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BLOOD PERFUSION OF THE KIDNEY OF *LOPHIUS PISCATORIUS* L.

II. INFLUENCE OF PERFUSION PRESSURE ON URINE VOLUME

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(Text-figs. 1–4)

In a previous publication (Brull, Nizet & Verney, 1953) it was shown that the kidneys of *Lophius*, perfused with heparinized blood, secrete urine which is similar to bladder urine. One of the conclusions was that 'changes in perfusion pressure up to 100–150 mm of water, raised the urine flow; above 150 mm there was no effect'. The object of the experiments described below was to investigate the relationship between perfusion pressure and urine flow, especially below the critical level of 150 mm water.

The experiments were carried out in July–August in the Plymouth Laboratory, where we were provided with a large supply of live *Lophius*, for which we are much indebted to the Director and Staff of the Laboratory.

Methods

We improved our perfusion technique by the use of a pump made of plexiglass, and a small rotating oxygenator built by one of us (Y. Cuypers) for this purpose.

The pump and oxygenator were started working before the kidneys were connected, so as to oxygenate the blood. A closed circulation circuit was made with plastic tubes, from the reservoir to the kidneys and from the kidneys to the pump. To prevent twisting of the vessels, the kidneys were laid on a thin layer of perforated wood on to which the cannulae could be tied down.

The venous flow was measured directly with a burette and stop-watch. The experiments were carried out at room temperature.

Results

Experiment 9

Two kidneys, from the same *Lophius* weighing 4·8 kg, were perfused by the same pool of blood, kidney A at a pressure of 80 mm water, and kidney B at 260 mm throughout the experiment (Table I).

The blood flow in kidney B was much higher than in A; but the figure was missed by accident. In this pair of kidneys, the urine flow was no better at 260 mm than at 80 mm; we are very likely above the critical maximum level of perfusion. The secretion needs to be studied while starting at lower perfusion pressures.

TABLE I. PERFUSION EXPERIMENT 9

	Kidney A (weight 9·5 g)				Kidney B (weight 9·5 g)			
		Urine				Urine		
Time (min)	Blood flow (ml./g/min)	No.	Vol. (ml.)	Flow (ml./g/h)	Blood flow (ml./g/min)	No.	Vol. (ml.)	Flow (ml./g/h)
0	Perfusion started							
30	—	—	—	—	Perfusion started			
45	Pressure regulated at 80 mm				Pressure regulated at 260 mm			
71	—	First drop in 3 min			—	First drop in 3 min		
130	—	1	1·0	0·10	—	—	—	—
145	—	—	—	—	—	1	1·0	0·09
245	1·3	2	2·0	0·13	—	2	1·7	0·10

Both ureteral cannulae contain 0·5 ml. extra urine.

TABLE II. PERFUSION EXPERIMENT 13

	Kidney A				Kidney B			
Time (min)	Perfusion pressure (mm blood)	Blood flow (ml./g/min)	Urine no.	Urine flow (ml./g/h)	Perfusion pressure (mm blood)	Blood flow (ml./g/min)	Urine no.	Urine flow (ml./g/h)
0	80	Perfusion started						
15	—	—	First drop					
45	—	—	—	—	25	Perfusion started		
60	80	0·45	—	—	25	0·10	—	—
74	—	—	1	0·18	—	—	—	—
100	80→70	—	—	—	25→70	—	—	—
107	70	0·40	—	—	—	0·70	—	—
120	—	—	—	—	—	—	First drop	
140	—	—	2	0·16	—	—	—	—
145	70→45	—	—	—	—	—	—	—
150	—	0·30	—	—	—	—	—	—
200	45→75	0·24	3	0·12	—	—	1	0·80
295	75	—	4	0·11	70	—	2	0·10

Experiment 13

Perfusion with the same pool of blood was carried out on two kidneys: kidney A weighing 11 g, from a fish of 6·4 kg; kidney B weighing 6 g, from a fish of 3·5 kg (Table II). At the first three stages of perfusion pressure, 80, 70 and 45, the urine flow of kidney A is parallel to the pressure: 0·18, 0·16 and 0·12. After 3 h 20 min of perfusion, the kidney no longer responds to a rise of pressure from 45 up to 75. Perfusion of kidney B at the low pressure of 25 gives no urine; at 70 mm secretion starts with an average output of 0·09.

Exps. 9 and 13 confirm our previous results, namely that the kidney is sensitive to changes in pressure below about 100 mm of water. We therefore decided to investigate this in detail by recording the number of drops of urine as a function of perfusion pressure.

