A STUDY ON THE PATTERN OF THE VASCULARIZATION IN BOVINE TESTES

by

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PATTERN OF VASCULARIZATION IN BOVINE TESTIS

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ABSTRACT

Meagre information about the vascular pattern in the bull testis necessitated its further exploration. Plastic casts of testicular arteries and veins were prepared, using vinyl acetate as injecting mass and corroding the tissue with 4 % HCl and 2.5 % pepsin.

Vascular distribution was studied in detail and the results were compared within the testes of the same bull, in different bulls and with the findings reported in other mammals. The vascular pattern in general is fairly constant within species, but it differs from other mammals described by some workers. Arteries show a great tendency to run a highly tortuous course within the cord and along the surface, but none of their branches enter the deeper parts unless it runs a superficial course.

The extraglandular and intraglandular peripheral distribution of arteries and their topographic relation with the veins strongly suggests, that the pattern of vascularization itself has a specific tendency towards a reduction of both the intraglandular temperature and pressure.

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INTRODUCTION

In the light of the ever increasing importance of both beef and dairy industry and its expansion into parts of the world where in the past such enterprises were considered to be infeasible, it has become imperative to elaborate on the physiology, especially of the reproductive system in cattle.

A limited knowledge is at hand with regard to the pattern of vascularization of the bovine testicles and their functional significance.

It is, thus, the objective of this study to attempt a contribution towards the closing of this gap by furnishing relevant information.

REVIEW OF LITERATURE

This review will be divided under two main headings:

I. The Technique.

II. The Pattern of Vascularization in the Bull Testis.

I. The Technique.

Some of the authors resorted to simple dissection in studying vascular organization.

An improvement in this technique was made by others who injected the vessels with different masses, prior to their dissection (16, 19).

The techniques of arteriography and micro-arteriography, employing colloidal bismuth carbonate in 20-25 % suspension in normal saline, "Cholobismol" and thoratrast as contrast media, were used for visualization of the vascular pattern (1, 7).

A continuous effort was maintained by workers to inject the vascular system with a suitable mass which would solidify, thus producing a stabilized cast permitting detailed studies. In this respect Hinman et al. (12) provided technical details for injection with a celloidin mass. Counsller and MacIndoe (3), using ice cold water for prefusion made slight modification in the technique developed by Hinman (12). They corroded the tissue of the injected gland with concentrated HCl. Various techniques employed so far were discussed critically by Witten (24) who prescribed further improvements in plastic injections and also discussed the process of corrosion and preservation of the casts.

Narat <u>et al</u>. (17) went a step further by using colored vinylite, a resin solution, which solidifies quickly after intravascular injection. In this manner he was able to prepare multicolored casts depicting veins and arteries. Latex solution was employed by some other workers, but most of them disagreedas to its suitability for injection of finer vessels. Moreover its technique was reported to be quite cumbersome (21, 2). Celloidin as an injection mass enjoyed quite a good reputation because of its ability to penetrate even into finer vessels. Trueta <u>et al</u>. (22), using this material, were able to produce impressive casts of an 'arterial tree' from kidneys.

A sizable study of vascular architecture was made possible by the use of another plastic material, vinyl acetate. Some of the workers using this material describe the technique of its application in different organs. Reynold (18) studied the spiral artery in the rabbit ovaries in situ by injecting vinyl acetate. Human ovaries were also studied using the same material (5, 18). These authors found that filling the cups of the cannulae with acetone, prior to allowing the flow of vinyl acetate solution prevents premature hardening of the plastic material. A solution containing HCl and pepsin was used for corrosion and digestion of the organic tissue.

Kazzaz and Shanklin (14, 15) injected canine coronary vessels and also studied the vascular pattern in kidneys, making vinyl acetate multicolored casts. They detail various steps taken in the preparation of the organ: intravascular injection with vinyl acetate; setting; corrosion and washing of the digested gland. A standard solution of vinyl acetate was used as injection mass after flushing the blood vessels with normal saline. The corrosion and digestion of the injected organs were carried out by placing them in a solution of 4 % HCl and 2.5 % pepsin under incubation at 37°C.

A fine jet of water was employed to wash off the digested tissue in order to obtain a clear plastic cast. The canine septal artery was studied by Donald and Essex (6) using colored vinyl acetate. The organ was prefused with 0.9 % saline and corrosion was affected with concentrated HCl.

Julian (13), who determined the static intravascular extracapillary volume of blood in canine kidneys using vinylite, describes an efficient technique for a complete injection. He modified previous techniques by pre-injecting vessels with acetone which was followed by a passage of air for some time.

II. The Vascular Pattern of the Bull Testis.

Hill (10) complained that the literature on the testicular vascularization was surprisingly meagre. This holds true even now, at least in regard to the bull. Sizable material has accumulated on the physiology of the mammalian testes, but only little is known about the pattern of their vascularization and their role in the overall physiology of the gland.

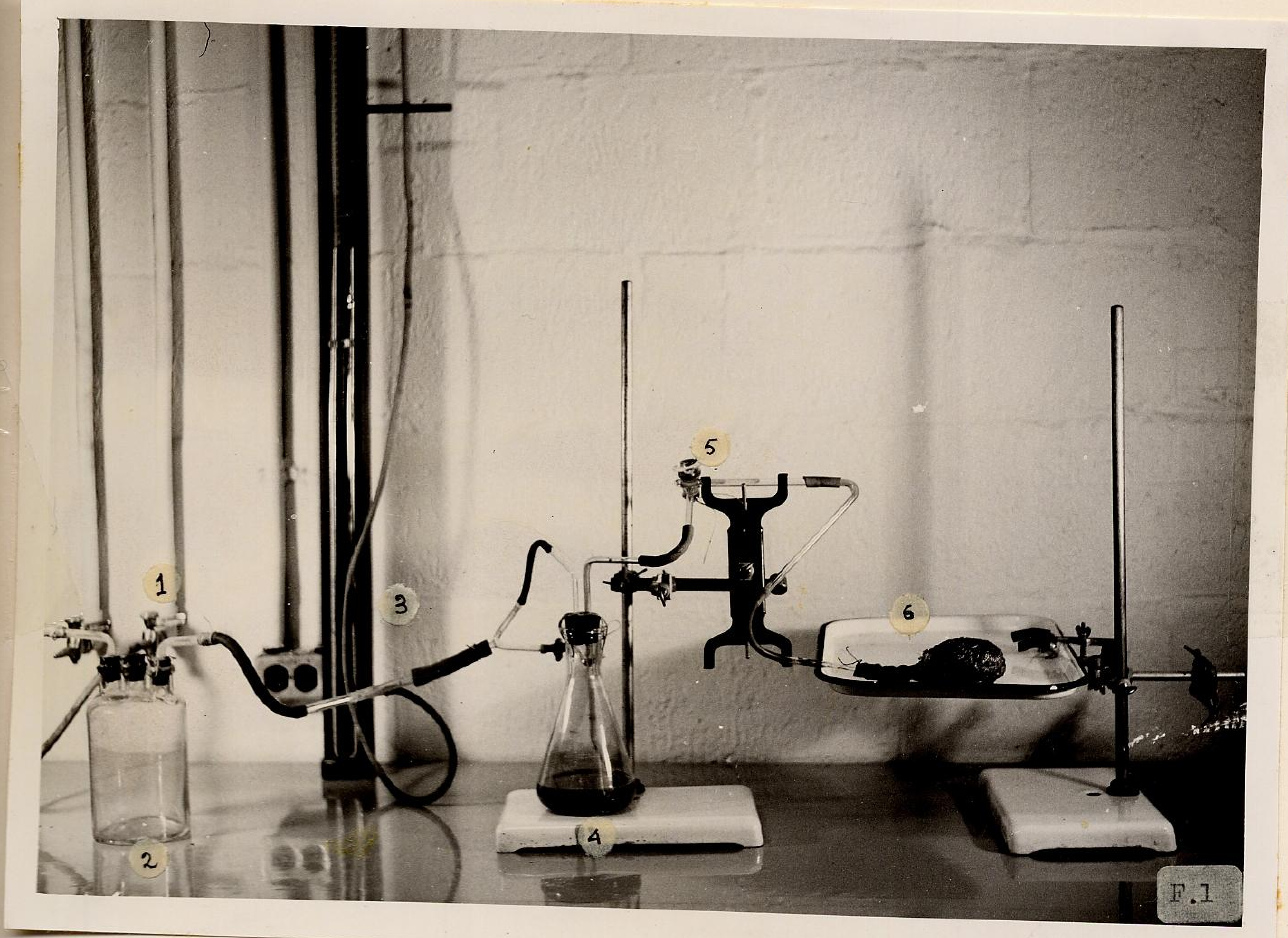
Harrison (7) traced the history of the developing knowledge about differences in vascular patterns in different mammals. He mentioned names of Graaf, Bimar, Jarisch, Gutzschebauch, Clark, Picque and Worms in connection with their work on the study of testicular vascular organization in livestock. Hill (10) studied the development of vascularization in pig testes at different age levels and describes the extra-glandular and intraglandular arrangements of the arteries. The same author (11) studied human testis and depicted the gross differences in vascular distribution.

