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THE EFFECT OF INTRA-ARTERIAL CUSHIONS ON PLASMA SKIMMING IN SMALL ARTERIES

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It is well known that when blood flows through a small artery, the cells occupy the axial stream, leaving a comparatively cell-poor peripheral zone; Bayliss (1959), however, has suggested that this effect may not be as marked as had been previously believed. It might be expected that a branch leaving such an artery approximately at right angles would sample mainly the peripheral zone, and this effect has, in fact, been observed by Krogh (1929) who first used the term 'plasma skimming' to describe the phenomenon. The only previous quantitative investigation is that of Pappenheimer (1958) who studied plasma skimming in glass capillary tubes and found that the blood emerging from the main tube contained 47·5 % of cells, while that from a side branch contained only 39 %. The uterine artery of the rat appears to be a vessel in which plasma skimming would occur, since it gives to the uterus a series of branches which leave the main trunk at right angles. However, it has been shown (Moffat, 1959) that the orifice of each of these branches is provided with a pair of intra-arterial cushions. These are streamlined longitudinally and pass on either side of the orifice of the collateral vessel, projecting into the lumen of the main trunk (Fig. 1). Similar cushions have been described in the arteries of many organs of a variety of species, including man. Since these cushions project into the region of the axial stream, it occurred to us that their function might be to abolish plasma skimming, or even to produce the opposite effect by increasing the cell concentration of the blood passing into the branch.

The object of the present study was to make a quantitative investigation of plasma skimming in the intestinal arteries of the rat, where there are no intra-arterial cushions, and to investigate the effect of the presence of such cushions in the uterine artery. The latter vessel was studied in both adult and immature rats, since in young animals the cushions are extremely small in relation to the size of the lumen (Moffat, 1959).

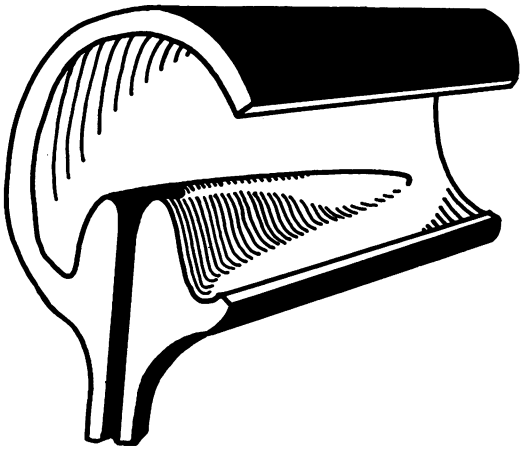

Fig. 1. Diagrammatic representation of the intra-arterial cushions at the origin of a branch of the uterine artery.

METHODS

The experiments were performed upon 66 Wistar rats divided into three groups. The first group consisted of 20 adult females and the second of 20 adult males; all these weighed over 200 g. The third group of 26 young females were over 9 weeks old but had a body weight of less than 200 g. The animals were anaesthetized by the subcutaneous or intraperitoneal injection of sodium pentobarbitone. The abdomen was opened by a left anterolateral incision and, in the case of the females, the left uterine horn and its mesentery were exposed. With the aid of a binocular dissecting microscope a suitable branch of the uterine artery was chosen and a wisp of cotton wool soaked in 2·4 % papaverine hydrochloride applied to the area. Heparin, 125 u. in 0·1 ml. saline solution, was then injected into the jugular vein. The operation site was mopped dry and the uterine branch divided a few millimetres from its origin, care being taken to avoid damage to the accompanying vein. A sample of 0·02 ml. of blood was taken from the bleeding end of the vessel. The bleeding point was then covered with a pledgelet of cotton wool, the main trunk divided near the origin of the branch, and a further sample of blood removed. All pipettes used had previously been calibrated with mercury. The haemoglobin content of the blood samples was estimated by the oxyhaemoglobin method (Dacie, 1956), using an E.E.L. portable colorimeter. In the male rats the procedure was repeated with a portion of the mesentery of the small intestine in which the selected vessels were similar in both size and arrangement to the uterine artery and its branches.

In both male and female rats portions of the main trunk at the origin of the sampled branch were removed for histological examination to confirm the presence or absence of intra-arterial cushions.

RESULTS

The difference between the haemoglobin values of the blood obtained from a main trunk and that from its branch in the adult animals is shown in Fig. 2. Of the 20 adult females, 17 had a higher Hb value in the sample of blood from the branch than in that from the uterine artery itself. In

two the values were equal and in the remaining animal the value was higher in the main trunk than in the branch. Of the 20 males, 16 had a lower Hb value in the sample from the branch than in that from the parent mesenteric vessel. In one the values were equal and in the remaining three animals the value was higher in the branch than in the main trunk.

