HISTOLOGY OF THE MALE REPRODUCTIVE SYSTEM

Dr. Paul W. L. Kwan
Tufts University School of Medicine

Learning Objectives

1. Know the organization of the testis.
2. Be familiar with the make up of the seminiferous tubules.
3. Be able to identify the various cells types found in the seminiferous epithelium and understand their roles in spermatogenesis.
4. Events involved in meiosis and the significance of cross over.
5. Understand the steps involved in spermiogenesis.
6. The clonal nature of developing sperms.
7. The ultrastructure of a sperm.
8. The structure and functions of the cells of Leydig in the interstitial tissue.
9. The roles of various hormones in the functions of the male reproductive tissues.
10. The interactions in the hypothalamus-pituitary-gonadal axis.
11. The effects of temperature and other factors on sperm development.
12. What forms the blood testis barrier and why this is functionally important?
13. The histology of the ductuli efferentes.
14. The cells that make up the ductus epididymis and the functions of this organ.
15. The structures found in the spermatic cord and their functions.
16. The location of the ejaculatory duct and structures associated with it.
17. The contributions made by the seminal vesicles to the semen. The histology of the organ.
18. The parenchymal and stromal components of the prostate gland. The contribution of its secretions to the semen.
19. The role of the bulbourethral glands.
20. The erectile tissues forming the penis. The mechanisms involved in erection.
21. Histology of the penile urethra.
22. Composition of semen and the contributions from accessory sex glands.

INTRODUCTION

The major components are:

1. Testis
2. Excurrent ducts
3. Accessory sex glands
4. Penis

<u>All of these structures depend on the male hormones for proper function</u>.

The major functions are:

1. Production of sperms
2. Production of hormones
3. Transfer of sperms to the female via the copulatory organ

THE TESTIS

In the fetus, the indifferent gonad develops into the testis under the control of testis-determining factor (TDF), a transcription factor from the sex-determining region of the Y chromosome (SRY).

1. This is a compound tubular gland with two major functions: as an exocrine cytogenic gland, it produces and releases sperms; as an endocrine gland, it produces hormones.

2. The testes are suspended in the scrotum outside the abdominal cavity at the end of the spermatic cords. Each testis carries with it a serous sac derived from the peritoneum called the tunica vaginalis (with an outer parietal and an inner visceral layer).

3. A thick, resistant connective tissue capsule called the tunica albuginea surrounds the testis. Underneath this is a layer of loose connective tissue with blood vessels, the tunica vasculosa. The tunica albuginea may become thickened in the posterior region forming the mediastinum testis. From the mediastinum, fibrous partitions (septula testis), project toward the capsule and divided the testis into numerous pyramidal, incomplete compartments called testicular lobules.

4. The septa are rather complete in the dog and boar. In other domestic animals, they are just inconspicuous connective tissue strands.

5. The location of the mediastinum testis varies in different species. In the stallion, cat and many rodents, it is relatively small and is located in a posterior position. In the dog, pig and ruminants, it is centrally located in the testis.

6. Each testicular lobule is occupied by 1-4 U-shaped, double-ended seminiferous tubules. A typical tubule is about 150-300 μm in diameter and 30-70 cm long. The tubules are tightly packed in the testes and each tubule can be cut several times in a histological section. The total length of all the tubules in a bull, joint end-to-end, is about 5,000 meters!

7. Between the tubules is the interstitial tissue.

Seminiferous Tubules

Each seminiferous tubule is U-shaped with the two ends opening in the rete testis.
A layered sheath of connective tissue surrounds each seminiferous tubule.
There may be peritubular cells present. They resemble smooth muscle cells in some species (boar) and myofibroblast in others (bull). Rhythmic contractions of these cells help to move the tubular contents.

The epithelium is a specialized, stratified epithelium, which contains two main cell types: the Sertoli or supportive cells and the spermatogenic cells of the seminal lineage.