Sisson (20) in his text book on anatomy, briefly describes the testicular artery in the bull as resembling that in the horse. The description of the equine artery does not go beyond the mere general remarks that the testicular artery divides into superficial branches and also stems into the intraglandular tissue.

Harrison (7) gives more detailed picture of testicular blood supply of the bull. His report is based on the examination of three specimens. He visualized the vessels by means of micro-arteriography. A division of the testicular artery into three or four main superficial arteries has been reported. Moreover, the formation of an anastomotic network along the mediastinum by the descending branches and a centrifugal arrangement of the finer branches has been described to exist within the glandular tissue.

The same author (7) quotes Jarisch and Wolfram for reporting the length of the coiled portion of the testicular artery in the cord as 140 cm. and 226 cm., respectively.

Fig. 1. Apparatus used for injection.
1- Tap for compressed air; 2- Woulfe bottle;
3- Mercury manometer; 4- Injection flask;
5- Glass tap; 6- Testis.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MATERIAL AND METHODS

This study was made with testes of young bulls raised at the farm of the American University of Beirut. The material and equipment used during the experiment is listed as follows:

I. Material.-

1. Testes: Six pairs of organs were collected from bulls of different breeds of 2, 3, 5, 8, 9 and 10 months of age. In addition some more testicles for practising the technique were secured from Beirut slaughterhouse. The animals employed in the experiment were healthy and normally developed.

2. Surgical equipment used for castration of the calves included scalpels, surgical scissors, suturing material, emasculator, forceps, probes, enameled trays and dressing material.

3. Injection apparatus included glass syringes, beakers, cannulae and different elements of the modified injecting apparatus, originally described by Counsller and MacIndoe (3) and Whitten (24).

Fig. 1 gives a detailed view of the above mentioned apparatus mounted ready for injection.

It consists of an air tap connected to one opening of a Woulfe Bottle, the other opening of which is connected to a 'Y' tube. One shank of the 'Y' is connected to a vertical mercury manometer and the other one to an injection flask through a bent glass tubing extending up to the bottom of the rubber stopper fitted in the flask neck.

Another long bent glass tube which reaches the bottom of the injection flask through the same stopper is connected with a glass tap. The distal end of this tap carries a tightly fitting rubber-tube.

The glass cannulae are inserted into the vessels to be injected and are maintained in situ by reliable ligatures. At the time of injections the cannulae are connected to the injection apparatus. Connections between various parts of the apparatus are provided by rubber tubing.

4. Chemicals.

(i) An anti-coagulant solution containing potassium oxalate 0.8% and ammonium oxalate 1.2 % was substituted for the heparinization employed by Kazzaz and Shanklin (14).

(ii) Vinyl acetate (a ready-made standard solution) was employed as injection mass. Material in different colors was used for arterial and venous injections; red or yellow for arteries and blue for veins.

(iii) An aqueous solution of 4 % HCl and 2.5 % pepsin hydrochloride was used for corrosion and digestion of tissues of the injected glands (14, 15).

II. Methods.

Methods are described in accordance with the different consecutive phases of the operation, starting from the collection of glands and ultimately leading to the presentation of results for their analysis and interpretation.

1. Collection of Testes. The testes were collected by surgical intervention. The scrotum was incised under due antiseptic precautions, and the glands were removed after severing the cord at a level above that of the vascular cone. To avoid injury to the blood vessels, the organs were secured along with both the tunica vaginalis and the cremaster muscle.

After stripping off the tunica, muscle and fat, the glands were immediately shifted to a cool place. Then arterial and venous ends were located and cannulated. The cannulae were secured by tight ligatures.

2. Preparation of the Gland. This phase, being of paramount importance, much practice was required to learn how the gland is rendered fit for final injection with the mass.

The main object of preparation was to remove from the vessels a maximum amount of blood and moisture, remnants of which would cause a premature solidification of the vinyl acetate and, thus, prevent its further intravascular transportation.

Prefusion with tap water or normal saline, followed by an injection of compressed air, as employed by various workers failed in achieving a complete cast due to insufficient evacuation of the moisture (3, 17, 14).

Apparently, the injected air meant for elimination of the moisture from the testicular vessels followed a shorter circuit through the epididymal vessels in by-passing the testicular circulatory system. With the following modifications previous techniques proved to be most practicable in adequate preparation of the gland for its further processing:

(i) The anti-coagulant was injected through the arterial stump immediately after removing the blood from the freshly collected testes by light palpation.

(ii) Subsequently, the vessels were prefused with 2 % NaCl solution instead of tap water or normal saline to avoid extra vascular infiltration.

(iii) While flushing with salt solution, only a very low pressure was employed, the injection being continued intermitently.

(iv) The cannulae for arterial injection were inserted at two levels, i.e. one at the proximal stump of the internal-spermatic artery, the other one into the posterior superficial artery prior to its division at the inferior pole.

(v) The air was allowed to pass through both cannulae for at least 12 hours, using a pressure not exceeding 30 mm. Hg. Minor adjustments in the time of injection were made according to the size of the gland.

(vi) Following Julian (13), about 30 cc. of acetone were injected after an evacuation of the air from the vessels. Then the insufflation was resumed and continued for another 30 minutes. This took care of any moisture possibly remaining within the vessels.

3. <u>Injection of the Plastic Mass</u>. The technique employed for intravascular injection with mass is similar to that described by Whitten (24) and Kazzaz and Shanklin (14). The viscosity of the standard solution of vinyl acetate was estimated and adjusted according to the size of the vessels to be injected. A solution, thin enough to pass freely through a 25 g. needle, was found to be suitable for the injection of finer vessels; while a less viscous solution was required for larger arteries and veins.

Stoppers and joints were checked for their ability to withstand the pressure of injection by closing the glass tap and raising then the pressure. Parts of the apparatus, through which vinyl acetate was to pass, were treated with acetone and dried by passage of air for some time.

Subsequently, the injection flask containing the vinyl acetate was connected with the Woulfe bottle and a column of the mass was allowed to rise up to the end of the rubber tube attached to the glass tap which was then closed. The cannula, inserted into the vessel, was first filled with acetone and then connected with the rubber tube attached to the distal end of the glass tap, avoiding access of any air. A moderate pressure was built up in the Woulfe bottle and the flow of vinyl acetate was then released.

Injection through the proximal end of the internal spermatic artery was made first and was followed by that made at the distal site. During the proximal injection a low pressure of 150-200 mm. of mercury was employed, while for that at the distal position a pressure as high as 500 mm. of mercury was required. The arterial ends at both levels were ligated upon completion of the injection prior to removal of the cannulae.

The veins were injected from a single site, i.e. the proximal stump within the cord. A relatively less viscous solution was injected at an initial pressure of 150 raising it to 250 mm. of mercury. The pressurewas built up slowly to allow ample time for the partially collapsed vessels to restore their normal form and conductivity.

During intravascular injection, especially in arteries, frequent interruptions of the flow proved to achieve more satisfactory results. The flow was withheld and resumed by closing and opening the glass tap, thus, creating a pulsation in the mass during its injection.

4. Setting. Upon completion of the injection, the gland was immersed in cold water and left for about ten hours. Any superfluous plastic material adhering to the gland was then removed.

5. Corrosion and Digestion. The injected testis was kept

Fig. 2. Bovine testis after injection with vinyl acetate.

A - Lateral view;

B - Anterior view;

C - Medial view.

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immersed in the afore mentioned solution and was incubated at 37°C for 72 hours or less, according to the size of the gland.

6. <u>Washing</u>. A modification was made in the technique employed by various previously listed authors, by connecting a fine, long drawn glass pippet to the rubber-tube at the end of glass tap of the injecting apparatus, and replacing the vinyl acetate with water in the injection flask (3, 14, 15). In this manner, a fine jet of water under controlled pressure was obtained for washing off the tissue debris without injuring even the finest structures of the cast.

7. <u>Preservation</u>. After thoroughly air drying, the casts were preserved in sealed glass jars, placing some menthol at the bottom of the jar (17).

8. <u>Presentation for Study</u>. The casts so produced, were presented for study in various ways:-

(i) In some cases, only the arteries were injected to facilitate the counting of their coils and to study their course and branches (Fig. 3, 5). Such casts were further utilized for tracing the profound organization of arteries within the glandular tissue.

(ii) Multicolored casts, prepared by injecting differently coloured vinyl acetate in arteries and veins, depicted the arterio-venous topographic relations at various levels of the gland, in addition to their individual pattern of distribution (Fig. 2, 3, 4).

