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EFFECT OF BLADDER DISTENSION ON ARTERIAL BLOOD PRESSURE AND RENAL CIRCULATION: ROLE OF SPLANCHNIC AND BUFFER NERVES

By S. R. MUKHERJEE*

From the Department of Physiology, University of Edinburgh

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Sherrington (1899) demonstrated that reflex vascular responses are obtained when certain hollow viscera, e.g. ureter, bile duct, are stretched. Guttmann & Whitteridge (1947) showed that the distension of the urinary bladder in paraplegics (C8–T5) is always associated with a marked rise in blood pressure. Subsequently Cunningham, Guttmann, Whitteridge & Wyndham (1953) suggested that splanchnic vasoconstriction is the likely mechanism.

Experimental investigations have therefore been undertaken to elucidate this problem. The splanchnic nerves (sympathetic) carry no afferent fibres from the urinary bladder in cats (Gillian, 1954). Watkins (1938) has shown that the distension of the urinary bladder in cats causes a rise in blood pressure. The problem has therefore been investigated by studying the changes in blood pressure with bladder distension in cats, both before and after bilateral splanchnicotomy.

Preliminary investigations showed that the blood pressure rises very little, with distension of the bladder, when the vagi and the carotid sinus nerves are intact, but after bilateral vagotomy and carotid sinus denervation the blood pressure always rises considerably higher. Bilateral splanchnicotomy almost completely abolishes these pressure responses. The role of these buffer nerves in the homoeostasis of blood pressure is well recognized. But their distinctive role in influencing viscerovascular reflexes has not been demonstrated previously. The recognition of this influence may help in explaining (*a*) why the peripheral circulation is easily upset in spinal conditions, particularly when the lesions are lower cervical or higher thoracic, and (*b*) why the reflex viscerovascular responses are less evident normally. A detailed investigation has been made into this problem.

The splanchnic nerves supply a large vascular bed, and it is not possible to measure the blood flow or study the circulatory changes in the splanchnic

* Present address: Department of Physiology, Science College, University of Calcutta.

vascular bed as a whole by any single technique. As the different components of this bed may not show identical changes, experiments have been designed to investigate these separately. The effect of the bladder distension on the renal circulation has been studied in detail, both before and after bilateral vagotomy and carotid sinus denervation and after bilateral splanchnicotomy as well.

The purpose of this paper is to report the role of the splanchnics and these buffer nerves in modifying these reflex vasomotor responses (changes in blood pressure and renal circulation) with bladder distension, in chloralosed cats. Other factors causing variations in the results obtained will also be discussed.

METHODS

Female cats varying in body weight (2–3·5 kg) were used. Anaesthesia was induced by ethyl chloride and ether and was maintained by an intravenous injection of a freshly prepared solution of chloralose (1% in 0·9% (w/v) saline). Chloralose was used in the dosage of 80 mg/kg body wt. A three-way T-tube was immediately put into the trachea. Throughout the experiment the animal's rectal temperature was kept at about 37° C.

Exposure and preparation of bladder, ureter and urethra. The bladder was exposed through a lower mid-line abdominal incision. Blood vessels and nerves sweep over to the bladder wall along the terminal part of each ureter. The ureters were therefore tied always 1 in. above their termination. Two double ligatures were used between which the ureters were cut. The proximal stumps were cannulated. The thin serous membrane connecting bladder to anterior abdominal wall was then cut between the ligatures. The urethra, gently cleared of periurethral tissue, was opened near the bladder neck and a polythene tube, which had a terminal opening and one adjacent lateral opening, was inserted into the bladder.

The polythene cannula was connected to a T-tube which was again connected by a Y-tube to an overhead reservoir containing freshly prepared 0·9% (w/v) NaCl solution. The side arm of the T-tube was connected to a mercury manometer for recording the intravesical pressure. The other end of the Y-tube was used for emptying the bladder. NaCl solution 0·9 (w/v), varying from 36° to 37° C, was used to fill the bladder. The pressure bottle was such that changes of 100 ml. in its capacity altered the height of the fluid column by 20 mm only.

Usually the filling rate for bladder distension was adjusted to 60 ml./min. Sometimes the rate was increased to 90–120 ml./min. This reservoir was adjusted at different heights so that the pressure at which the bladder was filled varied usually from 45 to 60 mm Hg and the intravesical pressure slowly approximated to the hydrostatic pressure applied. The right femoral artery was cannulated and connected to the same mercury manometer.

Vagotomy, carotid sinus denervation and exposure of splanchnic nerve. Particular care was taken to free the common carotid artery and its branches near its division from all the periadventitial tissue. The ascending pharyngeal branch has recently been shown by Daniel, Dawes & Prichard (1953) to represent the extracranial part of the internal carotid artery. In every experiment reported in this paper the parts of both the ascending pharyngeal and occipital branches lying in the space between the common carotid artery bifurcation and the base of the skull was carefully denervated. The proximal half inch of the external carotid artery and the common carotid artery were also denervated. By careful dissection the vagus was completely separated from other tissues in the region of the superior cervical ganglion and thus the carotid sinus was completely freed of any nerve connexion. Finally the vagus was cut at a level usually below the larynx. After an interval of 15–20 min the same procedure was carried out on the other side. Each splanchnic nerve was exposed extraperitoneally, and at the end of each experiment, division of the splanchnic nerve was verified by dissection.

Plethysmography of the kidney. The plethysmograph used is an 'Easter egg cosy'. This is an ordinary plastic container made in two parts (leaves), which can be obtained in various sizes. A side hole is bored through one leaf, usually near the end, and a small hard Perspex tube is permanently fixed into it. The Perspex tube is 2·5 cm long and 0·5 cm wide with a bore of 2 mm. The tube is fixed to the leaf in such a way that it projects 3–5 mm within the plethysmograph. A few drops of chloroform round the margin of the opening in the leaf keep the Perspex tube fixed to the leaf. At the middle of one side of the plethysmograph a hole 6–8 mm in diameter is made. The capacity of the plethysmograph used in the present series is between 55 and 57 ml.

