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An Angiographic Study of Erection in the Dog

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Summary. Erections were produced in dogs by stimulating the pudendal, the pelvic and the hypogastric nerves either singly or in combination and angiographic studies were then performed. During an erection an increase in blood flow to the erectile tissue could be demonstrated together with an impaired venous return.

Key words: Erection, Spongious tissue, Cavernous tissue, Angiography, Venous obstruction.

INTRODUCTION

The mechanism of erection has been studied anatomically (1, 2), by pressure measurements in the dorsal penile vein (3), and by measurements of the blood flow to the cavernous tissues (10). In previous investigations on electromicturition in dogs we employed angiography of the pudendal artery (6, 7). We have adapted this technique to the study of the mechanism of erection.

MATERIAL AND METHODS

Eleven mongrel dogs were studied. General anaesthesia was induced with Thiopentone sodium (Pentothal, INN) and supplemented with the same drug when necessary. Dual electrodes of platinum were applied to the hypogastric, pelvic and pudendal nerves according to the technique described by Holmquist et al. (8). The electrodes were connected to an electrostimulator (model S 4, Grass Instrument Co., USA) and to an oscilloscope (310 A, Tektronics, USA). A polyethylene catheter, PE 205 (Clay Adams, USA, OD/ID = 2.1/1.6 mm) was introduced suprapubically into the bladder. The catheter was connected to an elctromanometer (Siemens-Elema AB, Sweden) for pressure recordings. A straight radiopaque catheter (OPP 160, Portex, England, OD/ID = 1.6/1.1 mm) with a long tapered tip was introduced into the left common carotid artery. Under fluoroscopy the catheter was passed down to the terminal aorta. Then, avoiding the artery to the tail, it was manoeuvered into the right or left internal iliac artery and into the very first part of the internal pudendal artery. The position of the catheter was confirmed by injecting a small amount of contrast medium (Isopaque Coronar, Nyegaard A/S, Norway, metrizoate, NFN). Finally, the femoral artery and veins were cannulated for recording of the arterial blood pressure and for intravenous infusions. The body temperature was monitored and, if necessary, adjusted with a heating pad. During angiography, the contrast medium was infused into the pudendal artery at a constant rate for a period of 30 s. A series of exposures was made with the aid of a film changer (AOT 24 x 30 cm, Siemens-Elema AB). The pairs of nerves were stimulated alone or in various combinations for different periods of time. In a few experiments a thin polyethylene catheter was introduced into one of the dorsal penile veins and up to the confluence of these vessels. Pressure recordings were obtained from this vein with and without nerve stimulation as well as during direct electrical stimulation of the ischiourethral muscles. The arterial blood pressure, the pressure in the dorsal penile vein, the vesical pressure, the electrical stimuli, the period of injection and the exposures were registered on a polygraph (Fig. 1).

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SURVEY OF EXPERIMENTS

A. Tonic electrical stimulation of individual nerve pairs with and without different nerve transections (Table 1).
B. Combined tonic electrical stimulation of the pudendal and pelvic nerves with and without different nerve transections (Table 2).
C. Tonic electrical stimulation of the pelvic nerves combined with clonic electrical stimulation of the pudendal nerves with and without registration of the pressure in the dorsal penile vein.
D. Tonic electrical stimulation of the pelvic nerves combined with tonic and clonic electrical stimulation of the ischiourethral muscles.

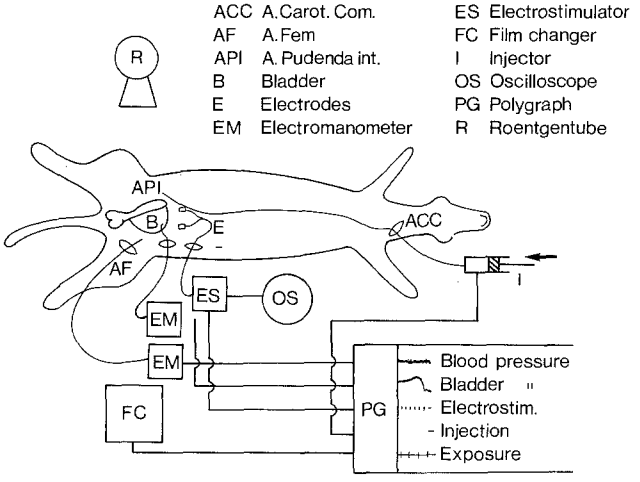

Fig. 1. Experimental design for the angiographic study of electrically induced erection in the dog

RESULTS

At angiography without electrical stimulation there was only scanty filling of the cavernous tissue within the corpora cavernosa and corpus spongiosum urethrae and of the spongy tissue surrounding the proximal urethra (Fig. 2). The dorsal penile vein formed a smooth curve with no kinking or stasis. The tone of the ischiocavernous and bulbocavernous muscles appeared to be low, as they made no impression upon the cavernous tissue.

