BLOOD PRESSURE IN THE INTERNAL SPERMATIC ARTERY OF THE RAM

G. M. H. WAITES AND G. R. MOULE

C.S.I.R.O., Division of Animal Physiology, Ian Clunies Ross Animal Research Laboratory, Prospect, N.S.W., Australia

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Summary. The pulsatile blood flow in the internal spermatic artery of the ram is changed by the arterial coils in the spermatic cord so that the testis receives a relatively pulseless blood flow at a lower mean pressure. The major pulse-pressure reduction occurs in the proximal one-third of the coiled length of the artery; in the distal two-thirds, the character of the coiling and structure of the artery change. These observations are discussed particularly in relation to the thermo-regulatory function previously suggested for the internal spermatic artery.

INTRODUCTION

The internal spermatic artery of many higher mammals is convoluted, but in the domesticated ruminants the coiling is so extensive that the artery forms a vascular cone on the dorsal pole of the testis (Bimar, 1888; Harrison, 1949). As the artery in most species is intimately surrounded by the pampiniform plexus, Harrison & Weiner (1949) and later Dahl & Herrick (1959) proposed that thermal exchanges occurred between the arterial and venous blood which, in favourable circumstances, could pre-cool the testicular inflow. Although a decreasing temperature gradient between the abdominal cavity and scrotal testes is thought to be necessary for normal spermatogenesis, the ovarian and some uterine endometrial arteries, which are also lengthened by coiling, supply organs at deep body temperature. This suggested that coiling in the internal spermatic artery may have functions in addition to that of heat exchange.

On the testis surface, the internal spermatic artery of the ram is pulseless, easily compressed and unusually thin-walled. This paper describes a study, initiated by these observations, of the blood and pulse pressures in this artery and discusses their possible significance.

METHODS

Twelve Merino rams, 1 to 8 years old and from 33 to 55 kg body weight, were lightly anaesthetized with intravenous pentobarbitone sodium (May & Baker). The experiments were done with the animal on its side and the scrotum horizontal. One internal spermatic artery was exposed where it emerged from

the external inguinal ring (Level A, Pl. 2, Fig. 4) and the contra-lateral internal spermatic artery was exposed on the posterior testicular surface (Level B, Pl. 2, Fig. 4). According to Ellenberger-Baum (1943), the internal spermatic artery at Level B is called the testicular artery. To avoid confusion in terminology and because the measurements made relate to the internal spermatic artery in the spermatic cord, this will be called internal spermatic artery, Level B. No attempt was made to correlate the haemodynamic effects described with fertility. However, eight of the twelve rams were used successfully for stud purposes during the previous season and good quality semen was collected from four (Rams 5 to 8) at the time of the experiment.

In seven experiments, siliconed hypodermic needles (0.75 mm internal diameter; 2 cm long) were tied into the proximal ends of each internal spermatic artery; care was taken at Level B to insert the needle proximal to any branches. The needles were connected by short lengths of rigid-walled polyethylene tubing filled with air-free heparin-saline solution, to rubber-membrane optical manometers; the natural frequency of the whole system was 20 to 30 c/s. Simultaneous end systolic, diastolic and pulse pressures were recorded on film by focusing the reflected light beams onto a ground-glass screen in front of a variable speed 35-mm recording camera. The manometers were calibrated immediately after each experiment. The records were examined by projection and mean pressures were estimated from the area under pulse curves recorded on film moving at 12 mm/sec.

In five experiments, lateral mean blood pressures were recorded from the internal spermatic arteries through 26-gauge hypodermic needles connected to mercury manometers.

Pressures were recorded with saline manometers from veins on the anterior surface of the testis, in the proximal part of the pampiniform plexus and in the internal spermatic veins. Pressures in the distal part of the pampiniform plexus were measured with an occlusion cuff; congestion below the cuff was observed with a dissecting microscope. The right auricle was used as the zero reference level for all pressures.

Injections of adrenaline (Parke Davis), 1-noradrenaline (Winthrop Laboratories) and acetylcholine (Roche) were given intravenously.

During post-mortem examinations, the internal spermatic arteries were washed out with warm 0.9 % sodium-chloride solution (saline). Neoprene latex (Boston B.B. Co., England) was injected at 200 mm Hg pressure into the artery from which pressures were recorded at Level B and the cast was recovered subsequently by maceration. The length of the cast was measured and the number of 'U' bends was counted.

Material was obtained for histological examination. This was fixed in Zenker's fluid or 10% formol-saline; sections were stained by the Verhoeff and Van Gieson method to show the elastin content of the arterial wall, and by haematoxylin and eosin to show the general histology. Measurements of the arterial wall thicknesses and lumen diameters were made by projecting and tracing the sections.

