Distribution of Blood Flow in the Digestive Tract of the Rat

By Sheldon H. Steiner, M.D., and Gustave C. E. Mueller, M.D.

A LTHOUGH a number of techniques are available for the measurement of total splanchnic blood flow, it has not yet been possible to measure blood flow to individual portions of the splanchnic bed without major operative procedures, which in themselves may influence the observed blood flow. The use of the isotope fractionation technique employing Rb\textsuperscript{86} as the indicator seemed particularly well suited to the estimation of functional perfusion rates in essentially undisturbed animals. The existence of physiological and anatomical gradients in the distribution of blood vessels through the small bowel suggests the existence of a blood flow gradient. In this investigation, the isotope fractionation technique was used to make comparative blood flow measurements to various portions of the gastrointestinal tract of anesthetized rats and to attempt to define the blood flow gradient through the small bowel.

Methods

Sprague-Dawley rats weighing 200 to 400 Gm. fasted for 18 hours with water ad libitum were anesthetized with veterinary pentobarbital (Abbott) 40 mg./Kg., I.P. This preparation is made up in 10 per cent alcohol; in the dose used, a 200 Gm. rat received 0.013 ml. alcohol. Nine animals were used to determine cardiac output by the indicator dilution technique employing Rb\textsuperscript{86}. Fractional distribution of blood flow was measured by the isotope fractionation technique described by Sapirstein. Two \( \mu \)c of Rb\textsuperscript{86}Cl were injected intravenously. Half the animals were killed at 20 seconds and half at 40 seconds after injection. Various organs of the gastrointestinal tract and associated structures were taken for counting (table 1.) Because of the difficulty in identifying the anatomical subdivisions of the small intestine, the ligament of Treitz was used to mark the termination of the duodenum, the remainder of the small intestine being arbitrarily divided into two equal halves to represent jejunum and ileum. Hollow organs were emptied of their luminal contents before weighing and counting.

In order to determine the detailed nature of the small intestinal gradient, another group containing 40 animals was studied. Immediately after death, the small bowel was stretched horizontally for two minutes by a 20 Gm. weight to minimize retraction. The first 10 cm. were cut into four 2.5-cm. lengths; the next 10 cm., into 5-cm. lengths; and the remainder, into 10-cm. segments. The segments were dried to constant weight at 70 C. after being counted.

Determination of Isotope Content

The Rb\textsuperscript{86} content of the organs was determined by gamma counting, using either a sodium iodide well crystal or a multiple bismuth tube well counter (Nucleonic Corporation of America). Recovery of injected isotope from the organs removed and the residual carcasses was 100 to 103 per cent of the injected quantity.

Relation of Organ Isotope Content to Blood Flow

The basic consideration in the determination of blood flow by the organ uptake of an indicator is that the organ content must be described at the time of the initial partition of the cardiac output during the first circulation. Since this time cannot be accurately determined, it becomes necessary to extrapolate from observations made early after the initial localization to this time. In the case of Rb\textsuperscript{86} and K\textsuperscript{42} changes after the initial delivery are so slow in all organs other than the brain and aorta that they are undetectable for at least three minutes. Thus, the extrapolation to the initial time is simplified and can be made by averaging the early observations, in this case, those made at 20 and 40 seconds. It is evident that whenever a new organ or physiological variable is investigated constancy of uptake with respect to time must be established after the first circulation has washed through in order to justify this type of "extrapolation."

Extrapolation of results obtained at 20 and 40 seconds to the moment of initial delivery presupposes that the organ in question does not contain shunt for the label. The existence of a shunt will be displayed by a rapid rise and fall of organ label content synchronous with the rise and fall of the arterial label concentration. The latter
Table 1