The left kidney, exposed extraperitoneally, is placed in the plethysmograph and petroleum jelly is smeared at the junction of the leaves. The perihilar fat of the kidney acts as a cushion to make the hole in the plethysmograph air-tight and no further sealing has been found necessary. The renal pulse volume and the changes in the renal vascular capacity were recorded optically by the use of a membrane manometer. The plethysmograph was connected to this manometer by a hard plastic tube. The sensitivity of the membrane is such that 0·1 ml. added air displaces the beam 3–4 cm at the camera, this displacement being within the linear range of the membrane.

RESULTS

For the sake of convenience, the results can be grouped under three heads: (A) before vagotomy and carotid sinus denervation; (B) after bilateral vagotomy and carotid sinus denervation; (C) after bilateral splanchnicotomy.

Changes in arterial blood pressure

A. *Response before vagotomy and carotid sinus denervation.* When the bladder was distended there was usually a very small rise in the blood pressure; sometimes there was no change. The results of eight individual experiments are shown in Table 1.

TABLE 1. Relation between intravesical pressure and rise in arterial blood pressure before vagotomy and carotid sinus denervation in eight experiments. The intravesical volume in these experiments varied between 50 and 55 ml.

Expt.	Intravesical pressure at the end of filling (mm Hg)	Arterial blood pressure (mm Hg)		
		Before filling	At the end of filling	Percentage rise in B.P.
1	34	123	123	0
2	38	126	131	4
3	40	114	116	1
4	45	114	120	5
5	58	126	140	11
6	60	123	135	12
7	62	135	149	10
8 (*a*)	62	117	117	0
(*b*)	66	117	122	4
(*c*)	67	107	112	4

It is evident from Table 1 that even when the intravesical pressure was as high as 65–67 mm Hg, the rise in the blood pressure was never more than 10–12% above the control level. The rise in blood pressure commenced after a lag varying between 2 and 40 sec and occurred only during the filling of the bladder. When the filling was stopped and the bladder was kept distended, the

blood pressure remained at a level which varied with the intravesical pressure. If the latter remained the same as that at the end of the filling stage, blood pressure remained steady at the high level. The rise in blood pressure was always a fluctuating one (Fig. 1), and in some instances these fluctuations were pronounced and regular in frequency (Fig. 2). When the bladder was emptied the blood pressure quickly returned to its original level.

In the same animal, when the bladder was filled at constant rate to the maximal volumes it would accept at different pressures or when the rate of

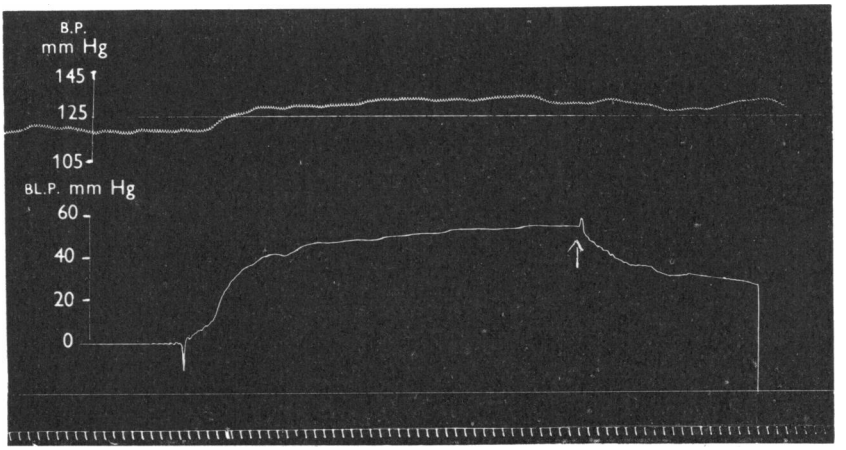

Fig. 1. Effect of bladder distension on blood pressure (vagi and carotid sinus nerves intact). B.P., blood pressure; BL.P. bladder pressure. Arrow indicates time filling stopped. Time, sec.

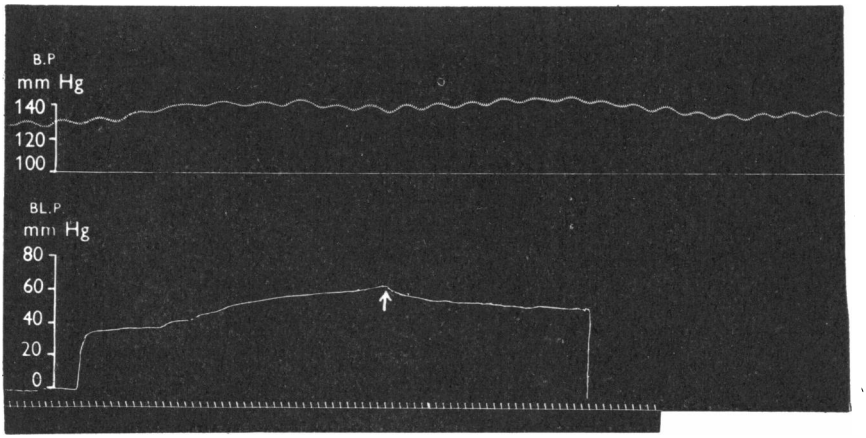

Fig. 2. Effect of bladder distension on blood pressure (vagi and carotid sinus nerves intact). B.P., blood pressure; BL.P., bladder pressure. Arrow indicates time filling stopped. Time, sec.

filling varied from 60 to 120 ml./min while the pressure was kept constant, the extent of the rise in blood pressure was usually related to the degree of distension of the bladder. But it was also observed that even when the intravesical pressure was as high as 62 mm Hg vasopressor responses were sometimes absent (Table 1, Exp. 8). When the filling of the bladder was repeated at intervals, with emptying and periods of rest of 5–10 min intervening, the vasomotor responses remained the same, as judged by the percentage rise in blood pressure (Table 4).

B. *Response after bilateral vagotomy and carotid sinus denervation.* As before, the rise in blood pressure under two conditions was observed, namely, when the bladder was distended at different pressure, but with the filling rate remaining constant, and when the rate of filling varied from 60 to 120 ml./min with a constant head of pressure. When the bladder was distended there was always a rise in blood pressure. The results of six individual experiments are shown in Table 2. The rise in blood pressure in each experiment was much higher than in any in Table 4. The intravesical volumes in the two groups of experiments are the same.

TABLE 2. Relation between intravesical pressure and rise in arterial blood pressure after bilateral vagotomy and carotid sinus denervation, in six experiments. The intravesical volume in these experiments varied between 50 and 55 ml.