Anatomical features of the vascular cones observed in experimental animals were confirmed by dissection of abattoir material, and by X-ray photographs.

RESULTS

PULSE AND MEAN PRESSURES IN THE INTERNAL SPERMATIC ARTERY

End pressures

In the first seven experiments in which end arterial pressures were measured, a marked reduction in pulse pressure occurred in the coiled part of the internal spermatic artery (Pl. 1, Fig. 1). A small reduction in mean blood pressure was also observed, but this did not always occur. These results are summarized in Table 1. Therefore, the pulsatile blood flow in the internal spermatic artery on its emergence through the inguinal canal is smoothed by the arterial coils to a relatively pulseless flow through the artery on the testicular surface.

TABLE 1

BLOOD PRESSURES RECORDED SIMULTANEOUSLY FROM ONE INTERNAL SPERMATIC ARTERY PROXIMAL TO THE VASCULAR CONE AND FROM THE OPPOSITE ARTERY ON THE TESTIS SURFACE

Ram No.	Age (years)	Blood pressures in the internal spermatic arteries (mm Hg)					
		Proximal to vascular cone (Level A)			On testis surface (Level B)		
		Syst./diast.	Pulse	Mean	Syst./diast.	Pulse	Mean
1	5	120/82	38	99	92/88	4	90
2	8	70/34	36	46	52/47	5	49
3	5	108/80	28	90	83/82	1	82
4	5	130/102	28	113	109/107	2	108
5	4	134/96	38	114	92/88	4	90
6	3	138/100	38	114	123/107	16	113
7	4	117/87	30	99	90/82	8	86

Intravenous injections of adrenaline, l-noradrenaline and acetylcholine were given to four animals (Rams 1, 2, 4, 6) to determine if the internal spermatic artery efficiently reduced pulse pressure during changes in systemic blood pressure. Pulse pressures of up to 60 mm Hg were recorded, but between Levels A and B they were reduced by about the same proportion as pulse pressures at resting levels (Pl. 1, Fig. 2). Mean pressures recorded at Level B during hypertension were always lower and during hypotension were always higher than those recorded simultaneously at Level A. However, the induced blood-pressure changes were transitory, and the effects of changes of longer duration were not examined.

Lateral pressures

End blood pressures obtained with the lumen of the artery occluded by the recording needle may differ from lateral pressures recorded without interruption of blood flow through the artery. To determine the true mean pressure drop between Levels A and B, therefore, lateral pressures were recorded through fine hypodermic needles inserted through the artery wall. The pressure differences recorded in five rams are given in Table 2. In one experiment in which the artery at Level A was difficult to expose without prolonged dissection and the risk of causing vasospasm, the pressures recorded from both internal spermatic

arteries at Level B were compared with the pressure in the left femoral artery. In all experiments, a substantial pressure drop occurred between the two recording sites.

TABLE 2
THE LATERAL MEAN PRESSURE DROP RECORDED ALONG THE INTERNAL SPERMATIC ARTERY OF FIVE RAMS

Ram No.	Age (years)	Lateral mean pressure internal spermatic artery (mm Hg)		Pressure drop (mm Hg)	Length of artery between recording levels (cm)
		Level A	Level B		
8	7	121 Left	95 Right	26	166 Cast
9	1	118*	{ 83 Left 77 Right	35 41	incomplete 143*
10	2	100 Left	68 Left	32	103
11	5	122 Left	72† Left	50	306
12	2	135 Left	104 Left	31	238

* From left femoral artery; internal spermatic artery length given was from start of first convolution to recording site, Level B.

† From one of the two equal branches arising from the internal spermatic artery, on the testis surface.

TABLE 3
A COMPARISON OF PULSE-PRESSURE REDUCTION WITH LENGTH AND DEGREE OF CONVOLUTION OF THE INTERNAL SPERMATIC ARTERY

Ram No.	Pulse pressure reduction (%)	Internal spermatic artery between Levels A and B				
		Length (cm)	Total 'U' bends	'U' bends/one-third artery		
				proximal	middle	distal
4	93	363	232	99	69	64
1	90	317	193	77	58	58
5	88	277	191	74	66	51
2	86	201	145	55	47	43
7	73	237	176	76	57	43
6	58	214	156	69	47	40