A. Tonic Electrical Stimulation of Individual Nerves with and without Different Nerve Transections

Neither stimulation of the hypogastric nerves nor sympathectomy, performed acutely or six weeks preoperatively, led to any change in the angiographic pattern. Stimulation of the pelvic nerves increased the rate of blood flow through the internal pudendal artery. This resulted in a

Table 1. Stimulation of individual nerve pairs with and without different nerve transections

Nerves stimulated	Nerves transected: Intact innervation			Hypogastric n.			Pudendal n.			Pudendal n. + hypogastric n.			Pelvic n.			Pelvic n. + hypogastric n.		
	A + E	A	E	A + E	A	E	A + E	A	E	A + E	A	E	A + E	A	E	A + E	A	E
Hypogastric n.	-o	-o	-o															
Pelvic n.	+o	-o	+o	+o		+o				+o	-o							
Pudendal n.	+*	+o	-*	+*	+*	-*										-*	-o	

A stands for afferent electrical stimulation, and E for efferent stimulation
A vascular reaction, defined as an increased flow to the erectile tissue of the cavernous bodies and the urethra, is indicated by +, and the absence of such an effect by -. A muscular reaction, defined as a contraction of the bulbocavernosus muscles (visualised by compression of the proximal parts of the corpora cavernosa and the urethral bulb) and a kinking of the early intrapelvic part of the dorsal penile vein, is indicated by *; and the absence of such a reaction by o

Table 2. Combined stimulation of the pelvic and pudendal nerves

Pelvic n. A + E combined with Pudendal n. A + E	Pelvic n. A + E combined with: Pudendal n. A	Pudendal n. E	Pudendal n. A + E combined with: Pelvic n. A	Pelvic n. E
+*	+o	+*	-*	+*

For abbreviations, see Table 1

remarkable augmentation in the amount of contrast medium filling the cavernous bodies and the spongious tissue of the urethra. Widening of the feeding artery and of the dorsal penile vein (Fig. 3) was also noted.

Stimulation of the pudendal nerves, i.e. stimulation of the striated muscles of the external genital organs, the muscles of the urogenital diaphragm and the urethral sphincter as well as of the afferent nerve fibres from the penis, caused increased filling of the cavernous tissue, resembling that at stimulation of the pelvic nerves, but slightly less in extent. Moreover, in this experiment, there was compression from below of the urethral bulb and of the proximal parts of the cavernous bodies. An additional finding was almost complete kinking of the dorsal penile vein, localised to the first part of its passage throught the pelvis (Fig. 4). There was a redistribution of contrast medium within the cavernous tissue, so that more reached the distal part of the cavernous bodies and the glans penis, whilst little or none reached the spongious tissue of the proximal urethra.

Stimulation of the pelvic nerves after transection of the pudendal nerves and the hypogastric nerves caused the same changes in the angiographic pattern as pelvic stimulation without previous nerve section.

Stimulation of the pudendal nerves after transection of the pelvic nerves caused considerably less increase in the filling of the cavernous tissues with contrast medium. There was still compression of the urethral bulb and the proximal part of the ischiocavernous bodies, disappearance of contrast medium from the spongious tissue of the proximal urethra, and kinking of the dorsal penile vein, as mentioned above.

Stimulation of the pudendal nerves after transection of the pelvic nerves and the hypogastric nerves led to the same changes in the angiogram as did stimulation of the pudendal nerves after transection of the pelvic nerves alone.

B. Combined Tonic Electrical Stimulation of the Pudendal and Pelvic Nerves with and without Different Nerve Transections

Combined stimulation of the pelvic and pudendal nerves gave a strong engorgement of the caver-