Expt.	Intravesical pressure at the end of filling (mm Hg)	Arterial blood pressure (mm Hg)		
		Before filling	At the end of filling	Percentage rise in B.P.
1 (*a*)	35	114	134	18
(*b*)	40	116	136	18
(*c*)	52	118	141	20
2	45	135	155	15
3	60	120	180	50
4	60	118	180	52
5	65	128	198	55
6	65	115	160	40

The differences in the percentage rise of blood pressure in five individual experiments on filling the bladder before and after bilateral vagotomy and carotid sinus denervation in the same animal are shown in Table 3. These results clearly show that when the vagi were cut and the carotid sinuses denervated, the blood pressure rise was greater than when the nerves were intact.

The percentage rise in blood pressure was dependent on the original level. When the original pressure was low (100–130 mm Hg), the percentage rise was always higher than that obtained when the original level was already high, 150 mm or above (Table 3, Expts. 1 and 2). Although the vasopressor response in an animal with a basal level of blood pressure of 135 mm Hg or above was small, nevertheless, when observed before and after bilateral

vagotomy and carotid sinus denervation, it was still sufficient to show the moderating effect of the buffer nerves. Such high basal blood pressures occur for about 45–50 min following chloralose injection and for 90–120 min following bilateral vagotomy and carotid sinus denervation.

As in the experiments with intact nerves, the rise in blood pressure commenced after a lag of 2–40 sec, but the pattern of rise was now a continuous slope.

TABLE 3. Relation between intravesical pressure and rise in arterial blood pressure (when the intravesical volumes are comparable) in five individual experiments: *A*, before and *B*, after bilateral vagotomy and carotid sinus denervation

Expt.	Intravesical pressure at the end of filling (mm Hg)	Arterial blood pressure (mm Hg)		
		Before filling	At the end of filling	Percentage rise in B.P.
1 *A*	58	137	149	9
B	58	153	185	20
2 *A*	60	107	117	10
B	60	155	186	20
3 *A*	60	130	140	7
B	60	130	201	54
4 *A*	65	134	148	10
B	65	130	172	33
5 *A*	66	117	123	5
B	66	128	200	57

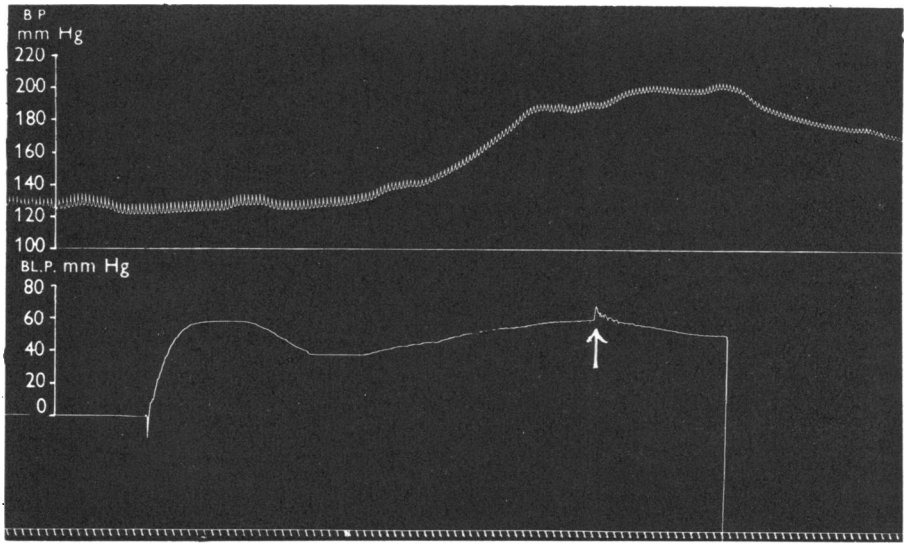

Fig. 3. Effect of bladder distension on blood pressure after bilateral vagotomy and carotid sinus denervation. B.P., blood pressure; BL.P., bladder pressure. Arrow indicates when filling stopped. Time, sec. (Cf. Fig. 2, same animal.)

Blood pressure rose continuously during the filling phase. When the filling was stopped and the bladder was kept distended, the intravesical pressure varied: if the latter was the same as that during filling, blood pressure continued to rise; if the intravesical pressure fell below the filling level, blood pressure became steady or came down slightly. When the emptying of the bladder commenced the blood pressure started falling. It did not always reach the original level immediately the bladder was empty, but fell to this level or lower in 2–5 min. Increased rate of filling the bladder also provoked more powerful vasomotor responses. When the bladder was filled and emptied a number of times at intervals of 5–10 min, the level of blood pressure following emptying gradually became lower and lower. Also the vasomotor responses became gradually smaller (Table 4, series B).

TABLE 4. Relation of intravesical pressure to rise in arterial blood pressure (at comparable intravesical volumes) in the same animal

Expt.	Intravesical pressure at the end of filling (mm Hg)	Arterial blood pressure (mm Hg)		
		Before filling	At the end of filling	Percentage rise in B.P.
	A, before vagotomy and carotid sinus denervation			
1	50	120	132	10
2	52	119	133	11
3	56	118	127	8
4	25	121	132	9
5	25	122	133	9
6	25	121	134	10
	B, after bilateral vagotomy and carotid sinus denervation			
1	45	134	170	27
2	45	130	158	22
3	48	108	142	31
4	25	102	122	20
5	25	107	122	15
6	25	107	122	15

There is greater rise in arterial blood pressure in *B* than in *A*. The interrelationship of intravesical tension and vasopressor response is evident in *B*: the basal level of blood pressure gradually comes down in *B* with repeated distension but not so in *A*; on repetition, vasopressor response in *B* gradually becomes smaller.

In preliminary experiments it was observed that, when the bladder was filled very quickly (180 ml. or more/min.) or filled with a high pressure head (80 mm Hg or higher), the reflex vasopressor responses present before became very poor or were abolished. The returning fluid from the bladder on emptying was tinged red and on examination, haematomas were found in the bladder wall and multiple punctate haemorrhagic points in the bladder mucosa.