Sertoli Cells, Structure

1. These are large cells that rest on the basal lamina and extend upward through the full thickness of the epithelium to the free surface at the lumen.
2. The nucleus is large with a euchromatic chromatin pattern and contains a prominent nucleolus (with its associated heterochromatin masses). There are usually one or more indentations in the nucleus.
3. The apical and lateral plasma membranes have irregular "pockets" which house developing sperms. Due to this irregularity, the cell boundaries of Sertoli cells are difficult to make out in a routine histological section.
4. There are a lot of microfilaments in the cytoplasm. These may be involved in changing the shape of the Sertoli cell and in sperm release.
5. Along the lateral surfaces of the Sertoli cells are elaborate intercellular junctions.
6. Before the animal reaches reproductive age, Sertoli cells are the predominant cell type of the seminiferous tubule. During the reproductive age, Sertoli cells make up about 10% of the population in the epithelium.

Sertoli Cells, Functions

1. During development, the Sertoli cells, under the influence of TDF, produce Mullerian inhibiting substance (MIS). The latter inhibits the development of the embryonic mullerian duct derivatives (oviduct, uterus and cervix).
2. These columnar cells lie on the basal lamina and have cytoplasmic extension that wrap around the germ cell elements. The apical cytoplasm reaches the tubular lumen. The nucleus of a Sertoli is irregularly shaped, highly folded, and contains a prominent nucleolus.
3. They form a physical support for the developing sperm cells.
4. They help to nourish the developing sperm cells. There are gap junctions between Sertoli cells as well as between Sertoli and developing sperm cells. Nutrients and other metabolites can pass from the Sertoli cells to the developing sperm cells.
5. They protect the developing sperm cells. The Sertoli cells form the blood-testis barrier (details later).
6. They secrete factors that are important in sperm development:
   - 6.1. Androgen binding protein secreted by the Sertoli cells maintains a high concentration of the male hormone testosterone in the tubular lumens. This is critical for sperm development.
   - 6.2. Potasium and bicarbonate secreted by the Sertoli cells into the testicular fluid help to propel the nonmotile sperms out of the testis.
   - 6.3. Inhibin is a hormone that inhibits the secretion of FSH (follicle stimulating hormone) from the pituitary as well as gonadotropin releasing factor from the hypothalamus.
   - 6.4. Activin is a hormone that exerts a positive feedback on the secretion of FSH.
7. The Sertoli cells phagocytize defective sperms and residual bodies.

8. By changing their surface contours (with the help of microfilaments and microtubules) the Sertoli cells release sperms into the lumen.

The Spermatogenic Cells

The germ cells are derived from tissues in the yolk sac and migrate in embryonic life to the gonadal ridges. They comprise the bulk of the cells in the adult seminiferous tubule.

These form the other major category of cell types in the seminiferous tubules and include:

1. Stem cells
2. Proliferating cells
3. Differentiating cells
4. Exfoliating cells

Spermatogenesis is the process by which the stem cells are transformed into spermatozoa. This is subdivided into three phases:
Spermatocytogenesis, production
Meiosis, division
Spermiogenesis, differentiation
In the bull, ram and stallion, this process takes about 50 days. In man this requires 64 days with 6 major stages in this process.

Spermatogonia (diploid, 2N chromosomes; 2N DNA)

These are the stem cells of the seminal lineage. These are the only sex cells present in the seminiferous tubules until the beginning of sexual maturity. (The other cells present throughout are the Sertoli cells).

Spermatocytogenesis is the process during which spermatogonia develop into spermatocytes.

1. The spermatogonia are found in direct contact ("sitting") on the basal lamina.
2. A number of species-specific mitosis takes place with the stem spermatogonia (e.g. a total of six in the bull), resulting in Type A and then Type B spermatogonia.
3. The division of a stem spermatogonium produces two daughter cells: another stem cell that continues the line of reserved stem cells, and a Type A spermatogonium.
4. The Type A spermatogonia divides further to finally form Type B spermatogonia.
5. The Type A spermatogonia are usually oval shaped and sit on the basal lamina.
6. The Type B spermatogonia are more spherical and begin to move away from the basal lamina.
7. Type B spermatogonia undergo mitosis and form primary spermatocytes.