RELATIONSHIP BETWEEN THE STRUCTURE OF THE INTERNAL SPERMATIC ARTERY AND ITS HAEMODYNAMIC PROPERTIES

Artery length

The latex casts of the internal spermatic arteries of six rams from which pulse pressures were recorded were 201 to 363 cm long; the vascular cones which they formed were 8 to 14 cm long. The amount by which pulse pressure was reduced appeared to be related to the length of the artery between Levels A and B. With the exception of Ram 2, it was found that the longer the artery, the more efficient the pulse reduction (Table 3). Although Ram 2 had the shortest internal spermatic artery, pulse pressure was effectively reduced. This animal was old and its resting blood pressure was low (46 mm Hg, Table 1). In other rams in which blood pressure was lowered by acetylcholine, the pulse pressure was reduced more efficiently than at resting blood-pressure levels. Therefore,

PLATE 1

FIG. 1. The reduction in pulse and mean blood pressures in the internal spermatic arteries of two rams. Upper records: from left artery, Level A. Lower records: from right artery, Level B; and in Ram 7, from a proximal coil of the right artery. Artery length refers to the right artery between the upper and lower recording positions.

FIG. 2. Blood-pressure responses recorded from the internal spermatic artery at Levels A and B to injections of adrenaline and acetylcholine.

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Radiographs of the posterior aspect of the testicular blood vessels of an adult ram.

Figs. 2 and 4: arteries injected with bismuth subnitrate suspended in gelatine. Figs. 1 and 3: same testis as in Fig. 2 but with veins subsequently injected with bismuth oxychloride ('Chlorbismol', May & Baker). Fig. 1, note level of first valve V and proximity to first arterial coil; Fig. 2, compare compact horizontal arterial coiling with the proximal coils in Figs. 1 and 4, see also Pl. 3, Fig. 7; Fig. 3, shows veins converging to dorsal pole of testis. Note larger diameter of artery on testis surface (and in terminal coils shown in Fig. 2) compared with same artery in Fig. 1. Fig. 4, hypodermic needles illustrate Levels A and B.

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the low blood pressure of Ram 2 might account for the efficient pulse-pressure reduction observed.

In Rams 4, 5 and 7, the hypodermic needle recording end pressures from the artery at Level B was removed and re-inserted into a coil in the proximal half of the vascular cone. In all three, the pulse pressures recorded at this level were almost as small as those in the artery on the testis surface (Pl. 1, Fig. 1). The length of artery between the recording points in Ram 4 was 120 cm and in Ram 7 was 77 cm; these were one-third of the total length of the artery in the respective vascular cones. Thus, in these experiments at this level blood flow was already almost non-pulsatile, and would also be relatively steady through the terminal coils of the vascular cone as well as in the artery on the testis surface.

Artery coiling, lumen diameter and wall thickness

The proximal one-third of the latex cast always contained more 'U' bends per unit length than the distal two-thirds (Table 3). In addition, the direction of turning of the arterial coils was more nearly longitudinal in the apical half of the cone and more nearly transverse in the basal half (cf. Pl. 2, Figs. 1 and 2; Pl. 3, Fig. 7); also the proximal coils were more loosely arranged than the distal coils which were flattened and compact. Because of the greater radius of turning, approximately two-thirds of the artery length were contained in the basal half of the vascular cone.

The size and structure of the artery also differed above and below its convoluted course. On the testis, the artery was elliptical in cross-section, apparently due to the tautness of the tunica albuginea, for when an overlying flap was removed the artery bulged and became round. The points of hypodermic needles could be clearly seen through the wall of the artery at both this level and in its terminal coils, which indicated that the walls were here unusually thin. This was substantiated by the following measurements which were obtained from stained sections of the artery taken from four experimental animals: mean thickness of the arterial wall at Level A was 0.27 mm and at Level B, 0.15 mm; the mean lumen diameters were 1.40 mm and 1.75 mm, respectively (Pl. 3, Figs. 5 and 6). Possible changes due to histological processing made these comparisons qualitative only. The wall of the artery on the testis surface had a thinner internal elastic membrane and fewer elastic fibres than at Level A.

VENOUS RETURN FROM THE TESTIS

The veins on the testis surface are 0.5 to 1.5 mm in diameter and are flattened and ribbonlike; lateral mean pressures within them were 14 to 25 cm saline. They converge to the dorsal pole of the testis, pass through the tunica albuginea and form a network of fine veins, 0.3 to 0.4 mm in diameter, closely applied around the arterial coils. Venous pressures in the upper half of the pampiniform plexus and in the internal spermatic veins were 9 to 14 cm saline. Venous pressures were recorded with the scrotum horizontal and were corrected for hydrostatic pressure. A pressure drop therefore occurred presumably due to increased resistance to flow offered by the pampiniform plexus.