Fig. 3. Vinyl acetate casts of vascular architecture of bull testis.

A- Both arteries and veins injected.

B- Only arteries injected.

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(iii) The arterial casts, after counting the number of their convolutions, were immersed in hot water for a minute to permit unrolling of the coils, so as to establish the actual length of the vessels concerned. This procedure has its superiority over the measurements made by arteriography (7).

(iv) In some other samples, only the tunica albuginea was washed off after partially digesting the gland (Fig. 8, 10, 11). The rest of the material was immersed in formaldyhide in order to solidify the remaining soft digested tissue, and to avoid putrefaction. Such samples presented the original position and distribution of the superficial vessels, which otherwise, might have collapsed.

(v) Another presentation was obtained by clearing the injected gland, using KOH, alcohol and glycerine (10). This technique was found to be of great assistance in following up the course of superficial vessels, especially, because the arterial walls remained intact and could easily be dissected from the softened translucent glandular tissue.

(vi) Photographs showing several aspects of vascular arrangements at different levels of the gland were taken after their injection and prior to their washing, and after partial or complete washing off the organic tissue.

(vii) Schematic drawings were prepared in order to depict the arrangements observed in various casts with the aim to facilitate the description of right and left testes, and to study the arterio-venous relations (Fig. 9, 12, 13).

OBSERVATIONS AND DISCUSSION

The pattern of vascularization in bull testes will be described and its possible role in the physiology of the gland will be discussed.

The description and discussion has been divided into four major parts:-

I. The detailed description of the arterial organization in the right testis.

II. A comparative description in the left testis.

III. The venous organization and its topographic relation with the arterial arrangements.

IV. The discussion on the general pattern of vascularization and its physiological significance.

I. Arterial Organization in Right Testis.

The internal spermic artery becomes known as the testicular artery after issuence of the epididymal branch in the proximal part of the vascular cone (Fig. 4).

Course:- The testicular artery after leaving the epididymal branch, runs along the anterior part of the spermatic cord. Its course within the cord is highly sinuous, but becomes more or less straight along the posterior border of the gland. It divides into superficial branches at the ventral part of the inferior pole.

Fig. 4. Cast of blood vessels in bull testis.
a) Internal spermatic artery; b) Epididymal branch; c) Vascular cone; d) Posterior superficial artery.

Fig. 5. Cast of testicular artery.
a) Highly tortuous conal part; b) Straight posterior superficial artery; c) part of capsular arteries.


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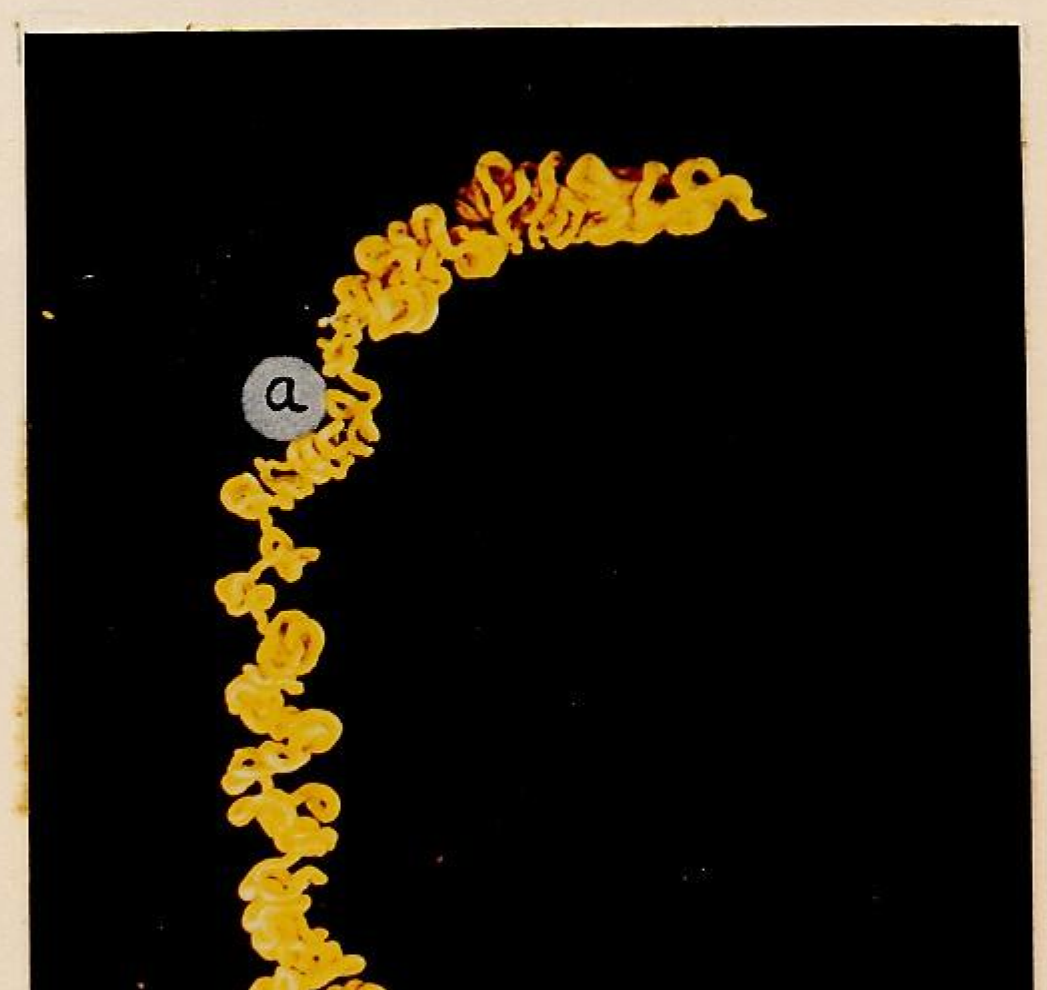
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The description of the testicular artery, studied in the experiment, will be presented according to the following topographic sections:-

A. The conal portion of the testicular artery.

B. The posterior superficial artery.

C. The superficial capsular arteries and their branches.

A. <u>The Conal Portion of Testicular Artery</u>:- (Fig. 4, 5) The testicular artery, within a distance of about 10 cm. from the superior pole, becomes highly convoluted, the convolutions being densely packed. This portion of the artery, covered by a pampiniform plexus of veins, presents a conical structure denominated during further description as 'vascular cone'. The tapering end of the cone extends proximally within the cord and its base rests upon the posterio-proximal surface of the superior pole. The conal part, extending over a length of 10-12 cm., accommodates about 150 arterial coils, which, when unrolled, measured 180 - 200 cm. These coils are knitted within the venous plexus into different positions in such a manner that the external face of the coils mostly remains denuded; while the deeper face and bends are fully embedded within the pampiniform plexus of veins. The coils forming the conal base are comparatively larger than those in the proximal part of the cone.

B. <u>The Posterior Superficial Artery</u>:- (Fig. 5, 2, 13) The testicular artery, emerging from the pampiniform plexus at the posterio-ventral part of the conal base, widens slightly

Fig. 6. Cast of superficial capsular arteries.

Fig. 7. Casts showing the straight course of descending arteries, formation of single or multiple mediastinal loops and ascending arteries.

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and undulates along the posterior border towards the inferior pole. It courses unbranched to the proximity of the inferior pole, accompanied by the pampiniform plexus on either side. Along the posterio-ventral aspect of the inferior pole, the artery forms a semicircular loop and divides into its main branches which immediately cross onto the anterior parts of the glandular surfaces.

C. <u>The Superficial Capsular Arteries</u>:- (Fig. 6, 2, 13) This term refers to all those branches which are derived from the posterior superficial artery and spread over the testicular surface, partially embedded in the tunica albuginea.

It appears appropriate to familiarize the reader with the terminology which has been suggested in accordance with the topographic position of the vessels for descriptive purposes.

The terms 'Anterior Superficial Artery', 'Medial Superficial Artery', 'Lateral Superficial Artery' were given to the main branches of the testicular artery, according to the surface occupied by them. The portion of the testicular artery along the posterior border was named as 'Posterior Superficial Artery'. The terms 'Primary', 'Secondary' and 'Tertiary' have been used for those branches which result from actual bifurcations at various levels, in contrast to 'Side Branches' which issue without similar division of the mother stem. The term 'Terminal Artery' refers to the end portions of the superficial arteries prior to their penetration into deeper parts. The term 'Profound Vessels' denominates the intra-glandular portions of arteries and veins. The portion of artery between its superficial terminus and the mediastinum, and that leading from the mediastinum to the periphery, was termed as 'Descending Artery' and 'Ascending Artery', respectively (Fig. 7). Denominations, viz., Capsular Arteries, Ascending Arteries, Descending Arteries and Peripheral Branches were used according to Hill (10, 11). A reference to Figures 2, 3 and 13 will illustrate the description of arteries and their relation to veins. The distribution of main arterial branches will be described in the order of their origin from the posterior superficial artery.