Primary Spermatocytes (2N chromosomes; 4N DNA)

1. The primary spermatocytes gradually lose contact with the basal lamina and move into the adluminal tubular compartment.
2. The nuclear DNA is replicated and all chromosomes consist of two sister chromatids.
3. The primary spermatocyte goes into the prophase of the first meiotic division (2N chromosomes; 4N DNA). This prophase is quite prolonged and primary spermatocytes are found in large numbers in sections of the seminiferous tubules. They can be identified by the thickened chromosomes in their nuclei.
4. The prophase of the first meiotic division is subdivided into the leptotene, zygotene, pachytene, diplotene, and diakineses stages.
5. During the pachytene stage, crossing-over occurs between the non-sister chromatids of the paired chromosomes. The result is the appearance of new unique chromosomes that are different from both the maternal and paternal chromosomes.
6. At the end of the prophase the nuclear membrane disappears,
7. The metaphase, anaphase, and telophase occur rapidly.
8. At the end of the first meiotic division (reductional division), secondary spermatocytes are produced.

Secondary Spermatocytes (N chromosomes; 2N DNA)

1. The secondary spermatocyte has only half the number of chromosomes but have two chromatids each.
2. These are short-lived, intermediate in size between primary spermatocytes and spermatids. They may not be easily identified in a histological section.
3. The secondary spermatocytes enter the second meiotic division (equational division) resulting in spermatids.

The two meiotic divisions accomplish:

1. A reduction of chromosome number from 2N (diploid) to N (haploid).
2. Random assortment of maternal and paternal chromosomes.
3. Increased genetic variations through the processes of crossover.

Spermatids (haploid, N chromosomes; N DNA)

1. These daughter cells of the secondary spermatocytes do NOT divide.
2. Each spermatid contains a haploid set of chromosomes.
3. They are small in size, have nuclei with areas of condensed chromatin and are located near the center of the seminiferous tubule epithelium.
4. These cells then undergo spermiogenesis.

Spermiogenesis

This is the process by which spermatids undergo a series of changes and differentiate into individual spermatozoa. This is a process of cytodifferentiation in which the cells are extensively modified but no cell division is involved.

There are four phases: Golgi phase, cap phase, acrosomal phase, and maturation phase.

The Golgi Phase

1. Small granules (pro-acrosomal granules), containing hydrolytic enzymes, arise from the Golgi apparatus. They fuse together and form a single, large granule called the acrosomal vesicle.
2. The vesicle makes contact with an indentation of the nucleus and this marks the anterior pole of the future sperm head.

The Cap Phase

1. The acrosomal vesicle grows and forms the head cap that covers the anterior two third of the nucleus.
2. The two centrioles assemble at the caudal pole of the nucleus, and the distal centriole gives rise to an outgrowing flagellum.

The Acrosomal Phase

1. The nucleus and cell body starts to elongate. The spermatid rotates so that the nucleus is pointing toward the basal lamina and the developing tail toward the lumen.
2. The nuclear material condenses into a dark staining, dense package of chromatin.
3. The acrosomal cap covers most of the nucleus.
4. The acrosome is a PAS-positive structure containing hydrolytic enzymes (proteases, hyaluronidase, neuraminidase, acid phosphatase etc.). These enzymes are involved in separating the cells of the corona radiata of the ovum and the digestion of the zona pellucida around the female gamete before fertilization can take place.