Experiments 21–23

In these three experiments (see Fig. 1) two kidneys from the same fish were simultaneously perfused by the same pool of blood at rising or decreasing pressures. The arrow on the tracings indicates whether the perfusion is started at low or high pressure. Urine drops were recorded and the urine flows are translated into ml per gram of kidney per minute.

At each rise of pressure the reaction of the kidney is usually slow, and a certain time may elapse before the urine flow reaches its maximum, as shown where some curves slope up at the beginning and down later when the pressure is lowered (22B).

In Exp. 21, we succeeded in perfusing one kidney only; during the first 2 h of perfusion, the pressure was progressively lowered (see curve $21B_1$), while during the next 2 h, the perfusion was carried out at rising pressures ($21B_2$).

The most striking facts shown by the slope of the six curves would seem to be the following. (1) Below about 25–30 mm pressure, no urine is secreted. (2) Between 30 mm and about 200–250 mm, the volume of urine secreted per minute follows the perfusion pressure in a regular way, the response following an exponential curve. (3) Above perfusion pressures of about 200–250, the urine flow is no longer influenced by further rises of pressure; this last finding confirms the results of the first publication on the same subject (Brull *et al.*, 1953).

The *blood flow* through the kidneys is of the same magnitude as in the experiments previously published (Brull *et al.*, 1953), in which arterialized blood was used. The results are shown in Figs. 2–4. In kidney A, Exp. 23, and at low pressure, we found the curve had the same tendency as reported before to change its slope (Fig. 4).

Discussion

In our opinion, one striking fact appears from these results: below a critical perfusion pressure varying from about 100 up to 225 mm from one kidney to the other, the urine flow responds to the pressure in the form of an exponential curve. We have plotted the figures of urine flow against the blood flow, but have not reproduced them here, because these curves are similar to those shown in Fig. 1. It would be interesting to find out which of the two factors is the determining one: pressure or blood flow.

In Exp. 21 (Fig. 2), there are two perfusion phases: we started with a pressure of 190 mm, decreased it to 75 mm, and raised it again to 220 mm;