C. 1. <u>The Lateral Superficial Artery</u>.

<u>Origin</u>: (Fig. 9) The lateral superficial artery, arising from the lateral aspect of the ventral loop formed by the posterior superficial artery, is the first and the proximal most branch.

<u>Course</u>: (Fig. 2, 8, 13) The artery runs along the lateral surface dividing into very tortuous branches which arrange themselves into a lateral zone, and extend towards the superior pole with a general tendency to spread on to the anterior parts of the gland sending only terminal branches to both the posterior border and the superior pole. The artery leaving its mother trunk performs a sharp ventral turn and then continues proximally forming coils of various shapes along the distal part of the lateral surface. Finally, it

Fig. 8. Lateral superficial artery and its branches along the posterio-lateral surface. (Testis semi-digested and partially washed, red wire indicates zonal demarcation).


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makes a well pronounced 'G'- shaped loop. From this point onwards the artery continues branching.

Branches: The branches will be described in order of their emergence from the main artery. A reference to Figure 9 will facilitate the following of all superficial branches.

1. The First Side Branch arises from the distal bend of the above mentioned 'G' loop of the lateral superficial artery along the distal part of the lateral surface. It runs a short course in a spiral manner towards the posterior border, where it penetrates the tunica albuginea and continues vertically as a descending artery to the centre of the mediastinum. Before reaching the mediastinum it gives off a small branch which bifurcates into two sub-branches, running dorsally and ventrally in opposite directions and subdividing into peripheral parts. The main descending artery, after coiling in the mediastinum, produces two ascending arteries. One of them is larger than the other. These branches run distally. The smaller one ramifies into peripheral branch while the larger one bifurcates, and the two resulting branches coil against each other, form circular loops and issue peripheral branches within the distal part of the inferior pole.

2. The Second Side Branch departs from the mother artery at the posterior aspect of the proximal curve of the 'G' shaped loop. This branch continues posterio-proximally parallel to the first side branch at a proximal level. It bifurcates into two branches which reach the mediastinum on

on its posterior side. One of these vessels, prior to its entry into mediastinum, stems out a branch which coils back ventrally and 'sways' in a circular fashion in the peripheral parts of the inferior pole and distributes sub-branches into all directions. After the issuence of this branch the mother artery coils twice within the mediastinum and runs ventrally to divide into peripheral branches along the lateral part of the posterior surface.

The second descending artery enters the mediastinum unbranched. It makes two loops and issues four ascending branches, providing the ventral most periphery of the inferior pole with its sub-branches.

The main lateral superficial artery, after issuing the second side branch, continues along the lateral surface forming loops which are arranged into a sort of rectangle with undulated sides. This arrangement along the anterior part of the lateral surface is well marked.

3. <u>The Third Side Branch</u> is given off posteriorly at the level of the posterio-proximal angle of the rectangle. The vessel coils along the main artery and then continues as a descending artery to reach the mediastinum. Here it forms a loop and emerges as an ascending artery branching into the lateral part of the posterior border.

The main artery, after issuing the third side branch, continues to ascend proximally under formation of coils along the anterior margin of its zone. Then it deviates posterio-proximally and forms a 'V' - shaped loop, in the posterior part of the lateral surface.

4. The Fourth Side Branch stems-out from the posterio-proximal bend of the above mentioned 'V' loop and courses in a spiral manner towards the posterior border. It bifurcates after reaching the proximal third of the lateral surface. One of the resulting branches ascends proximally and the other courses posteriorly. Both of them continue as descending arteries to the proximal part of the mediastinum. They twist against each other, issue recurrent branches posterio-ventrally and enter the mediastinum from the posterior side. Within the mediastinum both arteries make loops and course proximally dividing into ascending branches which run ventro-laterally.

The main artery, leaving behind the fourth side branch, continues in a tortuous manner anterio-proximally and bifurcates into primary branches.

5. The First Primary Branch, amongst all branches, is anteriormost in its course. It forms the proximal part of the anterior margin of the zone. The artery ascends vertically in a spiral manner towards the superior pole covering a short superficial distance. At its terminus it forms a complete loop and continues as a descending artery leading to the proximal part of the mediastinum. The ascending branches are distributed in the periphery along anterior parts of the superior pole.

6. The Second Primary Branch extends along the posterio-

proximal part of the lateral surface. Here it forms a 'V'-shaped bend and creates the fifth side branch.

7. The Fifth Side Branch leaving the second primary branch coils beneath the mother artery, and descends to the mediastinum entering it from the anterior aspect. The ascending branches lead to anterio-lateral part of the periphery.

8. The First Secondary Branch courses anterio-proximally in a flexuous manner along the anterior part of the lateral surface. After making a few coils it sends off the sixth side branch and itself continues as a terminal artery, which enters the gland near the superior pole. The artery loops in the proximal part of the mediastinum and its ascending branches ramify within the vicinity of the superior pole.

9. The Sixth Side Branch arises from the first secondary branch and courses flexuously between the first and the second secondary branches towards the posterio-proximal part of the lateral surface.

The descending artery, continuing from this branch, enters the mediastinum along with the descending artery of the first secondary branch. It coils within the mediastinum and divides into peripheral branches in the polar region.

10. The Second Secondary Branch arises along with the first secondary branch in the proximal third of the lateral surface and courses in a spiral fashion posterio-proximally towards the superior pole. Its terminal part, near the posterior border, undercuts the stem of the fourth side branch

Fig. 9. Superficial branches of the testicular artery, right testis. (Schematic drawing)

P, L, M, A - Posterior, lateral, medial and anterior superficial arteries.

P_1, P_2 - First and second primary branches.

S_1, S_2 - First and second secondary branches of first primary branch.

s_1, s_2 - First and second secondary branches of second primary branch.

$t, .. t_5$ - Terminal branches.

1, ... 8 - Side branches.

F.9

and subsequently continues as a descending artery to enter the mediastinum from its lateral aspect. Two ascending branches emerge from the mediastinum twisting against each other. They divide into short but thick branches extending over both sides of the mediastinum.

11. <u>The Seventh Side Branch</u>, arising from the second secondary branch is a rather small vessel. After coursing transversely along the posterior part of the superior pole, it continues as a descending artery and finally enters the mediastinum to issue ascending branches.

C. 2. <u>The Medial Superficial Artery</u>.

<u>Origin</u>: (Fig. 9) In order of origin, this artery arises next to the lateral superficial artery from the distal part of the ventral loop formed by the posterior superficial artery at the inferior pole of the gland.

<u>Course</u>: (Fig. 2, 10, 13) This artery is comparatively smaller than the other two main branches of the posterior superficial artery and runs sinuously along the distal part of the medial surface. Its terminal branches reach as far as the posterior border and the proximity of the superior pole. Its branches, in general, run spiral courses are are arranged in a zonal fashion along the medial surface. They do not form large loops, but are highly spiral in their course.

<u>Branches</u>: Close to its origin, the main artery makes a transverse 'C'-shaped loop along the medial surface from where it starts to branch (Fig. 9).

Fig. 10. Medial superficial artery along posterio-medial surface (testis semi-digested and partially washed, red wire indicates zonal demarcation).

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1. <u>The First Side Branch</u> originates from the distal end of the aforementioned 'C' loop and courses proximally in a vertical direction for a short distance. Then it takes an abrupt posterior turn to run beneath the main artery. Further on it continues on to the medial face of the posterior border of the gland giving off a small branch. This branch bifurcates after running a short posterior course. One of the resulting sub-branches making a loop in the mediastinum emerges as a single ascending artery and gives branches to the medio-posterior part of the glandular periphery in the distal third of the gland. The second branch emerges from the mediastinum without forming a complete loop and bends back to the peripheral part. Here, after leaving some small peripheral branches it returns to the mediastinum. This time it forms a complete loop and sends ascending arteries towards the periphery.

The first side branch, after stemming off this branch, divides into two terminal branches, the proximal and the distal terminals.

The descending artery continuing from the proximal terminal branch courses over a long distance to reach the mediastinum. Here, it loops and returns close to the surface alongwhich it runs for some distance and bifurcates. Out of the resulting vessels, the smaller branch coils within the mediastinum and sends ascending branches towards the posterior periphery. The second larger branch makes a number of loose coils in the mediastinum and gives a large number of sub-branches supplying the medial peripheral parts.

The distal terminal branch is comparatively smaller and produces four sub-branches prior to its entry into the mediastinum. Three of these sub-branches, after leaving the mediastinum, run back to the to the peripheral parts. The fourth branch enters the mediastinum to make a loop and sends ascending branches towards the medio-posterior periphery.

After issuence of the first side branch, the main artery forms a number of coils of various shapes and sizes , while coursing transversely towards the anterior surface.