C. *Responses after bilateral splanchnicotomy.* Bladder distension did not produce any change in blood pressure. In the same animal where blood pressure rose with the distension of the bladder, bilateral splanchnicotomy

abolished this response (Fig. 4). When the experiments which have been described were repeated with the bladder outside the abdomen, the same results were obtained (Fig. 5).

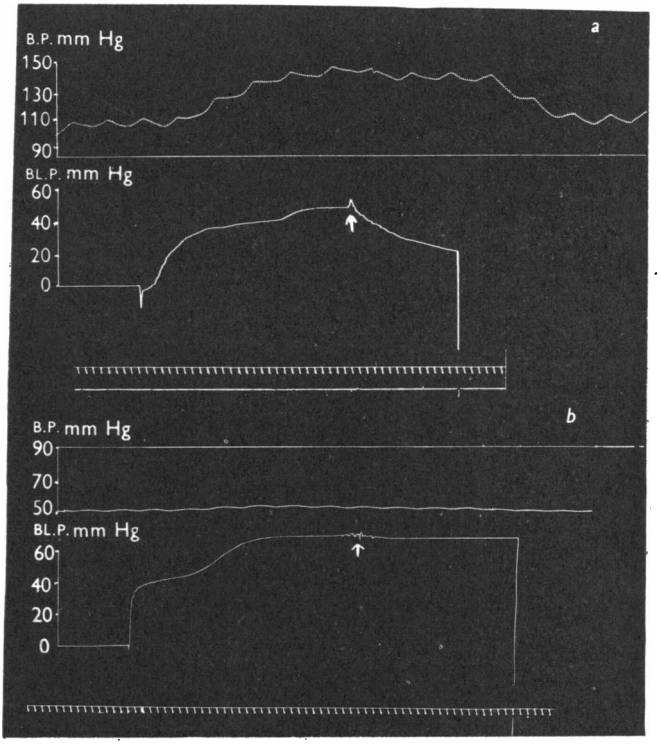

Fig. 4. Effect of bladder distension on blood pressure (in the same animal): *a*, after bilateral vagotomy and carotid sinus denervation (cf. Fig. 1, same animal); *b*, after bilateral splanchnicotomy. Arrows indicate when filling stopped. Time, sec.

Changes in renal circulation

A. *Before vagotomy and carotid sinus denervation.* During the filling of the bladder slight evidence of renal vasoconstriction was seen in five experiments only out of fifteen. In each of the five, after a lag varying from 2 to 20 sec, a reduction in the renal volume was seen and small intermittent variations in the volume were repeated during the filling phases (Fig. 6*a*). Reduction in the renal pulse volume was never observed. While the bladder was distended, but not further filled, the kidney response was similar to that during filling. Following emptying of the bladder the picture returned to the prefilling pattern immediately. In the other ten experiments there was no evidence of changes in kidney volume or pulse.

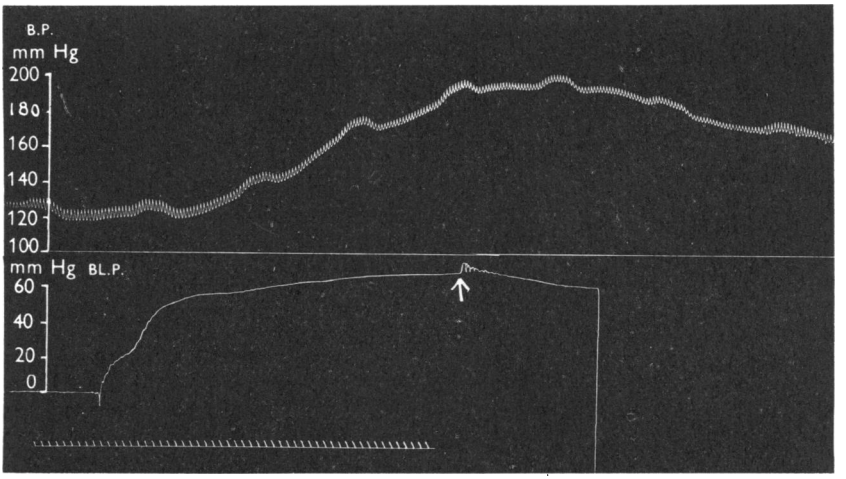

Fig. 5. Effect of bladder distension on blood pressure after bilateral vagotomy and carotid sinus denervation. Bladder was kept outside the abdomen while it was distended. (Cf. Fig. 3, same animal.)

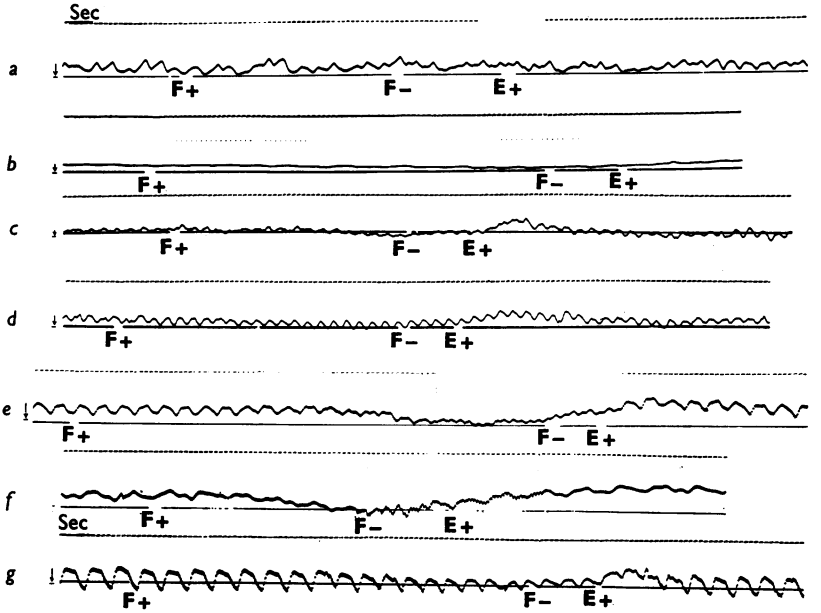

Fig. 6. Effect of bladder distension on renal volume and pulse. ↓, indicates reduction in renal volume. F +, filling starts; F −, filling stops; E +, emptying starts. Records *a*, *b*, *c*, *d* are experiments with the same animal, *a*, before, and *b*, *c*, *d*, after bilateral vagotomy and carotid sinus denervation. Records *e*, *f* and *g* are from three separate preparations after bilateral vagotomy and carotid sinus denervation. The preparation was given artificial respiration while record *g* was taken. Time, sec.

