The relationship of portal venous to mesenteric arterial pressure during normovolemic hemorrhagic shock suggests that significant volumes of blood may be pooled out of active circulation in the mesenteric vasculature, thus contributing to the development of irreversibility. This contention has received some support from reports by Delorme et al., who detected elevation of intestinal red cell volume during hemorrhagic shock by a method which recorded changes in the radioactivity of an intestinal segment. However, other reports have failed to corroborate this change in intestinal blood volume. Johnson and Selkurt, employing a tissue-weight method, and Reynell et al., utilizing Bromsulphalein sodium (BSP) extraction, failed to detect any frequent elevation in mesenteric and splanchnic blood volumes, respectively. This discrepancy may reflect the fact that the tissue-weight method does not distinguish between vascular and extravascular changes, and the possibility exists that alterations in blood volume may be obscured or negated by changes in extravascular volume. In addition, BSP extraction as an index of splanchnic flow and volume is of questionable value, since BSP removal by the liver is modified during hemorrhagic shock.

Since irreversible shock is associated with a reduction in circulating blood volume, and the intestinal vasculature may be a site of significant vascular pooling, the alterations in mesenteric plasma volume during the induction and development of hemorrhagic shock were investigated.

Methods

Mongrel dogs ranging in weight from 12 to 30 Kg. were used. The animals were anesthetized with pentobarbital (30 mg./Kg.) by means of intravenous injection. A midline abdominal incision was made, and the superior mesenteric artery, celiac artery, and portal vein were isolated from their investments and surrounding nerves. In addition, the carotid and femoral arteries and the jugular and femoral veins were similarly isolated.

A diagram of the experimental arrangement is presented in figure 1. The intestinal circulation was perfused through an external arterial circuit introduced between the carotid and superior mesenteric arteries. This exterior circuit was equipped with a T tube for blood pressure recording and an injection manifold for intra-arterial injections.

Another external loop was introduced into the venous side of the intestinal circulation: (a) by a double cannulation of the portal vein, thereby retaining the liver in series with the intestine; and (b) between the portal vein and the jugular, thereby bypassing the liver. While this variation in procedure did not introduce any modifications in the nature of the data, the latter procedure did provide more stable preparations.

The venous loop was equipped with a counting cell for radioactive assay, a T tube for venous pressure registration, and a stopcock for direct flow measurements.

Systemic arterial pressure was recorded from the femoral artery, which was also connected to a modified Lawson bottle for hemorrhage. The femoral vein was used for infusion. Hemorrhage was performed to a level of 60 mm. Hg, and reinfusion took place when 30 per cent of the maximum volume hemorrhaged had become auto-infused.

Mesenteric vascular volume was estimated by means of the indicator-dilution method of Stewart and of Hamilton et al. Radioiodinated albumin was injected intra-arterially, and its appearance characteristics on the venous side of the tissue were recorded with a scintillation-ratemeter-recorder system.

Resistance was calculated as the ratio of the net perfusion pressure (mesenteric arterial—portal venous) to the mesenteric blood flow and is expressed as mm. Hg/ml./min.

Results

Of the 35 animals used in this study, 21 were considered acceptable on the basis of the duration of the experimental procedure. Only
animals which were maintained for periods in excess of 90 minutes were used for analysis. These were classified into two groups in accordance with the changes in mesenteric vascular resistance (MVR). Group I consisted of those preparations which displayed a progressive elevation in mesenteric vascular resistance during the late hemorrhage phase, while group II animals exhibited little or no significant change in mesenteric vascular resistance throughout the hemorrhagic period.

The average control MVR of animals in group I was 0.75 P.R.U., and the average control mesenteric plasma volume (MPV) was 100 ml. Hemorrhage produced an increase in MVR averaging 120 per cent above control, and a decrease in MPV averaging 65 per cent. Reinfusion resulted in a slight net return of MVR to a level 100 per cent above control, and MPV also displayed a slight recovery to 50 per cent below control. In group II, control MVR averaged 0.5 P.R.U. and control MPV averaged 100 ml. Hemorrhage failed to produce any significant net change in MVR, but MPV declined about 25 per cent below control. Reinfusion had little lasting effect on MVR, while MPV recovered to about 10 to 15 per cent below control.

Group I

This type of response was seen in 11 of the 21 animals. Illustrations of two variations appear in figures 2 and 3. Immediately following hemorrhage, MVR remained essentially unaltered, while MPV declined. MVR did not rise until later in the hemorrhagic period when autoinfusion began. An additional, frequent observation during the autoinfusion period of hemorrhage was a progressive elevation in portal venous pressure (PVP). Despite this elevated PVP, MPV continued to decline somewhat. With reinfusion, MVR declined abruptly to approximately control levels. MPV exhibited a rise, but only infrequently did it approach control levels. In no situation was there any indication of hyperemia. At this
point in the response to reinfusion, one of two changes was seen. Either MVR returned rapidly to a markedly elevated level and MPV remained depressed (fig. 2), or MVR remained in the vicinity of the control range and MPV maintained a degree of restoration (fig. 3). In neither case did reinfusion restore mesenteric arterial pressure, and despite a marked increase in MVR, mesenteric arterial pressure declined progressively, and death resulted equally in both cases.

**Group II**

A typical group II response, observed in 10 experiments, is shown in figure 4. It will be noted that MVR remained essentially unaltered throughout the experimental period. MPV declined slightly and in a manner which seemed to parallel the reduction in mesenteric arterial pressure. Another interesting feature observed occasionally was the marked elevation in portal venous pressure which did not have any apparent effect on MPV. Group II animals were considered to be nonreactive, whereas those of group I were reactive. The reason for this discrepancy is not known.