Partial occlusion of the larger veins surrounding the proximal turns and the straight course of the internal spermatic artery, revealed that venous outflow from the pampiniform plexus was pulsatile. The veins receiving the outflow contained semilunar valves, the first of which always occurred close to the level of the first arterial convolution (Pl. 2, Fig. 1, V). No valves were detected in the pampiniform plexus.

DISCUSSION

Within the spermatic cord, the internal spermatic artery of the adult Merino ram is so coiled that 1 to 4 m of artery occupies a distance of only a few centimetres. Beyond the origin of the epididymal arteries and apart from small branches to surrounding connective tissue, the coiling artery is without major branches until it reaches the testis surface. Here, it presents several features which are unique for an artery of its size: it does not pulsate and blood flow through it is almost steady; lateral mean pressure is considerably lower than in the same artery before it starts to convolute.

Arteries which increase the surface area of their walls either by coiling, or by multiple branching as in the *retia mirabilia*, have been thought to act as pressure reducing mechanisms. For example, Reynolds (1950, 1952), when discussing the possible functions of the coiled ovarian arteries, stated: 'presumptive reasoning has led us to conclude that other, more basic physiological mechanisms are served by the helicoidal arrangement of the ovarian arteries. They provide for a sharp localized reduction in blood pressure'. This has been shown to be true for the internal spermatic artery of the ram, but in addition, the testicular inflow through this artery was relatively non-pulsatile and remained so throughout induced variations of systemic blood pressure.

The consequences of these characteristics for blood-flow regulation in the testis may be far-reaching. It is accepted that alterations in the peripheral resistance occur mainly in the arterioles and that these changes regulate the flow of blood to different parts of the capillary bed. The constant nature and the lowered pressure of the arterial inflow to the testis may permit a more precise distribution of blood by its arterioles. However, the observation that most of the pulse-pressure reduction occurred in the proximal one-third of the artery raised the possibility that, in addition to having direct significance for the testis, this property might be related to others previously proposed for vascular arrangements of this type.

In discussing the testicular rete mirabile present in many marsupials, Barnett & Brazenor (1958) favoured the proposal, originally made by Müller (1904) for the rete mirabile of the limb arteries of certain mammals, that venous return might be assisted by arterial pulsations. Venous pulsations were not measured but were repeatedly observed in the veins of the pampiniform plexus surrounding the proximal convolutions of the internal spermatic artery of the ram. For the reasons reviewed by Barnett, Harrison & Tomlinson (1958), the transmitted energy of the arterial pulse would accelerate venous flow in this region. This may be a significant factor in aiding venous return from the testicular vascular bed which, in standing adult rams, is 20 to 30 cm below the level of the right auricle.

PLATE 3

FIGS. 5 AND 6. Photomicrographs showing structural differences between an internal spermatic artery where it emerged from the inguinal canal (Fig. 5) and on the testicular surface (Fig. 6). The close application of the veins to the artery wall can be seen in Fig. 5, and the overlying tunica albuginea in Fig. 6.

FIG. 7. Latex cast of the right internal spermatic artery of Ram 2 to illustrate the change in the nature of the coiling. The coils are supported in as nearly their normal position as possible, compare with Pl. 2, Figs. 1 to 4.

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Harrison & Weiner (1949) suggested that thermal exchanges might be taking place between the testicular arterial and venous streams and assisting in the maintenance of the abdomino-testicular temperature gradient. This was substantiated by Dahl & Herrick (1959) who showed that the temperature of the testicular arterial blood in the anaesthetized dog was approximately 3° C lower than that of the aortic blood. The latex casts (Pl. 3, Fig. 7), X-ray photographs (Pl. 2, Figs. 1 to 4) and the analysis of the coiling per unit length of the internal spermatic artery summarized in Table 3 showed that the character of the coiling of the artery changed along its length. The proximal portion, where the major pulse-pressure reduction occurred, was more convoluted than the middle and distal lengths. Also, the larger lumen and lower mean pressure in the artery in its terminal coils suggested that blood flow along the distal length of the artery was slower. Furthermore, the terminal coils were compact (Pl. 3, Fig. 7) and the veins formed a fine network on the artery at this level. From these considerations it was concluded that the principal thermal exchanges would occur at the base of the vascular cone. The excellent angiographs illustrating the work of Harrison (1949), Harrison & Weiner (1949), and Kirby (1953) reveal that two zones of coiling may occur along the internal spermatic arteries of other species. This is particularly evident not only in the other domesticated ruminants examined by these authors, but also in the internal spermatic arteries of species as diverse as the dog, rabbit, rat, guinea-pig, lion, polecat, Indian palm civet and wart hog.

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