2. <u>The Second Side Branch</u> arises from the main artery along the anterior part of the medial surface and continues anteriorly in a transverse direction. Further it curves proximally and then posteriorly reaching upto the proximal third of the medial surface. Here it undercuts the second primary branch and continues as a straight descending artery. Now it runs perpendicularly from the anterio-medial surface to the central part of the mediastinum, forms coils and sends out closely running arteries towards the anterior aspect of the medial periphery.

3. <u>The Third Side Branch</u> is a small artery and penetrates into the gland after running a short spiral superficial course. Its further course within the gland was not traceable.

The main artery, after making a proximal curve, divides into its primary branches.

4. <u>The First Primary Branch</u> is the smaller of the two primaries and runs a very spiral course. After traversing vertically for a short distance, it gives off a minor branch. This branch after undercutting the mother artery runs posteriorly as a terminal branch and penetrates into the deeper parts of the gland.

The first primary branch, leaving behind this minor branch, continues for some distance in a flexuous manner and divides into two secondary branches.

5. <u>The First Secondary Branch</u> courses in a spiral fashion to reach the posterior border, where it divides into two terminal branches which course in opposite directions to enter the mediastinum along with the descending artery of the second secondary branch.

6. <u>The Second Secondary Branch</u>, after separating from its sister branch at the point of origin, runs in a direction opposite to that of the first secondary branch. After a short superficial course it continues as a descending artery and ultimately enters the mediastinum from the posterior side at a level distal to the entry of the descending artery of the first secondary branch.

The terminal arteries, originating from the first secondary and the second secondary branches, run posterioventrally to the proximity of the posterior border. Here, they leave the surface and continue as descending arteries to the mediastinum where they coil within the central part. They branch further and despatch ascending arteries towards the posterior periphery.

7. <u>The Second Primary Branch</u>, comparatively larger than the first primary, courses flexuously towards the proximal parts and stems out the fourth side branch.

8. <u>The Fourth Side Branch</u>, just after leaving the second primary branch, makes a large anterior coil and embeds itself beneath the mother artery. Proceeding posteriorly, it penetrates into the deeper parts and ultimately reaches the mediastinum from its medial aspect.

The second primary branch continues in a spiral manner anterio-proximally, then turns posteriorly to bifurcate into two secondary branches.

9. <u>The First Secondary Branch</u> courses posterio-proximally in a spiral way along the central part of the medial surface. It makes a circular loop at its terminus and continues as a descending artery to reach the mediastinum in the vicinity of the superior pole along with the descending arteries from the fifth side branch and the two terminals of the second secondary branch. The descending branches loop within the mediastinum and give off ascending branches coursing towards the medial aspect of the posterior border and ramifying into the peripheral branches.

10. <u>The Second Secondary Branch</u> is relatively a large one and runs vertically to the proximal third of the medial

Fig. 11. Arrangement of anterior superficial artery along the anterior surface. (Testis semi-digested and partially washed, red line indicates zonal demarcation).


B
F.11

surface. The artery is highly spiral and courses parallely to the first primary branch. Here it detaches a small branch, the fifth side branch.

11. <u>The Fifth Side Branch</u> is a minor artery which courses posterio-ventrally to leave the surface near the posterior border as a descending artery and enters the mediastinum from its medial aspect. After coiling within mediastinum, it sends back ascending arteries ramifying within the posterior part of the periphery.

12. The main second secondary artery, after issuing the fifth side branch, continues proximally to reach the superior pole along its medial side. Here, it bifurcates into terminal branches. The terminal branches, soon after leaving the surface, enter the proximal third of the mediastinum as descending arteries. The emerging ascending branches ramify in the medio-posterior part of the periphery.

C. 3. <u>The Anterior Superficial Artery</u>.

<u>Origin</u>: (Fig. 9) The main posterior superficial artery, after giving off the first two branches at the ventral part of the inferior pole, ascends along the anterior surface as the anterior superficial artery which is the largest of the three branches and is extremely tortuous.

<u>Course</u>: (Fig. 2, 11, 13) The artery and its branches form a large number of coils which are well packed, often overlapping eachother within a well demarcated area enclaved by the adjacent medial and lateral zones on either side. The

zone occupied by the anterior superficial artery is broader in its distal part in contrast to its narrowed proximal part. This artery and its branches often form oblong coils making more frequent twists while bending.

<u>Branches</u>: (Fig. 9)

1. <u>The First Side Branch</u> is the largest one amongst all side branches of the testicular artery. The artery arises from the lateral aspect of the first 'C'-shaped loop formed by the anterior suoerficial artery in the distal part of the anterior surface. It turns laterally and courses for a short distance, then makes a vertical 'C'-shaped loop and finally curves anterio-proximally forming a 'V'-shaped loop.

2. <u>The Second Side Branch</u> is given off from the distal part of the 'V'-shaped loop of the first side branch and courses along the curvature of the 'C'-shaped loop traversing distally. Further, it crosses beneath the loop and continues as a descending artery. This artery runs for some distance and bifurcates before entering the mediastinum. The resultant branches emerge from the mediastinum after forming loops within it and each of them further divides into two branches. The smaller of the two sub-branches ramifies in the peripheral part; while the larger one ascends anterio-ventrally and issues a small branch before reaching the peripheral parts. Here, it recoils from the periphery towards the mediastinum, but, before entering the mediastinum, sends another recurrent branch to the periphery. Once in the mediastinum, the artery

coils again and emerges as an ascending vessel which reaches the peripheral parts and ramifies.

The main trunk of the first side branch, after issuing the second side branch, courses anterio-proximally and then takes a lateral turn.

3. <u>The Third Side Branch</u> is a small branch and arises from the first side branch when this takes the above mentioned lateral curve. It courses proximally and then, after a short distance, it curves ventrally and continues as a descending artery which bifurcates before entering the mediastinum. The ensuing branches emerge from the mediastinum after looping within it. Once again each of them bifurcates sending one branch to the periphery and the other back to the mediastinum, from where it re-emerges as ascending artery and courses towards the anterior part of the periphery.

The main stem of the first side branch continues to ascend along the lateral part of the anterior surface between the opposing coils of the lateral superficial arteries. Then it bifurcates into two terminal branches near the center of the anterior surface. These stems according to their topographic situation could be called lateral and anterior terminal branches.

4. <u>The Anterior Terminal Branch</u> runs along the center of the proximal part of the anterior surface in a flexuous manner. It gives off a side branch, and itself continues as a descending artery which bifurcates before entering the

mediastinum. Each of the two resulting branches coils within the mediastinum and bifurcates into a small and a large branch after its departure as ascending artery. The small ascending branch ramifies close to the mediastinum in the proximal part, but the large ascending vessel runs ventrally to divide at a lower level.

5. The Fourth Side Branch arises from the anterior terminal branch at the center of the anterior surface. The artery courses anterio-ventrally and penetrates the tunica albuginea to enter the mediastinum from where it sends off ascending branches to the periphery.

6. The Lateral Terminal Branch runs parallel to the anterior terminal branch on its lateral side; while the main artery continues proximally, a small stem is given off from its lateral side - the fifth side branch.

The main artery penetrates the tunica albuginea at a level distal to that of the anterior terminal branch. Within the mediastinum the descending artery forms loops which are placed below those of the anterior terminal artery. The ascending artery bifurcates twice resulting into four sub-branches, one of which reaches the periphery and the others enter the mediastinum, form loops and despatch ascending branches to the anterior peripheral parts.

7. The Fifth Side Branch arises from the lateral face of the lateral terminal branch and runs a very short superficial course. It curves distally beneath the larger coils and continues as a descending artery towards the central

part of the mediastinum.

The main trunk of the anterior superficial artery after detaching the first side branch continues onto the proximal part of the anterior surface. After having a short straight course it performs a large ventral 'C'-shaped loop and continues proximally to bifurcate into primary branches.

8. <u>The First Primary Branch</u> runs over a short distance along the medial aspect of the anterior surface and, after forming a number of coils, it bifurcates into two secondary branches - the first and second secondary branches.

9. <u>The First Secondary Branch</u> is relatively a short one as compared to the second secondary branch. It courses along the medial aspect of the anterior surface in a flexuous manner and returns to the level of its origin. Hereafter it continues within the deeper parts as a descending vessel towards the mediastinum within which a complete loop is formed. The two ascending arteries which emerge from the mediastinum ramify within the medial part of the periphery.

10. <u>The Second Secondary Branch</u> runs along the medial part of the anterior surface in a spiral way covering a short distance. The artery at its terminus, makes a complete circular loop; continues as ascending artery; bifurcates and finally embed the resulting branches within the mediastinum. The ascending arteries twist along their long axes and divide into peripheral branches traversing into all directions.

The second branch continues as an ascending artery which ramifies within medial periphery of the superior pole.

