly the same amount as it had early after the hemorrhage.

Abdominal Aortic Distribution

1. *Blood Pressure Change.* The relationship between abdominal aortic inflow and systemic arterial pressure is shown in Figure 6. It will be seen that blood pressure fell to about 15 per cent below the control value and was only slightly related to the reduction of aortic inflow which ranged up to 65 per cent below the control values. One-quarter of the aortic inflow values represent a reduction of 50 per cent or more while arterial pressure was reduced only about 22 per cent.

Since the mean control arterial pressure for all animals was 122 millimeters of mercury, a 15 per cent reduction would indicate a mean arterial pressure of 104 millimeters of mercury. For this reason it seems acceptable to refer to this state as *hemorrhage without hypotension.*

2. *Splanchnic Flow (excluding renal).* Alteration in splanchnic flow as a function of abdominal aortic inflow is shown in Figure 7. It is apparent that splanchnic flow fell in almost exact proportion to the reduction of inflow. Since the regression line falls below and to the left of the line of direct proportionality it is suggested that there is a slight preferential shift of blood

FIG. 6. Alteration in arterial pressure plotted against change in abdominal aortic inflow. Little depression in blood pressure resulted even during marked reduction in aortic inflow.

away from the splanchnic area but this shift is of borderline statistical significance.

3. *Renal Flow.* Figure 8 shows the relationship of renal flow alteration to aortic inflow change. While there is a rather wide scatter of values, it will be noted that only 18 of the 100 values fall more than 10 per cent below the line of *direct proportionality* and the remainder fall above it. When aortic inflow was markedly reduced (50% or more, shaded area), renal flow was reduced in almost direct proportion. However, when aortic flow was reduced less than 50 per cent there was marked preferential flow distribution toward the kidney. Furthermore, it will be seen that in 40 of the 100 measurements renal blood flow was equal to or exceeded control renal blood flow.

4. *Somatic Flow.* A comparison of somatic flow change to aortic inflow change is seen in Figure 9. From this illustration it is seen that somatic flow reduction equalled aortic inflow reduction when the latter exceeded 45 per cent (shaded area) but that preferential shift of blood flow away from the hind-limb area occurred when the aortic inflow reduction was less than 45 per cent.

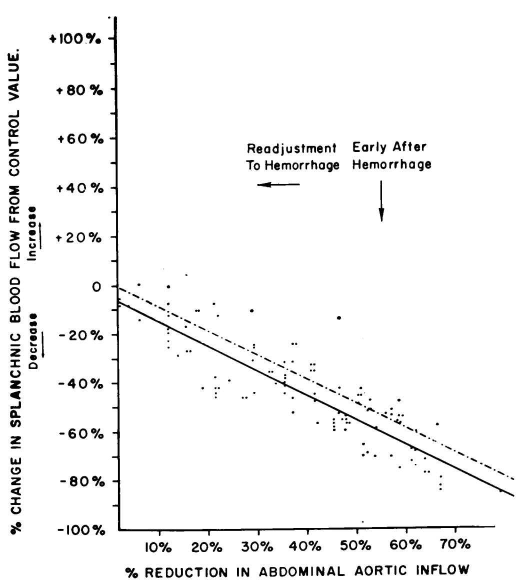

FIG. 7. Alteration in splanchnic (less renal) flow plotted against change in abdominal aortic inflow. Splanchnic flow fell in direct proportion to reduction in aortic inflow.

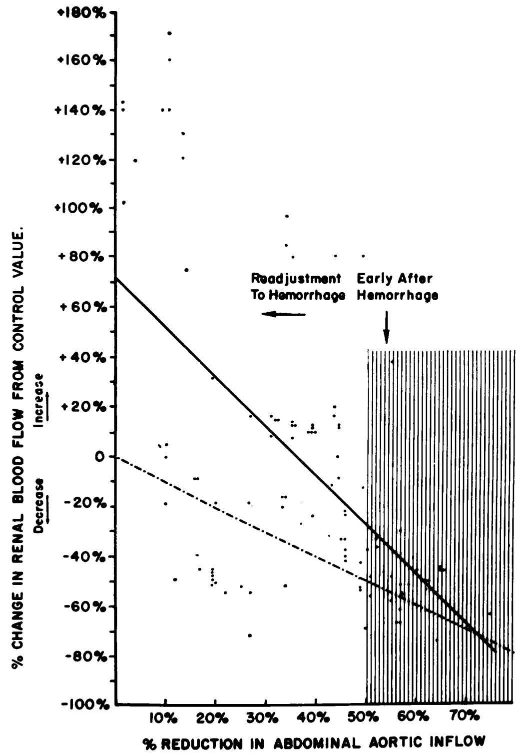

FIG. 8. Alteration in renal flow plotted against change in abdominal aortic inflow. Early after hemorrhage renal flow was depressed in almost direct proportion to reduction in inflow; during recovery marked preferential flow shift toward the renal vessels became evident.