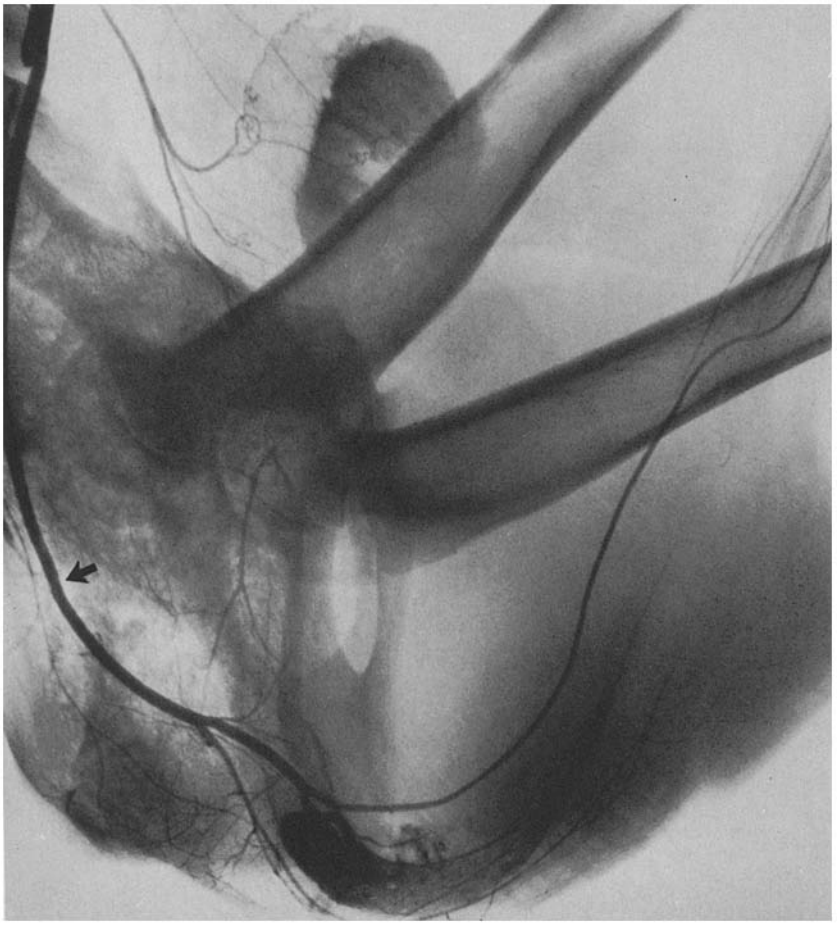

Fig. 2. Angiography of the pudendal artery (←). Lateral projection

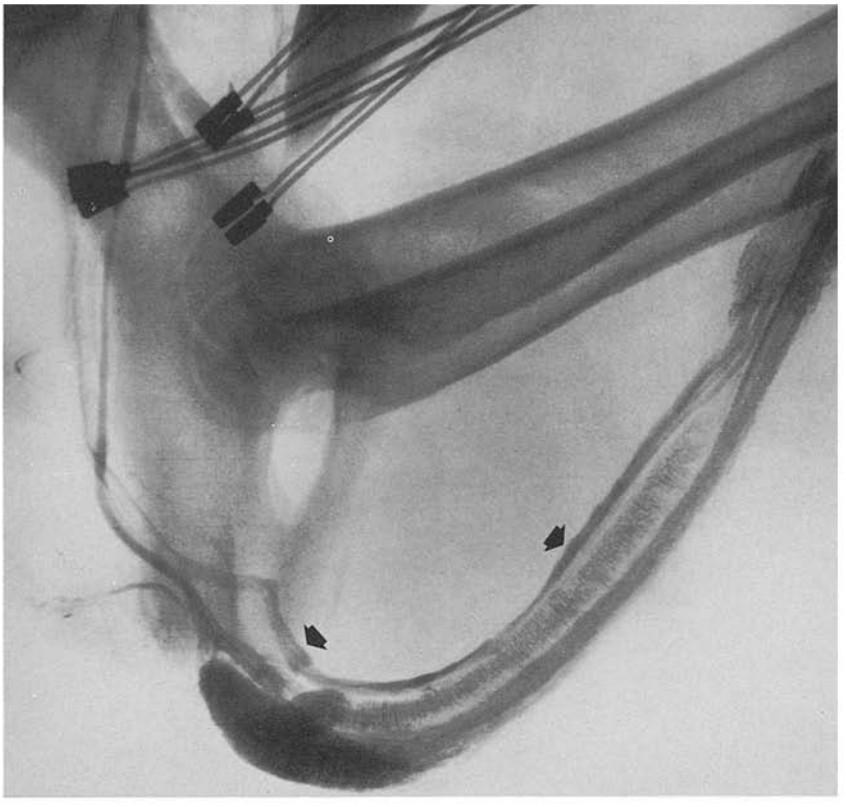

Fig. 3. Angiography of the pudendal artery during stimulation of the pelvic nerves. Late phase, in which the cavernous tissues are strongly opacified and the dorsal penile vein (⬅) is well filled with contrast medium

Fig. 4. Angiography of the pudendal artery during stimulation of the pudendal nerves. Late phase, in which the cavernous tissue is opacified. Note the compression from below (➥) of the urethral bulb and the proximal parts of the cavernous bodies, and the kinking of the dorsal penile vein (⬅)

nous tissue and an increased dilatation of the dorsal penile vein, in addition to the finding observed at stimulation of the pudendal nerves alone. When the pelvic nerves were transected distal to the point of stimulation, the result obtained was the same as after efferent stimulation of the pudendal nerves alone. After transection of the pudendal nerves distal to the point of stimulation the result obtained was the same as at afferent plus efferent stimulation of the pelvic nerves alone.