<table>
<thead>
<tr>
<th>Digestive Tract Blood Flow*</th>
<th>Flow fractions</th>
<th>Injected dose/Gm.†</th>
<th>Injected dose/Gm.‡</th>
<th>Blood flow (17 rats) ml./min./Gm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teeth (incisors)</td>
<td>0.2 ± 0.09†</td>
<td>0.2 ± 0.08‡</td>
<td>0.2 ± 0.08§</td>
<td></td>
</tr>
<tr>
<td>Salivary glands</td>
<td>0.5 ± 0.14‡</td>
<td>0.5 ± 0.15‡</td>
<td>0.4 ± 0.12‡</td>
<td></td>
</tr>
<tr>
<td>Tongue</td>
<td>0.5 ± 0.26‡</td>
<td>0.5 ± 0.25‡</td>
<td>0.4 ± 0.25‡</td>
<td></td>
</tr>
<tr>
<td>Esophagus</td>
<td>0.6 ± 0.15‡</td>
<td>0.5 ± 0.17‡</td>
<td>0.6 ± 0.14‡</td>
<td></td>
</tr>
<tr>
<td>Stomach</td>
<td>0.4 ± 0.17‡</td>
<td>0.4 ± 0.13‡</td>
<td>0.4 ± 0.13‡</td>
<td></td>
</tr>
<tr>
<td>Duodenum</td>
<td>1.1 ± 0.32‡</td>
<td>1.2 ± 0.12‡</td>
<td>1.1 ± 0.28‡</td>
<td></td>
</tr>
<tr>
<td>Jejunum</td>
<td>0.9 ± 0.47‡</td>
<td>1.0 ± 0.18‡</td>
<td>0.9 ± 0.40‡</td>
<td></td>
</tr>
<tr>
<td>Ileum</td>
<td>0.7 ± 0.23‡</td>
<td>0.7 ± 0.09‡</td>
<td>0.7 ± 0.19‡</td>
<td></td>
</tr>
<tr>
<td>Cecum</td>
<td>0.5 ± 0.19‡</td>
<td>0.6 ± 0.28‡</td>
<td>0.5 ± 0.19‡</td>
<td></td>
</tr>
<tr>
<td>Colon</td>
<td>0.6 ± 0.20‡</td>
<td>0.6 ± 0.14‡</td>
<td>0.6 ± 0.17‡</td>
<td></td>
</tr>
<tr>
<td>Rectosigmoid</td>
<td>0.2 ± 0.19‡</td>
<td>0.2 ± 0.09‡</td>
<td>0.2 ± 0.20‡</td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td>0.9 ± 0.39‡</td>
<td>0.9 ± 0.33‡</td>
<td>0.8 ± 0.35‡</td>
<td></td>
</tr>
<tr>
<td>Pancreas</td>
<td>0.6 ± 0.18‡</td>
<td>0.5 ± 0.10‡</td>
<td>0.5 ± 0.16‡</td>
<td></td>
</tr>
<tr>
<td>Spleen</td>
<td>0.9 ± 0.22‡</td>
<td>0.8 ± 0.17‡</td>
<td>0.8 ± 0.19‡</td>
<td></td>
</tr>
</tbody>
</table>

*In 17 rats.
†F = variance ratio = 1.99 — highly nonsignificant (differences between 20 and 40 second rats).
‡Standard deviation.

Results

The nine animals used to establish the level of the cardiac output for the animals in this colony averaged 260±25 (S.E. mean) ml./Kg./min. This value corresponds well with others that have been reported.18-20

The fraction of the Rb⁶⁷ found per gram of each organ is given in table 1. Separate values are given for the animals killed at 20 seconds and at 40 seconds. An analysis of the variance in the means obtained for the two killing times showed no significant differences in any organ. This fulfills the necessary condition for the use of an average of the observations for the extrapolation to zero time which is required for the application of the isotope-fractionation technique for measurement of functional blood flow.

Upon converting these values to flow per gram of tissue, the duodenum is seen to have the highest perfusion rate of any structure in the gastrointestinal tract. The perfusion rate for the stomach is less than half as great; the jejunum, ileum, colon, and rectosigmoid show a progressive fall from the duodenal maximum.