B. *After bilateral vagotomy and carotid sinus denervation.* Diminution in renal volume and reduction in size of the renal pulse were observed immediately after the vagi were cut and the carotid sinuses denervated, and the blood pressure of the animal rose sharply (Fig. 7). Such evidence of renal vasoconstriction was obtained even when the animal was ventilated by the pump throughout the experiment (Fig. 8).

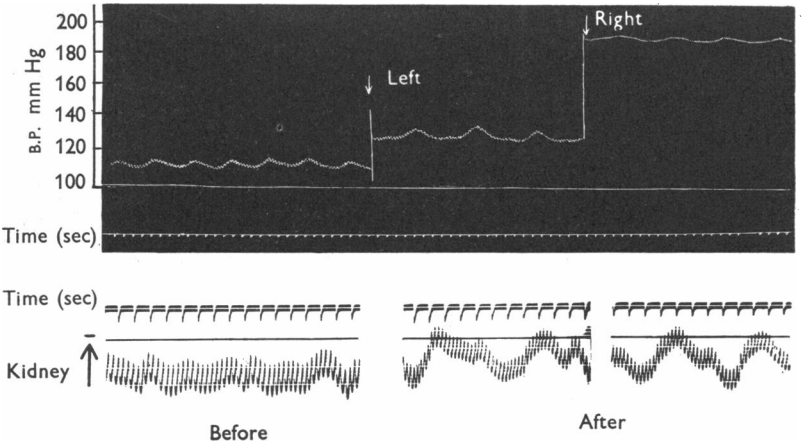

Fig. 7. Effect of vagotomy and carotid sinus denervation on blood pressure, renal volume and pulse (animal breathed spontaneously). $\overline{\uparrow}$, reduction in volume. Respirations became slow when vagi were cut and carotid sinuses denervated.

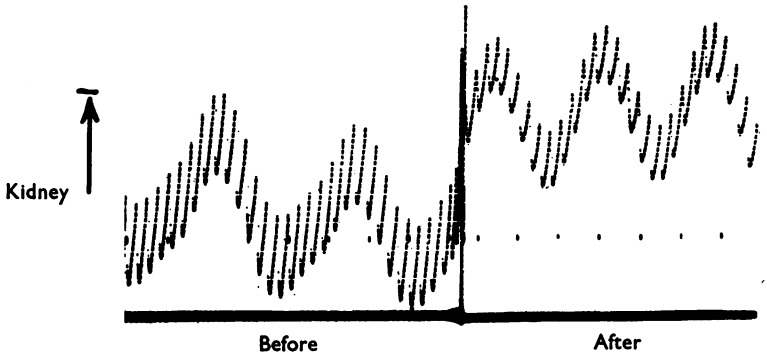

Fig. 8. Changes in renal volume and pulse before and after bilateral vagotomy and carotid sinus denervation. The respiratory rate of the animal was the same throughout the experiment, the animal being ventilated by the pump. $\overline{\uparrow}$, indicates reduction in volume. Time, sec.

For a period of 1½–2 hr and sometimes for even 3–4 hr after this, bladder distension failed to produce any marked change in the renal vascular bed. If there was any change, it was always suggestive of renal vasoconstriction (Figs. 6*b*, *c*, *d*), more marked than it was when the buffer nerves were intact. There was no evidence of intermittent variations in the renal volume during

the filling of the bladder. Gradually the renal pulse became bigger in size and normal renal volume was restored. The blood pressure of the animal also came down during this period to a lower level but still above that when the buffer nerves were intact.

The effects of the bladder distension on the renal vascular bed were now more evident as is described below.

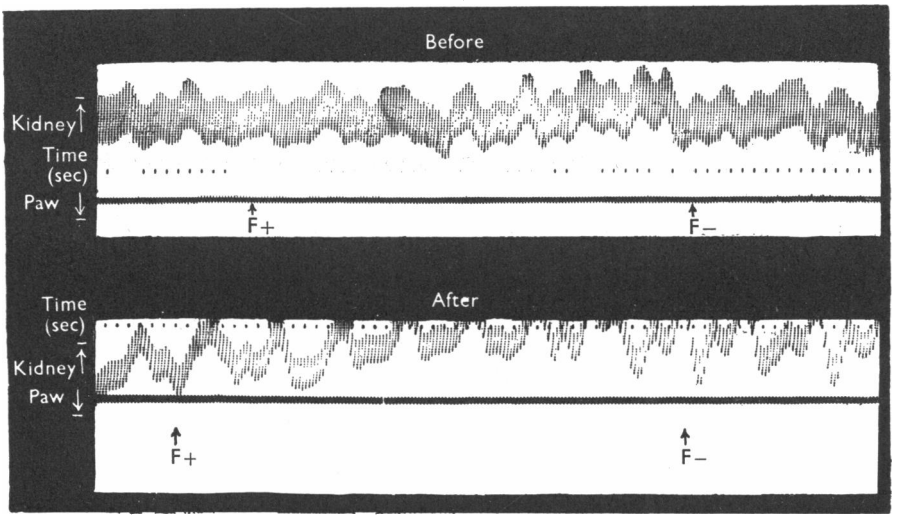

Fig. 9. Effect of bladder distension on renal and paw volumes before and after bilateral vagotomy and carotid sinus denervation. ↓, reduction in volume. F+, bladder filling commenced; F−, filling discontinued. There is little reduction in renal volume and a quick return to normal when buffer nerves are intact and a progressive reduction in renal volume without any tendency to return to normal when buffer nerves are severed (see Fig. 6*a*, *b*, *c*, *d*). There is no change in paw volume during the filling of the bladder.

During the filling phase. In fifteen individual animals definite evidence of renal vasoconstriction was obtained in each instance. Within 2–20 sec from the beginning of filling changes in the renal volume were observed. There was always a progressive and continuous reduction in the volume as the bladder was filled. In most of these experiments the renal pulse also became smaller as the bladder was distended (Figs. 6*e*, *f*; 11*a*, *b*, *c*).