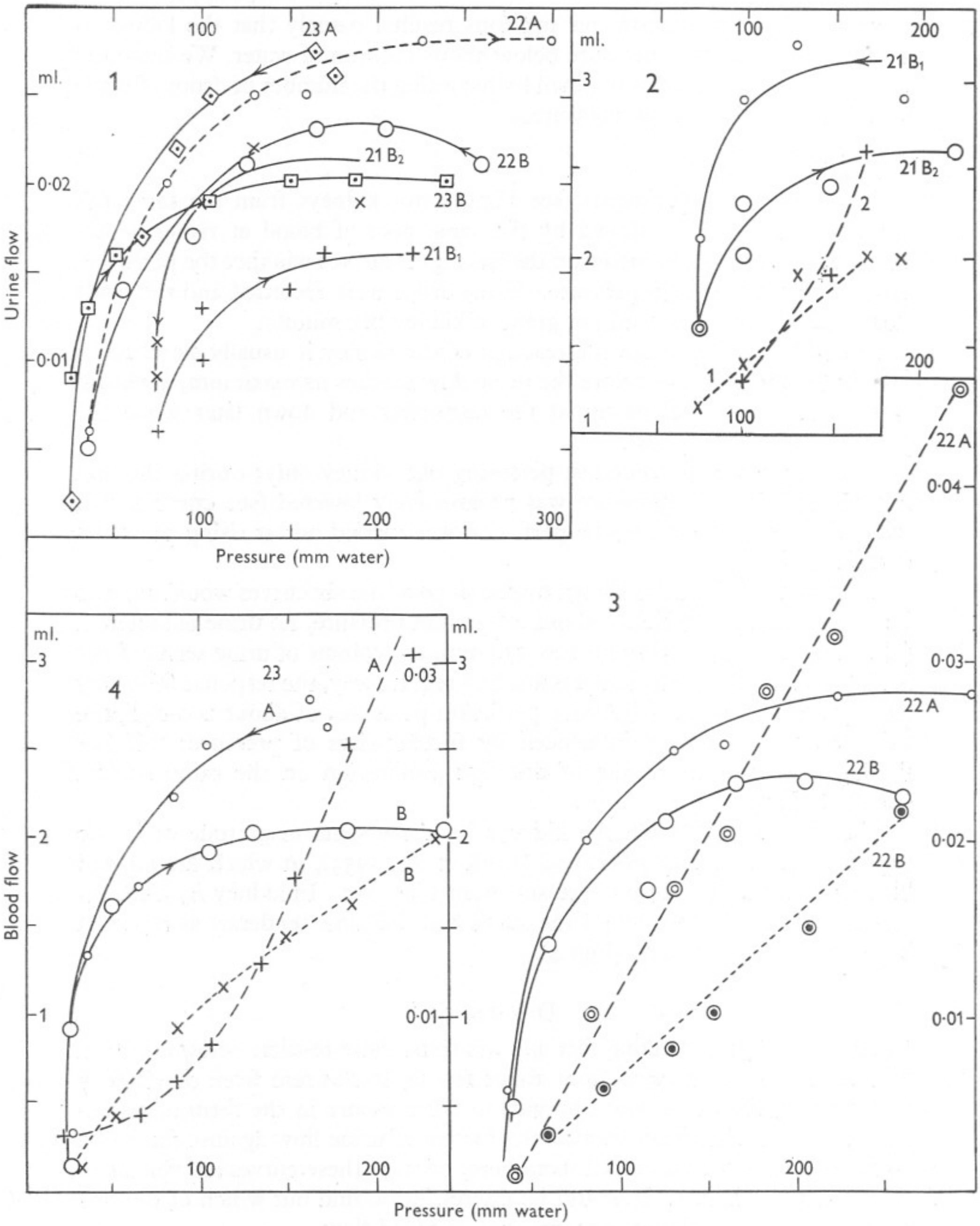

Fig. 1. Urine flow (in ml./g/min) plotted against perfusion pressure (in mm water) in five kidneys, two in Exp. 22, two in Exp. 23, one in Exp. 21 at two stages. The arrows indicate whether the perfusion started at high or at low pressure.

Figs. 2–4. Renal blood flows (dotted lines) and urine flows (plain lines) in three experiments.

during the first stage, the curve of urine flow runs higher than during phase 2, whereas there is no similar difference to be seen in the blood flow.

In Exp. 22 (Fig. 3), two kidneys were perfused at the same ranges of pressure, kidney A starting from a low level, kidney B from a high level; the first kidney produces more urine, and its blood flows are higher. Exp. 23 (Fig. 4) was carried out under similar conditions: here, kidney A, with higher urine flows, has higher blood flows at the beginning and lower ones at the end.

Owing to the inconsistency of these results, we cannot conclude that blood flow may be more determinant than perfusion pressure. The question remains open.

The question arises whether the water is secreted through a purely physical force or through an active process. A detailed cataphoretic analysis of plasma proteins has been published in a previous paper (Brull & Nizet, 1953) and gave 39 g/l. of total proteins with 6·7 albumin and 93·3% globulin. This might mean a colloid osmotic pressure of about 6·5 mm of mercury or 85 mm of water. Since urine is secreted at pressures of 30 and 40 mm of water, this must be done against the osmotic pressure of the proteins, through an active process.

On the other hand, Bieter (1931) found that the kidney of *Opsanus tau*, also aglomerular, secretes urine at a pressure higher than that in the dorsal aorta. Yet this finding is irrelevant when *Lophius* is considered, since Nizet (in press) has shown that China ink injected into the arterial blood does not reach the tubules, going no farther than the capsulae. The blood supply to the tubules is conveyed solely by the renal portal veins.

Thus, admittedly, the tubules of *Lophius*, which have lost their glomeruli during the first stage of life, secrete water like a salivary gland. Have glomular kidneys lost such a property? This question will be worth discussing elsewhere, in the light of research done by one of us on the kidney of the dog.

Let us consider for a moment the *oxygen consumption* of the *Lophius* kidney. We already know (Brull *et al.*, 1953) that perfusion with oxygenated blood does not provide more, or more concentrated, urine than venous blood as it is collected from the fish. In the present experiments, our attempts to measure the degree of oxygenation of the blood have shown that the venous blood which normally irrigates the kidney contains no 'measurable' amount of oxygen. If an increased flow of arterialized blood acted merely by way of increasing the oxygen supply, it would be difficult to explain how a similar increase of venous blood supply would produce a result of the same magnitude.

It seems that the oxygen requirement of the *Lophius* kidney is very small. Its significance requires further study. Still, there are very active enzymic systems in such kidneys, considering they concentrate Mg about 50 times (with venous blood as well).

SUMMARY

The urine secretion of the kidneys of *Lophius piscatorius* perfused with heparinized *Lophius* blood is very sensitive to perfusion pressure below a critical level, above which it becomes insensitive. The response of the urine flow to pressure takes the form of an exponential curve.

The blood flow through the kidneys, while rising slowly at pressures of about 20–30 mm of water, responds arithmetically to pressure above such levels.

At present it is impossible to make out whether pressure or blood flow has the greatest influence on secretion.

Water secretion in the aglomerular kidney is an active process. The oxygen consumption of the *Lophius* kidney is unmeasurably low, yet remains a possible factor in secretion.

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