The existence of a small bowel flow gradient is also indicated by the observations on the smaller segments which are described in figure 1. An analysis of the variance in the means obtained for the killing times of 20 and 40 seconds for all the segments showed no significant differences, and the fractions can then be extrapolated to zero time. The means are presented together. When the results are expressed on the basis of per cent of small bowel blood flow per unit mass, the perfusion rate increases progressively from the pylorus.
to its maximum at the tenth cm. (ligament of Treitz); distally the perfusion rate is diminished. The fall from the maximum to the fiftieth cm. is 42 per cent and from the fiftieth cm. to the last segment a 14 per cent decrease is observed. Expressed as per cent of small bowel blood flow per unit length, there is a very steep fall in perfusion rate in the first 10 cm. of bowel and a less precipitous fall in the remainder. Analysis of the differences in means (Newman-Keuls) shows a high degree of significance ($P < .05$) for the values by either method of expression, except for the initial increase on the dry weight basis which was just below the 95 per cent confidence level.

**Discussion**

The hepatic blood flow of the fasting anesthetized rat, calculated by addition of the isotope fractions of the liver and the organs which contribute to the portal bed, represented 42 ml./Kg./min. body weight or 190 ml./min./100 Gm. liver. These values are in close agreement with those reported for the dog.21-23

There is a wealth of anatomical evidence for the existence of a small bowel blood flow gradient.8-11 For the most part, the gradient has been described in terms of unit length rather than unit mass. In our findings, when the results were expressed on the basis of length, there was a continuous downward gradient in blood flow from the pylorus to the ileocecal valve; when they were expressed on the basis of unit mass, there was a progressive rise in the perfusion rate to a maximum value at a position which corresponded to the ligament of Treitz and a downward gradient, most marked in the jejunum, distal to this point. The progressive increase in flow in the length of the duodenum fits well with observations made by Wilkie10 on the vascularity of various portions of the duodenum of human cadavers.

Our findings for the blood flow gradient throughout the major portions of the small bowel are in very close agreement with those of Geber,24 who recently reported the results of direct cannulation of the mesenteric vessels in pentobarbital anesthetized dogs. Not only was the same gradient observed, but almost the same flow values per gram were reported.

We have noted previously that the technique employed does not measure total arterial inflow, but rather functional perfusion rates. Anatomical and functional shunts are not measured. Grim and Lindseth,25 using Na$^{24}$ glass microspheres, reported a shunt flow of 2 to 4 per cent for the dog jejunum and ileum. It has been demonstrated by Shepard et al.29 that functional shunting through the liver is very small for K$^{42}$ and Rb$^{86}$. However, since organ flow values are based on cardiac outputs from animals not used for the determination of flow fractions, it seems most advisable to place emphasis on the relative relationships between functional perfusion rates rather than on the absolute numerical values.

**Summary**

The rubidium fractionation technique has been used to make comparative measurements of functional perfusion rates in the gastrointestinal tract of relatively undisturbed but fasted and anesthetized rats. The duodenum has the highest functional perfusion rate per unit mass of the entire digestive tract; the stomach is less than half as well perfused. The remainder of the tract to the rectosigmoid shows a progressive decrease. The small intestine shows a progressive increase in func-

![Figure 1](http://circres.ahajournals.org/)

**Small bowel blood flow gradient.** Per cent injected dose/cm. in 40 rats (—); per cent injected dose/Gm. dry weight/cm. in 20 rats (—–).

_Circulation Research, Volume IX, January 1961_
tional flow per unit mass from the pylorus to the ligament of Treitz and then a progressive decrease, most marked in the jejunum to the ileocecal valve. Blood flow values to other structures of the gastrointestinal tract are also given.

Acknowledgment
The authors wish to acknowledge the helpful cooperation and encouragement of Dr. Leo A. Sapirstein, in the preparation of this work. We are indebted to Dr. James Prine, Captain, USAF (VC), for preparation and review of microscopic sections.

References
Distribution of Blood Flow in the Digestive Tract of the Rat

SHELDON H. STEINER and GUSTAVE C. E. MUELLER

doi: 10.1161/01.RES.9.1.99

Circulation Research is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1961 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7330. Online ISSN: 1524-4571

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circres.ahajournals.org/content/9/1/99

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation Research can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation Research is online at:
http://circres.ahajournals.org/subscriptions/