The Maturation Phase

1. Nuclear condensation is complete.
2. Most of the mitochondria gather around the axoneme of the flagellum in a helicoidal fashion. This is the future middle piece of the spermatozoon. The arrangement of the mitochondria around the flagellum is an example of the concentration of these organelles at sites of high energy consumption.
3. A system of fibers and a fibrous sheath develop around the flagellum.
4. The volume of the spermatid is greatly reduced. Excess cytoplasm is detached as residual body. Residual bodies are partly phagocytosed by the Sertoli cells, partly lost into the tubular lumen and partly subjected to rapid autolysis.
5. The spermatid is released into the tubular lumen by the supporting Sertoli cell. Microfilaments and microtubules in the cytoplasm of the Sertoli cell are involved in this process.
6. Myoid cells, surrounding the seminiferous tubules, have contractile ability. They are important in the movement of the non-motile spermatozoa toward the rete testis.

Clonal Nature of the Developing Sperm Cells

In the division of all male germ cells, from spermatogonia B to late stage spermatids, cytokinesis (division of the cytoplasm) is incomplete and tiny cytoplasmic bridges attach the germ cells to each other. They constitute a syncytium-like cell clone with synchronized differentiation.

Spermiation: Spermatids are released as spermatozoa into the lumens of the seminiferous tubules. This involves the breaking of the cytoplasmic bridges. Excess cytoplasm is cast off as residual bodies although a little cytoplasmic droplet may remain around the middle piece. A failure of the breaking of the cytoplasmic bridges is reflected in the tubular lumen and the seminal fluid by the presence of multinucleated spermatids or multi-headed spermatozoa.

Since a large number of healthy, mature sperms in the ejaculate are needed for fertility; it is advantageous to the animal to synchronize sperm production and release.

Structure of the Spermatozoon

Spermatozoa vary in length between 60 μm (boar, stallion) to 75 μm (ruminants).
In the light microscope the spermatozoon appears to have only two parts: the head and the tail.
In the electron microscope, the tail can be subdivided further into the neck, the middle piece, the principal piece, and the end piece.

Head. The shape of the head is species-dependent and subject to great variations. The acrosomal cap covers the anterior portion of the nucleus. The base of the nucleus is surrounded by the postacrosomal sheath, which consists of fibrous proteins rich in sulfur. The plasma membrane of the postacrosomal head region contains receptors for the recognition of a homologous oocyte. The nucleus is greatly condensed with the somatic histones replaced by protamines. The latter helps to stabilize the tightly packed DNA.

Neck, also called the connecting piece. This is a short and narrow structure between the head and the middle piece. It consists of two centrioles with the centrally located centriole giving rise to the axoneme. There are also nine peripheral, longitudinally oriented coarse fibers that are continuous with the outer fibers of the middle piece.

Middle Piece. The core of the middle piece is the characteristic structure of a flagellum: axoneme of 9 (doublets) + 2 microtubules. These are surrounded by 9 longitudinally oriented, tapered outer fibers that are connected to the fibers of the connecting piece. These are in turn surrounded by the mitochondria in a helicoidal arrangement.

Principal Piece. This is the longest portion of the spermatozoon. The central axoneme is surrounded by outer dense fibers. Two of the outer fibers fuse to form a characteristic peripheral fibrous sheath.

End Piece. The termination of the fibrous sheath marks the beginning of the end piece, which contains only the axial filament complex.

Cyclic Events in the Seminiferous Tubules

Inside a seminiferous tubule there may be several series of spermatogenesis going on at the same time but at different levels of development. Since all the descendants of each stem cell develop synchronously, successive cell generations follow each other with cyclic regularity. When you look at a section of a seminiferous tubule you will notice one predominate cell type. (Think of this as a particular flavor in a roll of candy.) When you move along the tubule you will find another predominate cell types until the cycle starts again. (When the same flavor shows up again.) A complete sequence of cellular changes that occurs between two consecutive identical stages in a spermatogenic segment is called a spermatogenic cycle. In the testes of the bull, ram and boar, eight stages can be identified in the seminiferous tubules.