C. Tonic Electrical Stimulation of the Pelvic Nerves Combined with Clonic Electrical Stimulation of the Pudendal Nerves, with and without Registration of the Pressure in the Dorsal Penile Vein

Superimposed stimulation of the pudendal nerves during pelvic nerve stimulation gave the same result as combined stimulation of the pudendal and pelvic nerves. When the superimposed stimuli were interrupted, the compression of the urethral bulb and proximal parts of the cavernous bodies disappeared, the filling of the spongious tissue of the proximal urethra reappeared, the kinking of the dorsal penile vein disappeared, and the dilatation of this vein diminished.

During pudendal nerve stimulation there was a persistant increase in the pressure in the dorsal penile vein of 25 mmHg. Pelvic nerve stimulation alone caused no change in pressure from that registered in the non-stimulated animal.

D. Tonic Electrical Stimulation of the Pelvic Nerves Combined with Tonic and Clonic Electrical Stimulation of the Ischiourethral Muscles

The angiographic findings at superimposed stimulation of the ischiourethral muscles during pelvic nerve stimulation were the same as after stimulation of the pelvic nerves alone, except for the re-introduction of the kink in the dorsal penile vein and a simultaneous increase in the pressure in the dorsal penile vein.

DISCUSSION

Selective angiography of the internal pudendal artery by the technique described is a relatively atraumatic method which is suitable for studying the effect of different stimuli on the erectile tissue. As the catheter is introduced via the common carotid artery, no operative trauma is caused to the structures to be studied. If the tip of the catheter is long and tapered and is not introduced too far, no spasm of the pudendal artery will occur. The injection rate must, however, be adjusted to the rate of blood flow in the internal pudendal artery to assure satisfactory filling of the erectile tissue by contrast medium. If the injection rate is too low in relation to the rate of blood flow, the contrast medium will be diluted with blood and, if the rate of injection is too high, there will be spill-over to the parietal branches of the internal iliac artery. If this is born in mind when appraising the angiograms, it is possible to make a rough estimate of the flow in the internal pudendal artery or at least to assess changes in this flow. Using this method, it was clearly established that electrical stimulation of the pelvic nerves evoked a profound increase in the flow through the internal pudendal artery.

In the dog, as in man, there are two types of erectile tissue: the cavernous tissue of the paired erectile bodies and the spongious tissue of the urethra, including the glans penis. There is evidence to indicate different mechanisms for the haemodynamic regulation of erection in these two types of tissue (1, 5), but in both the basis for erection is a profound increase in blood supply (10, 3). It has been suggested that the increase in blood flow, of up to twenty times the resting level, is due to the opening of arteriocavernous shunts (2). The significance of the establishment of venous stasis as part of the mechanism of erection has also been debated (1), but has been regarded to be of minor importance (3) especially with regard to the corpora cavernosa.

Compression of the urethral bulb and the proximal parts of the corpora cavernosa by contraction of the bulbocavernous and ischiocavernous muscles will introduce an instant increase in erection (10). A muscular contraction of this nature is accompanied by an increase of pressure in the dorsal penile vein. Christensen (1) ascribed the rise in pressure to a proximal obstruction in the vein, but this view was challenged by Dorr and Brody (3). Two mechanisms have been suggested for the establishment of a proximal obstruction in the dorsal penile vein: compression of the vein between the corpora cavernosa and the symphysis, and kinking of the vein during its passage through the ischiourethral muscles.

In the present investigation no proximal obstruction could be demonstrated in the dorsal penile vein when erection was induced by electrical stimulation of the pelvic nerves. An obstruction could, however, be established by simultaneous stimulation of the pudendal nerves, or by direct stimulation of the ischiourethral muscles. In both instances there was kinking of the dorsal penile vein at its passage through the ischiourethral muscles, with a concomitant elevation of the pressure in the dorsal penile vein. The angiograms confirmed that there was an augmentation of the erection.

In the dog a complex reflex muscular activity occurs during ejaculation. There is clonic activity of the bulbocavernous and the ischiocavernous muscles, and a tonic contraction of the ischiourethral muscles can be demonstrated (4). Applying electromyography in man, Kollberg et al. (9) found evidence for reflex muscular activity of the striated muscles of the pelvic floor and urethral sphincter of the same kind as in the dog. It thus seems possible that the reflex muscular activity of the striated muscles associated with the genital organs increases the erection during the period of ejaculation. Augmentation of the erection of the spongious tissue will result in a reduction of the urethral lumen, which must occur if ejaculation is to be complete.

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