Figure 3 shows, for the 46 females of groups 1 and 3, the difference between the Hb values of the blood taken from the uterine artery and that from its branch, plotted against body weight. With few exceptions rats weighing under 200 g had a lower Hb value in the branch than in the main trunk, while rats weighing over 200 g had a higher value in the branch than in the trunk.

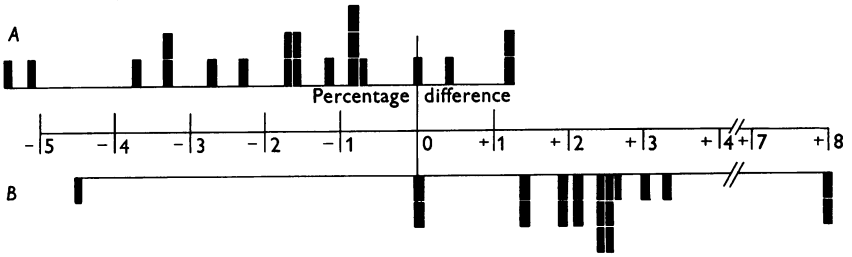

Fig. 2. Difference between Hb readings of blood from an arterial branch and that from its parent trunk, expressed as a percentage of the trunk Hb; each block represents one experiment: + value higher in the branch than in the trunk; − value lower in the branch than in the trunk. *A*, mesenteric arteries, group 2; *B*, uterine arteries of adult females, group 1.

Histological examination confirmed the presence of intra-arterial cushions in the uterine arteries of the female rats, and their absence in the branches of the mesenteric arteries of the males. Figure 4 compares the cushions in an adult (group 1) and a young (group 3) female and illustrates the relatively small size of the cushions in the young rats.

DISCUSSION

Some inaccuracies in the haemoglobin values obtained may have been introduced by the method of blood sampling. The vessels had to be torn across with watchmaker's forceps, which necessitated the use of papaverine to prevent spasm. Nevertheless, it was felt that this was the best method of obtaining a suitable sample, since the use of micropipettes has the disadvantage that blood may be removed from either the peripheral or the axial stream. Any bias introduced by operation or sampling technique would have affected all the results in a similar way, as an identical procedure was followed in each experiment.

The readings obtained for the uterine arteries showed less scatter than those for the mesenteric arteries, since the latter vessels varied somewhat

in size and the branches did not always leave the main trunk exactly at right angles.

The results of the studies on the mesenteric vessels confirm that plasma skimming occurs in arteries of this size without intra-arterial cushions.

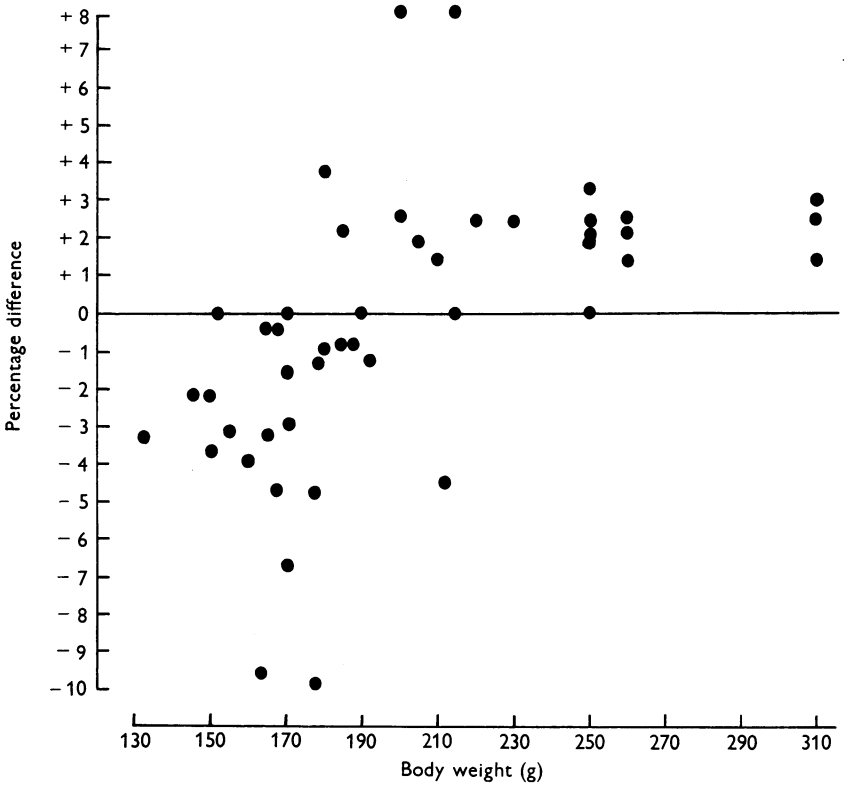

Fig. 3. Difference between Hb readings of blood from a branch of the uterine artery and that from the parent trunk, expressed as a percentage of the trunk Hb and plotted against body weight. + value higher and − value lower in the branch than in the trunk.