The Interstitial Tissue

1. Between the seminiferous tubules the interstitial spaces contain loose connective tissue, blood and lymph vessels, free mononuclear cells, and interstitial endocrine (Leydig) cells.
2. The cells of Leydig produce testicular androgen and, in the boar, large amounts of estrogens as well.
3. These cells are under the influence of luteinizing hormone from the pituitary.
4. Interstitial cells constitute about 1% of the entire testicular volume in the adult ram, about 5% in the bull, 20-30% in the boar.
5. The cells of Leydig have ultrastructure of steroid synthesizing/metabolizing cells with a lot of smooth endoplasmic reticulum and mitochondria with tubular cristae. Lipid droplets are found in the cytoplasm of Leydig cells in all species, but are particularly abundant in the cat.
6. In a routine histological section stained with H&E, the Leydig cells have eosinophilic cytoplasm with small, clear lipid droplets.
7. The lymphatics in the interstitial tissue are rather extensive and there is a close functional and structural relationship between the lymphatics, the Leydig cells and the seminiferous tubules.
8. Thus high concentrations of testosterone are delivered to the tubules and the testosterone that diffused into the blood reaches the rest of the body.

Histophysiology

1. The Leydig cells secret androgen, which is essential for the functions of the seminiferous tubules.
2. The seminiferous epithelium depends on the continual presence of high concentrations of androgens to enable the germ cells to develop properly. Androgen binding protein secreted by the Sertoli cells maintains this gradient in the microenvironment in the seminiferous tubules.

3. Androgens stimulate the differentiation and proliferation of peritubular myoid cells. These cells in turn secrete a protein, PmodS that stimulates Sertoli cell function.
4. Androgen is needed for the maintenance of normal size and secretory activity of the seminal vesicles, the prostate and the bulbourethral glands.
5. Androgen is also needed for the development and maintenance of secondary sexual characteristics.
6. Testosterone is the main male hormone, important in spermatogenesis and the functions of the epididymis. It is converted to dihydrotestosterone (DHT) by the enzyme 5 α-reductase. DHT is a potent androgen and is important in the functions of the prostate, penis, etc.
7. Prolactin is also important in the male reproductive system. By itself, prolactin has little effect. It regulates the gene expression of the LH receptor and thus potentiates the effects of LH on the Leydig cells. Prolactin is also produced locally in some of the male reproductive tissues (e.g. prostate) and may play a paracrine role in cell proliferation and differentiation.

Hypothalamus-Pituitary-Gonadal Axis

1. The hypothalamus and the pituitary both serve to control and to integrate the 2 major testicular functions: steroid hormone production and spermatogenesis.
2. Hypothalamic gonadotropin-releasing hormone (GnRH) mediates the pituitary release of the gonadotrophins LH (luteinizing hormone) and FSH (follicle stimulating hormone).
3. LH binds to receptors on Leydig cells. This leads to the production of secretion of testosterone and some estradiol.
4. These sex steroids act on the brain and the anterior pituitary where they exert control of gonadotrophin release via negative feedback mechanisms.
5. FSH binds to receptors in the Sertoli cells, leading to the production of factors including androgen binding protein. ABP concentrates and maintain a high level of androgens in the seminiferous tubule and epididymis microenvironments, a condition essential for the production and maturation of sperms.
6. The Sertoli cells also secrete a nonsteroidal testicular factor called inhibin, which suppress FSH release from the pituitary.
7. Activin, also from the Sertoli cells, stimulates FSH release.
8. Light has a profound effect on this axis and affects breeding behavior.

Effects of Temperature and Other Factors on the Testis

1. The cells of the seminal lineage are susceptible to toxic chemicals, heavy metals, ionizing radiation and especially, high temperature. For sperm to develop properly, they need to be in the scrotal sacs, which are 1.5 to 2.5, °C lower in temperature than that of the abdominal cavity. The scrotal sac and the spermatic cord play an important role in the thermal regulation of the testis.
2. In the case of cryptorchism (undescended testis), sperms will not develop normally in the testis subjected to higher temperature.