Discussion

Most of the recent studies of hemorrhage and *shock* involves some modification of the Wiggers[5] or Fine[3] technic in an experimental animal, usually the dog. While every investigator uses some minor modification, basically these technics involve bleeding a heparinized animal from a major artery into a reservoir which then automatically fixes the arterial pressure at a level determined by the height of the reservoir above the animal. Arterial pressures of 20–50 mm. Hg are commonly chosen and, after holding the pressure at

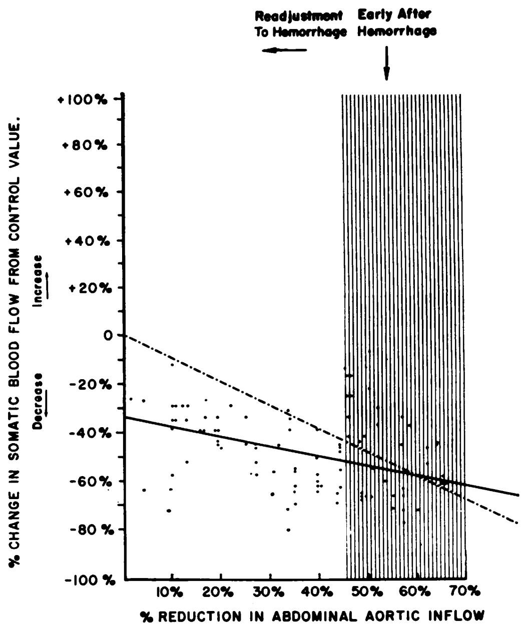

FIG. 9. Alteration in somatic flow (hind limbs) plotted against change in abdominal aortic inflow. Early after hemorrhage flow to this area was reduced in direct proportion to inflow; during recovery preferential shift of flow away from this area resulted.

this level for an arbitrary time, the shed blood is reinfused.

While much useful information has come from these technics, they have the basic defect that there is no clinical parallel situation. Blood loss immediately results in homeostatic mechanisms being activated which restore the arterial pressure toward normal, while the experimental technics described above continuously defeat this readjustment. This study has been concerned with flow and pressure readjustments which occur as a result of hemorrhage when such homeostatic mechanisms are permitted to operate. *Protective* redistribution of blood flow to *vital* areas has long been hypothesized but with relatively little confirmatory evidence. Previous work done in this laboratory[1] has shown that under conditions of total cardiopulmonary bypass in the dog, blood flow was shifted to the abdominal viscera and away from the lower extremities at low pump flow rates. Renal versus gastro-intestinal distribution was not determined in that study. Recently Williams and co-workers,[6] also working with cardiopulmonary bypass in the dog, reported that the percentage of total body flow distributed to the superior mesenteric and renal veins rose as total flow rate was reduced.

While flow redistribution under extracorporeal bypass is of great importance, it still remains doubtful as to whether information obtained in such preparations can be applied to the organisms with an intact propulsive mechanism. The animals studied here were hypovolemic. During extracorporeal circulation, there is no sure way to know whether the subject is hypovolemic, normovolemic, or hypervolemic.

Data obtained in the present study utilizing the intact animal are somewhat at variance with the finding reported by Williams[6] in that while renal flow was preferentially supported following hemorrhage, intestinal flow (splanchnic less renal) was not so supported. This redistribution of flow toward the kidneys could fairly be termed *protective* but the small shift away from the gastro-intestinal tract might well be detrimental in view of the very poor tolerance to ischemia of the gastro-intestinal tract demonstrated by Edwards.[2] The striking preferential preservation of coronary flow as a result of this small hemorrhage could certainly be termed protective. Finally, the findings of this study emphasize that arterial blood pressure may be a poor criterion for blood flow following hemorrhage.

Summary and Conclusions

1. Before and at frequent intervals for one hour following 15 cc./Kg. hemorrhage, the flow was measured in the following vessels or areas of the dog: coronary, brachiocephalic, left subclavian, descending aorta, abdominal aortic inflow, splanchnic area (excluding renal), somatic (hind limbs), and ascending aorta. Eight hun-

dred separate flow measurements were performed.

2. A marked discrepancy was noted between alterations in arterial blood pressure and change in cardiac output: cardiac output was reduced 40 per cent when blood pressure was reduced only 15 per cent.

3. There was preferential maintenance and often absolute increase in coronary flow (59 of 115 measurements).

4. Early marked reduction in renal blood flow was followed by return to levels equalling or exceeding control values in 40 of 100 measurements.

5. Shift of blood flow away from the gastro-intestinal area was noted but was felt to be of borderline significance.

6. Marked shift of flow away from the hind limb somatic area was noted.

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Announcement

The Editorial and Advisory Board, and the publisher of ANNALS OF SURGERY are pleased to announce the appointment of two distinguished Surgeons to the Editorial Board: Doctor Oscar Creech, Jr., and Doctor Harris B. Shumacker, Jr.

Doctor Creech is William Henderson Professor of Surgery and Chairman of the Department at Tulane University. Doctor Shumacker is Chairman of the Department of Surgery at Indiana University.