During the distension phase there was no further reduction in volume and pulse. On the other hand, the tracings obtained indicated that there was a tendency for the renal volume to be restored to that in the prefilling stage, but this restoration alternated with the vasoconstriction obtained during the filling phase.

Following emptying. As the bladder was emptied, renal vascular volume was restored and sometimes even an increase in volume was evident. The renal pulse did not always return immediately to its original amplitude. Fig. 9

shows, in the same animal, the differences in the extent of the renal vasoconstriction during bladder distension, before and after bilateral vagotomy and carotid sinus denervation. The rate of filling the bladder in these experiments was 60 ml./min and the pressure head used in distending the bladder was 65 mm Hg.

In animals without buffer nerves, it was observed (*a*) the vasoconstriction responses became poor if the bladder were repeatedly distended at frequent

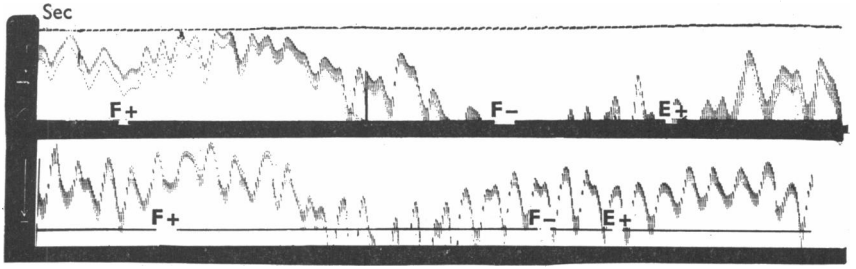

Fig. 10. Effect of bladder distension on renal volume and pulse after bilateral vagotomy and carotid sinus denervation. ↓, reduction in volume, F +, filling starts; F −, filling stops; E +, emptying starts. Upper tracing shows reduction in renal volume and pulse while the bladder was filled. Lower tracing shows the same at the earlier part of the filling phase. At the later part of the filling phase the renal pulse is smaller still but the renal volume is returning to normal.

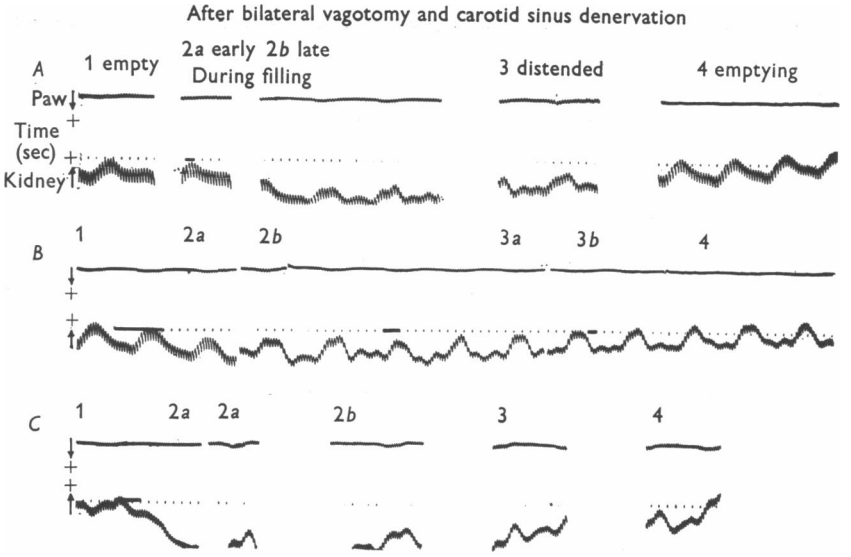

Fig. 11. Effect of bladder distension on changes in renal volume and pulse and in paw volume (on repetition in the same animal). ↑, increase in volume for kidney; ↓, increase in volume for paw. State of the bladder is shown at the top. (−), signal indicates the beginning of the next stage. *A*, *B*, filling rate 60 ml./min; *C*, filling rate 120 ml./min. Pressure 65 mm Hg; time, sec.

intervals of 1–5 min (Fig. 11*A*, *B*); (*b*) such responses became more marked if the rate of inflow were increased from 60 to 120 ml./min or the pressure increased (Fig. 11*C*); (*c*) as the responses became poor, the tendency for renal volume to return to normal became marked even during the terminal part of the filling phase (Fig. 11*A*, *B*). When the bladder was distended keeping it outside the abdomen, this tendency for the renal volume to return to normal was not observed.

C. *After bilateral splanchnicotomy* no evidence of renal vasoconstriction was obtained. In the same animal the renal vasoconstriction which had been observed on the distension of the bladder following bilateral vagotomy and carotid sinus denervation, was abolished immediately following bilateral splanchnicotomy. Occasionally, however, an increase in renal volume was observed during the terminal stages of the filling of the bladder and the distension phase (Fig. 13).

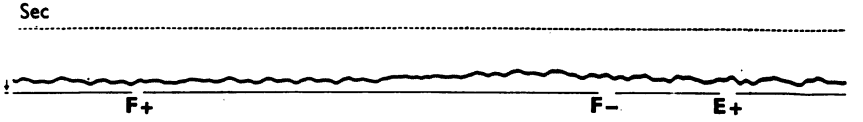

Fig. 12. Effect of bladder distension on renal volume and pulse after bilateral splanchnicotomy. ↓, reduction in volume; F +, filling starts; F −, filling stopped; E + emptying starts.

DISCUSSION

Effect of anaesthesia

The present finding confirms the views of Rosenblueth & Schwartz (1935) and Watkins (1938) that with the dosage used in these investigations reflex vasomotor responses can be elicited satisfactorily in cats under chloralose anaesthesia. It may be that Downman, Goggio, McSwiney & Young (1943–4) could not elicit reflex vasomotor responses satisfactorily in cats under chloralose because the basal level of blood pressure was very high, as is usual for 45–50 min following chloralose injection.

Effect of the increase in intravesical pressure and volume on blood pressure

Distension of the bladder causes a rise in blood pressure. This confirms the similar observations of Watkins (1938). The duration of the lag observed in the present series (2–40 sec) is not in agreement with that (2–5 sec) reported in Watkins's series. The difference may probably be due to the fact that in the latter's experiments the bladder was distended at a quicker rate and at a higher pressure head.