3. Descent of the testicles: Ruminants and pig --- before birth. Carnivores --- shortly after birth. Horse --- 10-14 days before or after birth.
4. In some animals the testes may be in the abdominal cavity during non-breeding season. These must descend into the scrotum during breeding season.
5. Cells involved with mitosis and meiosis are also susceptible to drugs that are anti-mitotic, e.g. some of those used in cancer chemotherapy. The effect is usually transient because the dormant stem cells are not affected.
6. The Sertoli cells and the Leydig cells are less sensitive to noxious factors.

THE BLOOD TESTIS BARRIER

1. During sperm development new genetic combinations appeared a result of crossing over. Since sexual maturity occurs long after the development of immunocompetence, the differentiating sperm cells can be recognized as 'foreign' and provoke an immune response that will destroy the sperms.
2. This does <u>not</u> happen because a blood-testis barrier protects the developing sperms.
3. Very elaborate occluding or <u>tight junctions</u> make up the blood-testis barrier between Sertoli cells. The junctions divide the seminiferous epithelium into a <u>basal compartment</u> and an <u>adluminal compartment</u>.
4. Large molecules such as immunoglobulins cannot penetrate the tight junctions and thus are unable to reach the developing sperms.
5. Note that the spermatogonia are located <u>outside</u> the barrier (they are genetically identical to the somatic cells) and can respond to various factors. The spermatocytes are <u>inside</u> the barrier and they may express novel proteins on their surfaces.

THE EXCURRENT DUCTS: Intratesticular and Extratesticular

INTRATESTICULAR DUCTS

<u>Tubuli recti, rete testis, ductuli efferentes</u> are the three excurrent ducts that are situated in the testis.

<u>Tubuli Recti and Rete Testis</u>

1. The last segment of the seminiferous tubule opens into a short, straight duct that is lined with simple cuboidal cells, this is the <u>tubuli recti.</u>
2. The tubuli recti connect to a vast network of tubules, the <u>rete testis</u>, which occupies most of the space within the mediastinum testis. These channels are lined with a simple cuboidal epithelium with some of the cells each having a single flagellum.
3. The epithelial cells secrete fluid, which helps the nonmotile sperms to move along. As much as 40ml of fluid are secreted per day by the rete testis in the ram.
4. Connecting and draining the rete testis channels are 10-15 convoluted ducts called the <u>ductuli efferentes</u>.

<u>Ductuli Efferentes</u>

1. The epithelium of the ductuli efferentes is pseudostratified columnar. Externally the tubule has a fairly smooth contour. Internally the lumen is scalloped or stellate in outline due to alternating patches of cuboidal and columnar cells.
2. Some of the cells are ciliated and are involved in moving sperms forward. Other cells do not have cilia and are involved with fluid absorption. Both cell types contain brown pigment granules, which may be some kind of secretory products.
3. Much of the testicular fluid is absorbed here and new fluid secreted into the lumen.
4. The epithelium rests upon a distinct basal lamina and there is a layer of smooth muscle cells around the tubule.

EXTRATESTICULAR DUCTS

DUCTUS EPIDIDYMIS

Structures

1. The ductuli efferentes empty their contents into the ductus epididymis, which is a single tube. This is highly coiled and tortuous so that you will see multiple cross sectional profiles of the same tube in a histological section. The total length of the ductus is about 40 m in the bull and boar, up to 70 m in the stallion.
2. The duct can be divided into three regions: the caput or head, the corpus or body and the cauda or the tail.
3. The epithelium is pseudostratified columnar. There are tall principal cells with stereocilia, which are long, branched, nonmotile microvilli. These cells have well developed Golgi apparatus. Small basal reserve cells sit on the basal lamina.
4. There are layers of smooth muscles outside the epithelium. In the head region, the layer is circumferential. In the body there are two layers, inner circular and outer longitudinal. In the tail there are three layers, circular, oblique and longitudinal. The muscle layers exhibit peristaltic movements and propel and sperms along the ductus epididymis.