11. <u>The Second Primary Branch</u> is comparatively more developed than the first one and traverses latero-proximally along the anterior surface. It covers a long sinuous superficial course making a number of coils and at the same time bending itself in all directions in a zig-zag-fashion. During its course it deviates medially and forms three prominent loops before it stems out a side branch - the sixth side branch.

12. <u>The Sixth Side Branch</u> arises from the lateral face of the second primary branch near the center of the anterior surface. After a short lateral course it forms a circular terminal loop along the surface and leaves it as a descending artery which enters the central part of the mediastinum where it bifurcates. One of the stems runs to the anterior periphery, while the other one courses proximally within the mediastinum and then ascends anteriorly at a more proximal level.

The main stem of second primary artery, after issuence of the sixth branch, runs on to the proximal parts of the surface and divides into two secondary branches.

13. <u>The First Secondary Branch</u> covers only a short superficial distance while coursing flexuously along the anterior surface. In the proximal parts of the gland, it deviates medially and gives off a branch - the eighth side branch.

The main artery, after issuing this branch, covers a short distance and divides into two terminal branches, the proximal and distal terminals.

14. The Eighth Side Branch, leaving its origin, curves proximally along the anterior surface. Then it deviates medially and leaves the surface as a descending artery. This artery bifurcates before entering the mediastinum and the loops formed by the ensuing branches are placed on top of each other.

The artery ascending from the distal loop curves distally to divide into the medial part of the periphery; while that from the proximal loop runs at a relatively higher level. Each of the ascending arteries bifurcates sending one branch towards the periphery and the other one back into the mediastinum. This process is repeated for a number of times till the final ascending artery loops and sends a tuft of minor branches distally from the proximal most level of the superior pole.

II. The Comparative Arterial Organization of the Left Testis.

A detailed description in the right testis was given in order to provide a comprehensive picture of the topographic arrangements and distribution of the testicular artery. This would now furnish the basis for a comparison with the arrangements in the left testis. In both organs, although there is a similarity in the pattern of superficial and profound arterial organization, there are, however, a few variations regarding origin and topography of vascular distribution. These call for a more elaborate comparative

Fig. 12. Superficial branches of testicular artery, left testis (schematic drawing).

P, L, M, A_1, A_2	- Posterior, lateral, medial, first anterior and second anterior superficial arteries.
P_1, P_2	- First and second primary branches.
S1, S_2	- First and second branches of first primary branch.
s_1, s_2	- First and second secondary branches of second primary branch.
t, ...t_5	- terminal branches.
1, ...8	- Side branches.

F.12

Fig. 12. Superficial branches of testicular artery, left testis (schematic drawing).

P, L, M, A_1, A_2	- Posterior, lateral, medial, first anterior and second anterior superficial arteries.
P_1, P_2	- First and second primary branches.
S1, S_2	- First and second branches of first primary branch.
s_1, s_2	- First and second secondary branches of second primary branch.
t, ...t_5	- terminal branches.
1, ...8	- Side branches.

description. In order to facilitate the comparison, the description is given according to various sections of the artery (Fig. 12). The observed variations have been pointed out as for each section of the testicular artery.

1. The Vascular Cone: No significant difference was observed in this region.

2. The Posterior Superficial Artery: A pronounced variation in branching of this artery was noticed at the distal third of the posterior surface. The lateral superficial artery in the right testis arises from the main trunk which further gives off the medial superficial artery and then continues as anterior superficial artery. In the left testis, on the other hand, - the posterior superficial artery bifurcates into the lateral superficial artery and a common stem for one medial and two anterior superficial arteries. The medial and anterior superficial arteries arise from a common point of division.

The division of the posterior superficial artery occurs at a higher level along the posterior surface, thus, resulting in the distribution of main vessels along a more distal part of the surfaces.

3. The Lateral Superficial Artery: (Fig. 12) i. The first side branch is given off at a comparatively shorter distance and instead of proceeding towards the posterior surface it courses along the anterior surface. This branch is comparatively more developed than that in the right testis. It covers a more superficial distance and contrary to the right testis

divides into two terminal branches.

ii. In the left testis the sixth side branch is absent.

iii. The general course of the artery and its branches are both more sinuous and more pronounced along the distal part of the left gland.

4. <u>The Medial Superficial Artery</u>: i. Arises in common with two anterior superficial arteries at a more proximal level and is comparatively more developed (Fig. 12).

ii. The first side branch mainly courses along the anterior part of the medial surface. This is contrary to its distribution along the posterior surface in the right testis.

iii. The first primary branch runs along the posterior surface at a more distal level.

5. <u>The Anterior Superficial Arteries</u>: There are two anterior superficial arteries arising in common with the medial branch from the same point (Fig 12). The first anterior superficial artery substitutes the first side branch in the right testis, but is more developed, more tortuous and covers a larger surface area than that in the right testis. In contrast to this picture, the second anterior artery is less developed than the anterior superficial artery in the right testis and spreads along the medial aspect of the anterior surface in its proximal part.

III. <u>Venous Organization and its Topographic Relation with the Arterial Distribution</u>.

Whereas, the arterial organization has a significant tendency towards a spiral and tortuous pattern, the testicular veins characterize for the formation of plexi at different levels of the glandular surface.

The description of the venous organization is divided into two parts:-

1. The intraglandular organization.

2. The extraglandular organization.

1. The Intraglandular Organization: Its description has been based upon a careful study of the multicolored casts. The profound veins for descriptive purpose are classified into two groups according to their origin and course.

i. The first group embraces vessels which start in the form of tufts of small veins from the peripheral parts and run along the arteries of the corresponding regions. These veins, during their further course, run straight to the mediastinum where they become confluent forming larger vessels.

The arteries and veins in the proximity of the mediastinum do not run side by side, nor do they form loops in the mediastinum. They are often arranged in rows and traverse to the surface in a perpendicular fashion. On their way to the surface they remain uncoiled and receive at all levels a large number of tributaries. Their concentration is well marked within the central part of the mediastinum from where they are diverted into all directions towards the surface.

ii. The second group consists of those intraglandular veins which arise from different levels of the parenchyma and unite into larger vessels running to the surface without passing through the mediastinum. The number of such vessels is comparatively less than of the first group. They drain the peripheral parts of the gland. Such veins, after reaching the surface, join others which arrive via the mediastinum.

2. The Extraglandular Organization: Veins arriving from the profound parts of the gland continue to course along the surface side by side for some distance and merge to form larger vessels. The resulting veins course from the distal to the proximal parts of the surface (Fig. 2, 3, 13).

Veins originating from the posterior surface merge with the posterior plexus formed by collateral anastomoses; while those appearing at the anterior surface deviate along either the lateral or the medial surface of the gland.

Veins emerging at the proximal part of the lateral surface incline posterio-proximally dividing into finer branches which are incorporated into the posterior plexus. Large vessels, interconnected collaterally, are also derived by merger of veins reaching the medial surface, the distal part of the anterior surface and in the proximity of the inferior pole.

A. Superficial Arterio-Venous Relation: The dual-colored casts revealed that arteries do not accompany veins especially during their superficial course, but maintain their respective distinct zonal distribution (Fig. 13).

Major veins remain apart from arteries until after the veins spread out into a fine network. The major veins course along the posterior surface and the adjacent parts of the medial and the lateral surfaces. A fine meshwork of veins accompanies the posterior superficial artery on both of its sides and becomes proximally continuous with the posterior plexus. The glandular surface is encapsulated by venous network which spreads beneath the coils of the superficial arteries.