It is of interest to decide what is the change in the bladder when it is filled, that gives rise to the vasomotor reflex. When the bladder is filled at a lower pressure (30–40 mm Hg) the reflex rise in arterial blood pressure is small,

both before and after vagotomy and carotid sinus denervation. As the bladder is further distended by raising the pressure, the arterial blood pressure response becames more marked, particularly after vagotomy and carotid sinus denervation. After vagotomy and denervation of the carotid sinuses a fast rate of filling provokes a more powerful vasomotor response than does a slow rate, but it is not alone the active stretching of the bladder wall that excites the reflex, for when the bladder is filled and is left at constant volume the reflex remains active: the blood pressure is maintained and may even continue to rise provided the intravesical pressure does not fall. If the intravesical pressure falls the arterial blood pressure may remain steady or may fall slightly. It would seem probable that the vasomotor reflex response may result from either (i) the intravesical pressure, or (ii) the increased volume of the bladder.

Part of the results of the present experiments, together with those of Watkins (1938) on the non-spinal cat and those of Guttmann & Whitteridge (1947) on chronic spinal men, shows a relation between the height of the intravesical pressure and the extent of the rise in the arterial blood pressure. It has been observed, however, in the present experiments that when bladder filling is continued at constant intravesical pressure, the arterial blood pressure rises progressively. For this reason it seems probable that the tension in the bladder wall rather than the absolute intravesical pressure is the effective stimulus for a rise in arterial blood pressure.

The relation between the intravesical volume and the reflex rise in blood pressure can be explained by Laplace's Law, which states that $P=2T/R$ for a sphere, and $P=T/R$ for a cylinder, where P is the internal pressure over the external one, T is the tangential tension in the wall and R is the radius. As the bladder is filled the radius increases and if P remains constant, T will vary with R. That is to say, at the same intravesical pressure the fuller the bladder, the greater is the tension in its wall. Schumacher & Guthrie (1951) have also found in paraplegics that an increase in bladder volume leads to further increase in the reflex effects, though the intravesical pressure does not increase or even sometimes diminishes.

Effects of bilateral vagotomy and carotid sinus denervation and bilateral splanchnicotomy

Important and interesting observations in the present series have been as follows: (i) The rise in blood pressure on bladder distension is always more marked following bilateral vagotomy and carotid sinus denervation and (ii) such reflex vasopressor responses are abolished following bilateral splanchnicotomy. Splanchnic vasoconstriction is therefore the main cause of the rise of blood pressure that occurs with the distension of bladder in chloralosed cats. Even if any other peripheral vascular bed takes part simultaneously in the increase

of peripheral resistance, its contribution is not of any marked significance in cats.

The rise of blood pressure is never marked when the vagi and carotid sinus nerves are intact. The possible explanation is the buffer action through the agency of the carotid sinus and aortic baroreceptors. Therefore the response shown in the rise of blood pressure remains poor. The interrupted pattern of the rise of blood pressure, when these buffer nerves are intact, fits in with this explanation. An alternative to this explanation is that the effects of splanchnic vasoconstriction may be counteracted by simultaneous compensatory vasodilatation in other peripheral vascular beds.

The experimental observations of Lindgren & Uvnas (1953) support the present postulate that the buffer nerves are responsible for modifying the pressor responses by controlling directly the excitatory tone of the medullary vasomotor centre and through it the tone of the spinal centres concerned with the splanchnic outflow. When the vagi are cut and the carotid sinuses denervated, the rise of blood pressure is not only greater but less interrupted than that when buffer nerves are intact. On the basis of this interpretation, it is possible to explain why Downman & McSwiney (1946–7) could not elicit viscerovascular reflexes satisfactorily in the non-spinal preparations with buffer nerves intact. Sherrington (1899) showed that the vascular tone in the spinal animal can be altered by spinal reflexes and he demonstrated, on the anaesthetized animal, that a rise of arterial blood pressure can result from stimulation of the viscera by distending the ureter or common bile duct. Downman & McSwiney (1946–7) remarked from their experimental observations that viscerovascular reflexes could be satisfactorily demonstrated in the spinal preparations only. These findings are in agreement with the present interpretation, which explains also why Guttmann & Whitteridge (1947) found that the rise in blood pressure with bladder distension was always much more marked in the paraplegics with high lesions (C8–T5) than in those with lower lesions (T6–T10), because with higher lesions the effect of buffer nerves annulling the reflex vasopressor responses was much less.

Robertson & Wolff (1950) could not demonstrate any appreciable rise in blood pressure with distension of the rectum in normal healthy individuals. But Pollock & Finkelman (1954) have shown recently that in paraplegics (cervical lesions) there is always a marked rise in blood pressure after the administration of an enema. It may also be explained now why in non-spinal preparations, where buffer nerves are intact, blood pressure changes are never so marked as they are in paraplegics. This is why the clinicians have found a poor rise in blood pressure in patients suffering from 'Dumping Syndrome'.

Izquierdo (1930) stimulated the peripheral ends of the splanchnic nerves in anaesthetized rabbits, cats, dogs and hares, with a constant faradic current

under similar conditions, first with two sets of aortic and carotid sinus nerves intact and then with these nerves partially or totally eliminated. He observed that, when the aortic and carotid sinus nerves are eliminated, the rise in blood pressure is always much more marked. Comparing the effects observed after elimination of either both aortic nerves or both carotid sinus nerves alone, he found that the carotid sinus nerves exert the more important inhibiting effect upon the height of the blood-pressure rise. The present findings supplement Izquierdo's observations.

Effect of bladder distension on respiration

When the buffer nerves are intact, there is no change in the respiratory rhythm or rate when the bladder is distended. Following bilateral vagotomy and carotid sinus denervation, the respiration of the animals becomes slow. As the bladder is filled, some disturbances in respiration, e.g. quickening of the rate and irregular rhythms, have occasionally been observed. The mechanism of such changes has not yet been investigated.