Functions

1. The epididymis is where sperms are stored and mature (mainly in the caudal segment).
2. Fluid absorption and modification take place in the lumen.
3. The epithelium secretes sialic acid, glycerophosphoryl choline and other factors including forward motility protein.
4. The epithelial cells phagocytize residual bodies.
5. Sperms are transported through the ductus via rhythmic contraction of the smooth muscles. As the sperms travel through the length of the ductus, they undergo maturation and change from nonmotile, infertile to motile and fertile gametes. The time for transit takes about 10 to 15 days regardless of the length of the epididymis.
6. The proper functioning of the epididymis depends on androgens.

7. In bulls, boars, cats and other domestic species, the final stage of maturation in which the spermatozoa becomes a fully fertile gamete takes place in the female reproductive tract during a process called capacitation.

DUCTUS DEFERENS

1. The end of the epididymis enlarges into the ductus deferens, also known as the vas deferens.
2. It transverse the inguinal canal and courses behind the peritoneum toward the urethra. In the inguinal canal and the scrotum the ductus deferens courses with the spermatic cord (ductus deferens, testicular artery, pampiniform plexus of veins, lymphatic vessels and nerves).
3. Fascia and the striated cremaster muscle enclose the spermatic cord.
4. The epithelium of the ductus deferens is pseudostratified columnar with variable distribution of stereocilia.
5. The columnar cells secrete a fluid rich in carbohydrates and amino acids.
6. The muscular layers outside the epithelium are thick and are arranged into three layers: thin inner longitudinal, robust middle circular, and thick outer longitudinal. Strong contractions of the muscular layers expel the sperms in ejaculation.
7. The ductus deferens ends in a short, dilated segment (in the stallion, ruminants, dog) or as a straight tube (boar, cat) near the prostate. This segment is known as the ampulla. The lumen becomes larger and there is a vastly increased infolding of the mucosa into many long, complicated and anastomosing ridges.
8. The proper functioning of the ductus deferens depends on testosterone.

THE EJACULATORY DUCTS

1. After the ampulla, the excurrent duct becomes the short, straight ejaculatory duct, which pieces the body of the prostate at the base of the urinary bladder.
2. The opening is like a small slit into the prostatic part of the urethra, on a small thickening of its dorsal wall, the colliculus seminalis (also known as the verumontanum).
3. The slit-like openings of the ejaculatory ducts are located to the right and left of a blind invagination on the summit of the colliculus, the utriculus masculinus (utriculus prostaticus) that is the vestigial homlog of the uterus.
4. The ejaculatory duct is lined by simple or pseudostratified columnar epithelium. Near the urethra, the epithelium becomes transitional.
5. The wall of the ejaculatory ducts is formed by fibrous tissue only. There are no muscle layers.
6. In the stallion and ruminants, the ductus deferens unites with the excretory duct of the seminal vesicle to form a short ejaculatory duct. In the boar, the ductus deferens and the excretory duct open separately into the urethra. In carnivores, the ductus deferens joins the urethra alone because the seminal vesicle is absent.

THE ACCESSORY SEX GLANDS: Seminal vesicles, prostate, and bulbourethral glands.

The functions of these structures are regulated by androgens (testosterone and DHT)

THE SEMINAL VESICLES, The Vesicular Gland

1. Stallions: true vesicles, with wide central lumen into which open short, branched tubuloalveolar glands,
2. Boar: the two vesicular glands possess a common connective tissue capsule. The lumens are wide and the secretory epithelium is folded.
3. In the bull, the vesicular gland is a compact, lobular organ.
4. Carnivores do not have vesicular glands.
5. The epithelium is pseudostratified with columnar secretory cells and basal reserve cells. The cytoplasm f the columnar cells contain a large amount of lipid droplets.
6. The gland has three layers of smooth muscles but they are not organized into distinct layers.
7. Secretion from the seminal vesicles is yellowish and viscous. This amounts to 25-30% of seminal fluid volume in the bull, 10 to 30% in the boar and 7 to 8% in the ram and buck.
8. The secretion is rich in fructose (30% by weight, nourishment for the sperms), fibrinogen, ascorbic acid and prostaglandins.
9. Secretions from the seminal vesicles help to coagulate the semen.
10. Structure and functions depend on androgens.
11. This is not where sperms are stored.