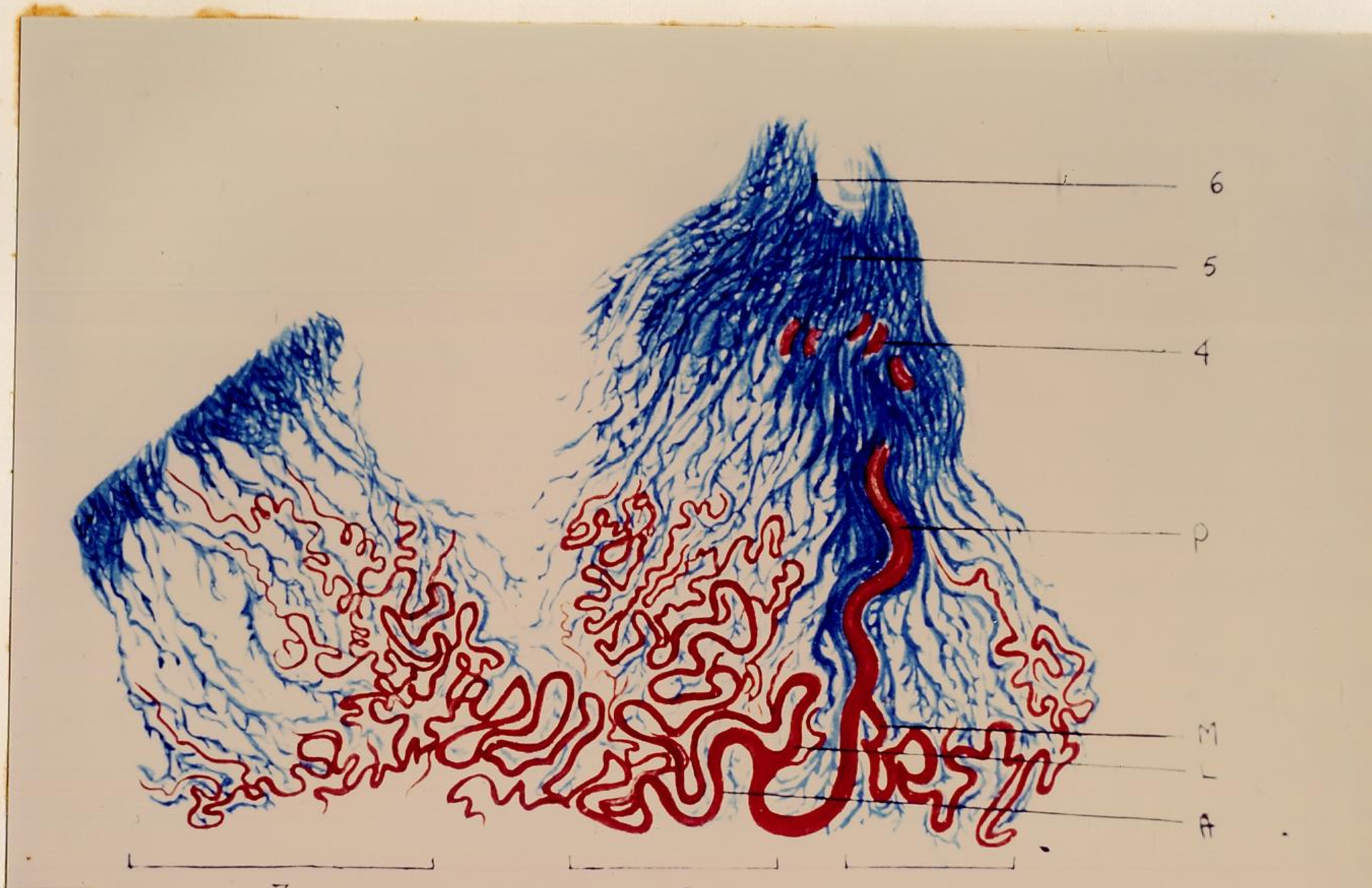
According to the predominance of arteries or veins in a particular area the glandular surface could be divided into arterial and venous zones. An insignificant number of veins were observed along the distal and the central parts of the anterior surfaces which is predominantly occupied by the arteries. In contrast to this the parts along the superior pole and the posterior surface are mainly occupied by veins (Fig. 2, 13).

B. Superficial Venous Organization: Veins from all sides, except those from the proximal part of the anterior surface where they ascend perpendicularly, deviate posterio-proximally and then converge towards the proximal pole. The larger vessels in zones dominated by veins divide into finer vessels forming the anterior and the posterior venous plexi. Furtheron, vessels derived from these two plexi contribute towards the formation of the pampiniform plexus occupying the vascular cone in the distal part of the spermatic cord.

Fig. 13. Drawing produced from a multicolored plastic cast showing arterio-venous distribution.

1 - Medial surface; 2 - Lateral surface;
3 - Anterior surface; 4 - Base of vascular cone;
5 - Posterior venous plexus; 6 - Pampiniform plexus.

P - Posterior artery; A - Anterior superficial artery; L - Lateral superficial artery;
M - Medial superficial artery.



F.13

i. <u>Posterior Venous Plexus</u>: Veins coursing along the posterior surface become confluent into larger vessels. In the proximity of the posterior superficial artery veins divide to form a fine meshwork which stretches out proximally along either side of the artery. The two plexi are not interconnected transversely, but the artery remains denuded below its point of emergence from the conal base. Later, the two plexi on the sides of the posterior superficial artery merge proximally, embedding the testicular artery at the level of the conal base. In this part the artery remains uncovered at a few points.

ii. <u>Anterior Venous Plexus</u>: Veins from the lateral surface deviating posteriorly form a posterior venous plexus, but some of them continue on to the dorsal surface of the superior pole - a part situated anteriorly to the base of the vascular cone underneath the epididymal head. Some other vessels reach this part directly from both the anterior and the medial surfaces. Here, veins produce fine branches and pool into a formation of an anterior plexus which, at the conal base, is clearly demarcated from the posterior plexus.

iii. <u>Pampiniform Plexus of Veins in the Vascular Cone</u>: (Fig. 4, 13) Both anterior and posterior plexi contribute to the formation of a pampiniform plexus of veins which maintains the coils of the testicular artery embedded within the vascular cone. The plexus comprises of a number of strands traversing the loops of the convoluted artery, this especially so at its bends, thus knitting them in such a manner as to leave the external face of these coils denuded. Proximally to the vascular cone the vessels of this plexus merge into a small number of larger veins and finally form a single trunk.

COMMON VARIATIONS IN THE VASCULAR ORGANIZATION

The testes used in the experiment were obtained from calves of different ages and breeds. A comparative study of the casts produced from their vascular system revealed a fair uniformity of the pattern of organization at different levels of the gland, but at the same time the following variations were observed:-

1. Variations in Length and Size of Vessels.

These variations were quite apparent in testes of various size which in itself is dependent upon various factors like, age, breed and improper development of the gland.

2. Variations in Location of Vascular Divisions.

Such variations were quite common in arteries and were attributed to differences in shape and size of the organ as well as individuality of the animals.

3. Topographic Variations in Superficial Distribution.

The main arterial spread along the surface was observed to differ in the right and left testes. This difference, as will be discussed later, may be in relation to the thermal regulation of the gland.

4. Variation in Number of Branches.

The number of minor side branches and the terminal branches of the three superficial arteries was observed to differ to some extent in different testes but without making a gross change in the total number of terminal branches.

The detailed study of the above described variations, which can make a separate project itself, was beyond the scope of the present investigation. These variations are pointed out so that the information might be utilized for some future study aimed at the establishment of inter-relationship between any one of these variations and the factors affecting the morphology of the gland.

DISCUSSION

Though the detail of vascularization does not maintain a uniform character in all glands, yet it provides a sound base to apprehend the general pattern of the vascularization at which the study was aimed.

The observations were made in typical complete casts of bull testes. Detailed measurements were omitted to limit the study to the proper subject and to concentrate on the pattern of vascularization rather than to describe any particular part of the system.

The observations were compared with the findings of other workers who studied bull as well as some other mammals (10, 11, 8, 7, 20).

In this chapter the discussion is focussed on two major aspects:

a.- The anatomical comparison between present observations and the results reported by other workers.

b.- The possible functional significance of the vascular pattern at various levels in the gland.

The arterio-venous pattern is discussed sectionwise and its comparison made with corresponding parts in other mammals is described as follows:-

1. The Conal Vessels and their possible Role.

Within the vascular cone the bovine testicular artery is comparatively more flexuous and is longer than the corresponding portions observed in man, dog, ram and goat (7). In this region the artery is 180-200 cm. in length and consists of as many as 150 coils in a mature calf. The artery in bovines appears to be the longest if compared with those described in other mammals (9). Packing of the convolutions also appears to be more compact than that in other mammals. The arterio-venous relation within the vascular cone is apparently similar to that described by various authors (10, 7, 20).

In the bull, unlike other mammals, segments of the coils were observed to be partially covered by the veins of the pampiniform plexus. Their bends and the deeper face were seen embedded in the venous plexus while the major parts of the segments were left denuded (Fig. 4).

The length, intensity of convolutions, degree of compactness in packing and a peculiar arterio-venous relation in the conal part of the bovine artery strongly suggests the existance of a more efficient arrangement for 'pre-cooling' the arterial blood.

An arrangement for reducing the flow rate towards the distal parts of the vascular system appears to exist in bull testis also. The volume of blood flowing through the pampiniform plexus appears to have a regulatory effect on the arterial flow rate. An abnormal distension of veins in the plexus within which the bends of the artery lie embedded, would reduce the flow rate due to consequent arterial obliteration and a reduction in the angles of bends. In this manner, the vascular pattern within the cone appears to play an important role in the regulation of the flow rate, and consequently the volume of the blood flowing to the profound parts of the gland.

A previous work showed the existance of thermal gradient between the abdomeno-testicular temperatures in some mammals other than the bull. It was also suggested that the vascular pattern in mammals has its significance in maintenance of the gradient (9).

The observations made in the present study fully support these suggestions.

A number of workers agree that there are two major ways in which the vascular pattern assists the thermal regulation:

a) A counter-current exchange of heat between the arterial and venous blood within the vascular cone and along the posterior surface.

b) The slow flow rate along the glandular surface due to the peculiar pattern of vascular organization causing a prolonged exposure of blood to ambient temperatures (9,4,23).