When fully developed cushions are present, as in the uterine arteries of adult females, blood of a relatively high Hb content passes into the branch, and the most likely explanation of this is that the cushions sample the axial stream with its high proportion of cells. We propose to use the term 'cell skimming' for this phenomenon.

Figure 3 shows that plasma skimming occurs in the uterine artery of rats weighing under 200 g, whilst cell skimming takes place in rats whose body weight exceeds this figure. Figure 4 explains this difference. In the younger animals the cushions are small and project only slightly, if at all,

into the lumen of the main artery, whereas in the fully grown animals the cushions project almost to the centre of the lumen.

The cell-skimming function of intra-arterial cushions has not been previously described, since it has generally been assumed that they serve to control the flow of blood into the collateral branch by a sphincter-like action. However, Wagenvoort (1954), in a discussion of a somewhat different type of cushion in the aorta of *Petromyzon* suggested that their function may be to sample the axial stream, since, owing to the peculiar anatomical arrangement in this animal, the peripheral stream may contain de-oxygenated blood. Plasma skimming, on the other hand, has been observed *in vivo* by Krogh (1929) in the blood vessels of the frog and also by Thuranszky (1957) in the central zone of the retina of the cat's eye.

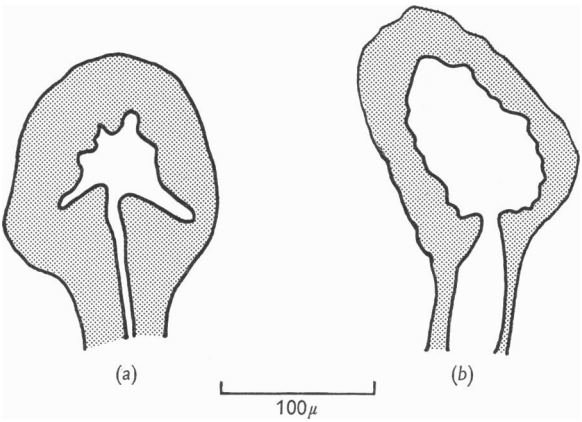

Fig. 4. Tracings of transverse sections of the uterine arteries to show intra-arterial cushions at the origin of a side branch. (*a*) Fully developed cushions from an adult female (group 1); (*b*) immature cushions from a female weighing under 200 g (group 3).

It is not easy to account for the functional significance of cell skimming in the uterine artery, but it is of some interest to consider the renal circulation in the light of these results, since Picard, Donnet, Chambost & Brechet (1950) and Picard & Chambost (1952) have described intra-arterial cushions at the orifices of the afferent vessels leading to the juxtamedullary glomeruli in the dog, cat and rat. In the rat the histological structure of the cushions in the kidney is similar to that of the cushions in the uterine artery and they show similar histochemical reactions (Fourman and Moffat, unpublished). It has been suggested by Pappenheimer & Kinter (1956) and Kinter & Pappenheimer (1956*a*, *b*), that plasma skimming occurs in the interlobular arteries and that this phenomenon may explain many aspects of renal physiology. One implication of this theory is that the relative

haematocrit of the blood in the interlobular arteries will increase as the arteries approach the more superficial layer of the cortex. Emery, Gowenlock, Riddell & Black (1959), who worked on the dog's kidney, have, however, shown that the value is higher in the deeper layers. This may readily be explained on the basis of cell skimming by the cushions at the orifices of the afferent arterioles of the juxta-medullary glomeruli. Such cell skimming, would, like plasma skimming, produce 'cell separation' and provide an equally satisfactory explanation of many of the findings upon which Pappenheimer and Kinter based their hypothesis.

SUMMARY

1. The Hb value of blood obtained from an arterial branch was compared with that of blood from the parent trunk in 66 rats.

2. In the 20 males, in which the mesenteric arteries were used, the Hb value was lower in the branch than in the main trunk. This was attributed to plasma skimming.

3. In the 20 adult females, in which the uterine arteries were used, the Hb value was higher in the branch than in the main trunk. In the 26 females which had a body weight of less than 200 g, the Hb value was lower in the branch than in the main trunk.

4. Large intra-arterial cushions in the uterine artery of the adult animals project towards the centre of the lumen to sample the axial stream, thus producing 'cell skimming'. In the immature animals the cushions project little, if at all, into the lumen, so that plasma skimming occurs.

5. The significance of similar cushions which are found in the kidneys of a number of animals is discussed.

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