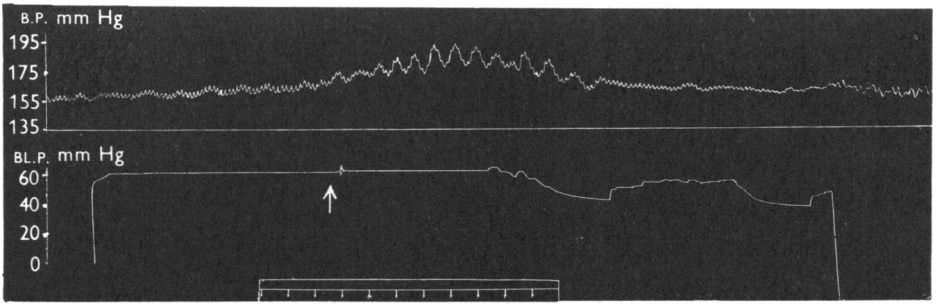

Fig. 13. Effect of bladder distension on blood pressure after bilateral vagotomy and carotid sinus denervation. B.P., blood pressure; BL.P., bladder pressure. Arrow indicates when filling stopped. Time, 5 sec. As the bladder stretched, 'Traube-Hering' patterns of circulatory undulations became evident. When filling of the bladder was discontinued, intravesical pressure remained the same as during filling, and these undulations continued: they disappeared only when the bladder was emptied.

Undulations in blood-pressure patterns with bladder distension

The rhythmical fluctuations in blood pressure which sometimes occurred when the buffer nerves were intact did not occur after bilateral vagotomy and carotid sinus denervation. In only two of the experiments after cutting the nerves did short-lasting waves, recognized as Traube-Hering patterns, appear during the distension phase. These disappeared as the bladder emptied. These were observed in animals where the basal level of blood pressure was very high (Fig. 13). Interpretation of such findings in the present experiments is difficult because there is no definite evidence as to whether the fluctuations

were due to disturbances in the vasomotor centre alone or in both the vasomotor and respiratory centres. But it is of interest that the fluctuations never occurred in animals with bladder distension when the basal level of blood pressure was low (100–130 mm Hg).

Effect of bladder distension on renal circulation

The dead space occupied by the plethysmograph and the tube amounts to 70–71 ml. The volume of the kidney varied from animal to animal between 8 and 12 ml. Therefore the changes in dead space caused by the diminution in the volume of the kidney could not mechanically affect the sensitivity of the membrane to cause changes in the size of the pulse. For the reason that the blood pressure rises when the bladder is distended, the diminution in the renal volume and reduction in the size of the pulse, as seen in the present investigations, are not passive responses but are due to active vasoconstriction. That bilateral splanchnicotomy abolishes these responses proves that a renal vasoconstriction is a reflex response to the distension of the bladder.

Fluctuations in the renal volume, as shown by its tendency to return to the prefilling level during the terminal stages of the filling phase or during the distension phase, may be due to either (i) mechanical disturbances such as (*a*) pressure of the full bladder on a renal vein directly or on the inferior vena cava, (*b*) increased intra-abdominal pressure, resulting from distended bladder, compressing the inferior vena cava or renal vein; or (ii) reflex neurogenic disturbances such as (*a*) increased intrarenal tension due to rise in blood pressure as shown by Swan, Moore & Montgomery (1952), (*b*) respiratory changes, (*c*) efferent arteriolar constriction. The influence of mechanical factors is a possibility because (*a*) these fluctuations become more prominent when vasoconstrictor responses become smaller and are not seen when the bladder is kept outside the abdomen while being distended, (*b*) increases in kidney volume are seen even following bilateral splanchicotomy. Linzell (1950) found that spontaneous volume changes in the mammary gland were due to mechanical disturbances caused by the distended bladder pressing on the inferior vena cava.

The increase in renal volume observed when the bladder is emptied or when emptying starts cannot be explained on the basis of the mechanical factors. As stated before, the amplitude of the renal pulse is still smaller at this stage than that in the prefilling stage. Moreover, such increases are never seen following bilateral splanchnicotomy. Whether such increases are due to delayed effects of small amounts of adrenaline in the circulation or reflex efferent arteriolar constriction has to be investigated. Whether the purpose of such a mechanism is to build up sufficient intraglomerular pressure for filtration is an interesting problem. Urine flow during these experiments has not been measured.

Following unilateral (left) splanchnicotomy, the bladder distension still produces a rise in blood pressure, and the increase in the volume of the left kidney in such experiments is a passive one as a result of the rise in blood pressure. It should not be confused with the present observations. Following bilateral vagotomy and carotid sinus denervation the respiration of the animal is slow and, as the bladder is filled, there is a disturbance in respiration, as discussed previously. For this reason in a small number of experiments the animals were artificially ventilated at the same rate as the spontaneous breathing before vagotomy and carotid sinus denervation. When the bladder was distended, the same changes were seen as described before in animals following division of the buffer nerves (Fig. 6*g*). This does not, however, exclude the possibility that respiratory fluctuations normally seen in these experiments can modify the findings. But certainly respiratory fluctuations are not responsible for the active renal vasoconstriction that occurs reflexly in the renal vascular bed following bladder distension.

The extent to which the renal blood flow is diminished as a result of bladder distension cannot be stated, as no quantitative measurement has been made. The small rise in blood pressure, the fluctuating pattern of the rise and the presence of slight renal vasoconstriction with bladder distension when the buffer nerves are intact, prove that there is no appreciable increase in the splanchnic vaso-excitatory tone, which is however greatly increased reflexly when the buffer nerves are cut. All these reflex vascular responses are abolished almost completely following bilateral splanchnicotomy.

SUMMARY

1. When the urinary bladder is distended in chloralosed cats arterial blood pressure rises.

2. When the buffer nerves (vagi and carotid sinus nerves) are intact, the rise in blood pressure is small and the pattern of rise is an interrupted one. In the absence of these buffer nerves the rise in blood pressure is considerably higher and the pattern is much less interrupted.

3. The rise in blood pressure is influenced by intravesical tension, intravesical volume and rate of distension and it is probable that the effective stimulus is the tension to which the bladder wall is subjected.

4. Distension of the urinary bladder reflexly causes renal vasoconstriction.

5. The renal vasoconstriction is more marked following bilateral vagotomy and carotid sinus denervation.

6. Bilateral splanchnicotomy abolishes these reflex vascular responses.

7. The role of the buffer nerves in modifying the viscerovascular reflexes with regard to the rise in blood pressure and splanchnic vasomotor tone has been discussed.

8. Other factors influencing the extent of rise in blood pressure are high basal blood pressure, and injury to the bladder with local haemorrhage.

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