On analysing the pattern under study, the above mentioned views appear to hold true also in the bull.

2. The Superficial Vascular Pattern and its Role.

The superficial arterial organization in the bull differs from the 'rib-like' arrangements described in the pig (10). It also differs from that in man where the testicular artery has been described to divide into a capsular artery and the terminal branches which enter the mediastinum at the anterior pole (11, 8). The pattern of superficial arrangements described in the ram and the goat (7) resemble that in the bull, but a detailed comparison was not possible due to lack of information on the profound vascularization in these animals.

The vascular distribution described by the same authors (7) in other mammals appears to differ from that in the bull in one respect or another. Contrary to that in the pig (10) the course of superficial arteries in the bull is highly sinuous. Unlike in the human testis (11) the bovine testicular artery branches at the distal part of the posterior surface, and none of its branches enters the mediastinum without taking a previous superficial course. This appears to provide a better chance for cooling of the blood. The superficial zonal arrangement of arteries and veins reduces the chance of the primarily cooled arterial blood to absorb heat from the veins.

The testicular artery, after emerging from the pampiniform plexus, slightly widens and becomes capable of more expansion as compared to its conal portion surrounded by the plexus. Thus, the blood leaving the vascular cone, is spread over a larger area enabling it to lose further heat and being simultaneously reduced in its flow rate. Arteries, due to their tortuous course, sharp turns after their division and loop formation by their descending branches, contribute towards the reduction in flow rate and thus prolong the retention of a large amount of blood for an extended period along the surface of the gland. These arrangements in the bull appear to be more developed than in other mammals on account of an apparently greater length and more pronounced tortuousity of the vessels.

The pattern of the superficial vessels was credited for the creation and maintenance of the externo-internal thermal gradient in the testis (9). This gradient in the bull testis can possibly be assumed as high on the basis of the findings in other mammals (9) where it has been found to be directly proportional to the size of the gland. Thus the assumption would explain the provision of an extremely flexuous pattern in the bull for the maintenance of an expectedly higher thermal gradient.

As a tentative explanation, a comparatively more distal location of the arterial branches observed in case of the left testis could be attributed to a corresponding unequal location of the testes within the scrotal sac. The proximal pole of left testis being closer to the body than that of the right testis, the main arterial coils are confined to a relatively more distal part of the surface in case of the former.

3. <u>Pattern of Venous Organization and its Role</u>.

The venous arrangement in various ways also seems to contribute to the process of "pre-cooling" of the arterial blood.

Veins during their course seldom accompany arteries, especially along the surface, but within the vascular cone the arterio-venous association is extremely close. This enables the venous blood to exchange heat with the arterial blood. Within the superficial venous zones the large veins carrying a relatively more blood split into finer branches and disperse the blood over a relatively larger area. These fine branches in the form of plexi become closely associated with the arteries in their further course towards the superior pole. They bring the blood previously cooled in the venous zone, close to the arteries carrying blood still at comparatively higher temperature thus enabling a counter-current heat exchange.

The surface of the gland is encapsulated by a network of fine veins lying beneath the arterial coils..This arrangement provides a better chance for losing heat from arterial blood. Had the veins been arranged over the arterial coils, the process of heat elimination would have been reversed.

4. Pattern of Profound Vessels and its Role.

Only a little information was available about the profound vascularization. The present study revealed that in an adult bull testis about 41 terminal branches, viz., 14 from the medial superficial artery, 15 from the anterior superficial artery and 12 from the lateral superficial artery, depart from the surface as descending arteries to reach the mediastinum. The formation of an anastomotic network around the mediastinum by the descending arteries, as described by Harrison (7), was found to be non-existent in the casts prepared during this study. Instead the arteries could be separated from the mediastinum individually. The reported anastomoses, if any, may be too fine to be injected, but their existence appears to be rather improbable.

The size and number of the descending arteries from the anterior and lateral surfaces is comparatively larger than those of the branches descending from the medial surface. This shows that the quantity of blood entering the gland from the more exposed parts of the surface is more than that from the relatively less exposed surfaces. This again suggests the role of the pattern in the thermal regulation of testis.

The course of the descending arteries in the bull differs from that of the corresponding arteries in human testis for the absence of terminal branches reported to enter directly into the mediastinum and then anastomosing with the branches descending from the capsular artery (11). Their pattern differs also from the pig in which they are not reported to make complete loops in the mediastinum, but simply bend forming 'hair pin' loops (10).

Though a further comparison was not possible due to lack of more detailed information, yet it appears worthwhile to comment on the possible role of the pattern of profound vascular organization in the bull. The formation of loops within mediastinum prior to the issuence of ascending branches suggests a finer regulation of the flow rate and facilitates the abrupt change in course taken by the ascending arteries when leaving the mediastinum. Moreover, a regulated flow rate may be a necessity for maintenance of an optimal intra-glandular pressure. Similar to the pattern in the pig, the descending arteries do not often make loops or give off peripheral branches on their way to the mediastinum (10). This arrangement appears to provide for a more accelerated transportation of the 'Precooled' blood from the surface to the deepest part of the gland.

The straight course of the ascending branches and their distribution on the same side of the mediastinum, from which the descending arteries are received suggests it to be a means of preventing additional heat absorption by blood due to a prolonged course within relatively deeper parts. This would be the case, if the end arteries had to cross over to the other side of the mediastinum.

The perpendicular course of the veins without any loop formation, apparently contributes towards the preservation of a low intraglandular pressure by offering less resistance to the venous blood during its exit from the gland.

The overall analysis of the pattern of testicular vascularization leads to the assumptions which could be summarized as follows: The arterial blood is primarily cooled in the conal part and then exposed for a prolonged time along the surface, thus, enabling it to give-off more heat. This 'precooled' blood, once it leaves the surface, is speedily transported to the mediastinum, where its flowrate is further reduced. The blood is then finally distributed to the peripheral branches coursing within the same side of the mediastinum from which the descending arteries have entered it.

The major role of vascular pattern appears to be the provision of arterial blood with an optimal physiological level of temperature and pressure before and after its entry to the glandular tissue. The venous blood, apparently also attains a temperature close to that of the body by absorbing heat from the arterial blood in the conal part.

The main bulk of arterial blood is distributed in the finer vessels occupying the peripheral parts of the gland from where the capillaries lead to the intertubular space. This peripheral arrangement of the arterioles combined with the superficial organization of the blood vessels clearly indicates the object of keeping the blood meant for intertubular supply at a relatively low temperature.

The apparent slow flowrate is expected to cause a reduction in pH value of blood due to prolonged absorption of CO_2 in the tubular regions. If this be correct, it could further be presumed as a measure for conserving the sperm's energy on the basis of previous work in guinea pigs, (25) where it is stated that the longevity of epididymal sperms is increased by higher levels of CO_2. So in this manner again, the vascular pattern plays an indirect role in the physiology of the gland by reducing the flow-rate of the blood.

SUMMARY AND CONCLUSIONS

The availability of limited information on the testicular vascularization in the bull in face of accumulating literature on the physiological aspect of the gland promoted an interest to embark on a detailed study. Thus, an experiment was designed and carried out in six calves and in a number of bovine testes obtained from the Beirut slaughter house.

A suitable technique for producing plastic casts of vessels was developed by modifying the techniques in other organs employed by various workers. A plastic material (vinyl acetate) of different colors was injected into the vessels and the organic tissue was washed off after its corrosion with HCl and pepsin.

The course and distribution of vessels were studied as follows:

1. By making casts from arteries alone and from veins and arteries together.

2. By washing the testes to different degrees after their injection and digestion.

3. By clearing the testes after their injection, with KOH, alcohol and glycerin .

Observations showed the testicular artery to run a long course within the vascular cone in a highly tortuous manner, and to divide along the distal part of the posterior surface into three main branches predominently occupying the distal and central parts of the surfaces. The terminal branches generally depart from the surfaces in the proximity of the superior pole or the posterior border. They coil in the mediastinum and finally divide along the periphery of the gland; thus, providing the major bulk of blood supply to the peripheral parts. The major veins course along the posterior surface and the superior pole. They divide to form anterior and posterior plexi along the surface and finally pool into the pampiniform plexus of the vascular cone.

The pattern of vascularization was compared as follows: within the testes of the same bull, testes of the various bulls and with those reported by various workers in other mammals. Within species, the pattern remains constant, although there were certain minor variations in the division of arteries. The bovine pattern differed in one way or another from those reported in other mammals.

As in other mammals, the vascular pattern in the bull forms a part of the overall physiology of the gland. The length, tortuosity, sharp divisions, size of lumen at different regions, loop-formation by the arteries and their characteristic relation with the veins, strongly suggest that the vascular pattern has a tendency to decrease both of the intraglandular temperature and pressure, and is therefore indirectly concerned with an optimal functioning of the gland.

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