**Discussion**

Hemorrhages of 2 to 4 per cent of the body weight produce a reduction in blood pressure which leads to an elevation of peripheral resistance. It would appear that the mesenteric vascular resistance does not contribute to this primary alteration in total peripheral resistance. It is not until autoinfusion from the hemorrhage reservoir begins that mesenteric vascular resistance proceeds to rise. Presumably, autoinfusion signifies the failure of the primary resistance elements to maintain the blood pressure. This late participation of the mesenteric vasculature in the perivascular response to hemorrhage suggests this vascular region may be a secondary resistance circuit. Similar discrepancies between total peripheral resistance and that of the mesenteric vasculature have been observed by Selkurt and Brecher and by Reynell et al. Since autoinfusion proceeds at an uninterrupted rate and blood pressure remains depressed, it would appear that this secondary contribution of the mesenteric vasculature to total peripheral resistance is either ineffective or is counteracted by reductions in resistance in vessels previously constricted.

Although the mesenteric vasculature does not contribute to the primary increase in peripheral resistance, it does participate in the total systemic response by contributing to venous return. The reduction in circulating plasma volume was approximately 30 per cent, whereas mesenteric plasma volume declined by about 45 per cent. This volume change implies an active contribution by the mesenteric circulation to the systemic circulation.

Presumably, the volume of blood contained within a tissue at any one time is determined by the inflow and outflow resistances, the mean level of tone within the vascular bed, and the elasticity of the vascular elements of the tissue. A portion of the reduction in mesenteric plasma volume must be due to the elastic recoil of a segment of the vasculature, probably arterial. However, one would expect the extent of this reduction to be determined by the transmural pressure gradient so that it should be closely related to the reduction in
circulating volume and blood pressure. Since inflow resistance remains relatively constant early in hemorrhage, mean vasculature tone must rise and/or outflow resistance must fall for tissue blood volume to decline out of proportion to circulating blood volume. Alexander has presented evidence of an elevation in tone of the large venous elements of the mesenteric circuit in response to hemorrhage. This change should produce a reduction in the capacity of the tissue vasculature. Whether the changes in outflow resistance occur as a consequence of hemorrhage is at this time somewhat conjectural.

With reinfusion, mesenteric vascular resistance declined, and mesenteric plasma volume rose. However, at no time was mesenteric plasma volume restored to control levels, and only infrequently did it approach control levels. There was no evidence of reactive hyperemia in any of the animals in this series. In addition, the rise in mesenteric plasma volume was usually very transient, returning rapidly to the preinfusion level. No evidence of vascular pooling as an immediate or progressive event was encountered.

On the basis of the reports of Selkurt et al. and Wiggers et al., it was expected that the mesenteric arterial-portal venous pressure ratio would exert some influence on mesenteric plasma volume, with the volume varying inversely to the ratio. No correlation between the pressure ratio and tissue plasma volume was noted. Apparently, a change in portal venous pressure is not a reliable index of mesenteric plasma volume changes.

There was a possibility that the volume estimated by the technique employed here represented the effective circulating plasma volume and did not include volumes of blood which might have become pooled or sequestered out of active circulation. Delorme et al. reported marked increases in intestinal red cell volume associated with hemorrhage and reinfusion. In order to clarify this discrepancy, the experiments of Delorme were repeated in every detail. In three attempts, we consistently failed to reproduce his findings. Instead, a pattern of change remarkably similar to that observed in most of our preparations was seen. This is shown in figure 5. The elevation observed by Delorme may reflect progressive contamination of the radioactive detector by extravasation of blood at the point of counting.

Since we have not been able to demonstrate an increase of blood volume in the mesenteric circulation during the development of irreversible hemorrhagic shock, we must conclude that pooling of blood in the mesenteric cir-

Figure 4
An illustration of a group II response of the mesenteric vasculature following hemorrhage and reinfusion.

Figure 5
The effect of hemorrhage and reinfusion on the red cell radioactivity of a loop of small intestine. The ordinate indicates the count rate recorded by a G-M detector-ratemeter-recorder system. The radioactive count rate is dependent on the dose and the site of counting; units would be entirely arbitrary and are therefore omitted.
culation is not a significant factor in the resulting failure of the animal.

Summary
The effect of hemorrhage and of reinfusion on the mesenteric circulation of dogs was determined. During the control period, the average mesenteric vascular resistance was 0.6 P.R.U., and the average mesenteric plasma volume was 100 ml. Hemorrhage produced an early reduction in mesenteric plasma volume, averaging 50 per cent, without any accompanying change in mesenteric vascular resistance. As the hemorrhagic period progressed, mesenteric vascular resistance rose to a level 120 per cent above control coincidental with the autoinfusion of blood from the hemorrhage reservoir. With the elevation in mesenteric vascular resistance, mesenteric plasma volume displayed a slight additional decline. Reinfusion produced only a slight and transient recovery of mesenteric vascular resistance and plasma volume. A comparison of mesenteric vascular resistance changes with those of mesenteric plasma volume indicates that no uniform relationship exists. Similar dissociation was seen between mesenteric plasma volume and portal venous pressure. No evidence of pooling of blood in the mesenteric circulation during the induction and development of normovolemic hemorrhagic shock was observed.

References
Mesenteric Circulation in Hemorrhagic Shock

JULIUS J. FRIEDMAN

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