THE PROSTATE

Structure

1. This is the largest of the accessory sex glands. It is present in all domestic animals.
2. It is composed of 30-50 tubulo-alveolar glands with 16-32 excretory ducts opening into the urethra to the left and right of the colliculus seminalis.
3. The glands are embedded in a fibromuscular stroma and enclosed in a fibroelastic capsule.
4. The stromal cells contain 5 α-reductase. They are the main source of DHT for the adjacent epithelial cells.
5. The epithelium is pseudostratified columnar with secretory and basal cells.
6. Most of the columnar cells secrete a proteinaceous material. Some mucus secreting cells may also be present.
7. Corpora amylacea (prostatic concretions) are laminated bodies in the acini. These structures may be calcified.
8. The prostate is homologous to the periurethral Skene's glands of the female.

Functions

1. Secretions make up 4-6% of the volume of the ejaculate in the ruminants; in the stallion it is 25-30%, and 35-60% in the boar.
2. Prostatic secretions contain bicarbonate, proteolytic enzymes, citric acid, zinc, lipids, and a variety of proteins.
3. Clotting enzymes, acting on the semen, forms the coagulum.
4. Profibrinolysin, liquefies the coagulum.
5. Prostatic acid phosphatase (PAP) is a tissue specific marker.
6. Prostate specific antigen (PSA) is a proteolytic enzyme that liquefies coagulated semen. Measurements of this antigen reflect on the functions of the prostate, especially in pathological conditions.
7. Prostatic fluid helps to neutralize acid vaginal secretions.
8. The structure and functions of the prostate are dependent on dihydrotestosterone (DHT).

The Bulbourethral Glands of Cowper

1. These are small glands with ducts that enter the membranous urethra.
2. They are compound tubular glands in the boar, cat, and buck. They are tubulo-alveolar in the stallion, bull and ram.
3. Dogs do not have bulbourethral glands.
4. The epithelium contains light staining secretory cells.
5. Secretion from the glands is clear, viscous, mucus-like and is rich in sialoproteins.
6. The secretion may serve as lubricant for the urethra. In pig, the secretion of this gland contributes to the formation of a post-ejaculatory cervical seal.
7. Analogous to the greater vestibular glands of Bartholin in the female.
8. Structure and functions depend on androgens.

PENIS, THE COPULATORY ORGAN

Structure

Basic architecture

1. Three cylinders of erectile tissues and the penile urethra.
2. The cylinders of erectile tissues are enclosed by connective tissue and then by skin.
3. The single corpus spongiosum encloses the urethra and enlarges terminally into the glans penis.
4. The paired, parallel and dorsal cylinders of erectile tissues are the corpora cavernosa, extending only as far as the glans.

Corpora Cavernosa

1. Two cylinders of erectile tissue. The caudal ends are called crura penis. The rostral ends stop at the glans penis.

2. Each cylinder is enclosed by thick, dense, fibroelastic connective tissue, the tunica albuginea. The partition between the two cylinders is incomplete, allowing vascular spaces to communicate.
3. Erectile tissue is made up of a vast honey comb-like system or irregular cavernous blood spaces. The walls of the spaces, trabeculae, are made up of smooth muscles, nerves and dense connective tissue. Endothelial cells line the surfaces of the walls.
4. Deep artery runs through the center of each cylinder.
5. The major veins are at the periphery, beneath the tunica albuginea.
6. This erectile tissue is similar to the crura of the clitoris in the female.

Corpus Spongiosum

1. Single cylinder of erectile tissue, which is blunt at both ends: rostral – glans penis, caudal – bulbus penis.
2. A thin tunica albuginea surrounds the cylinder.
3. The trabeculae have more elastic tissue and less smooth muscle.
4. In the center of the cylinder is the urethra.

Mechanism of Erection

1. There are two types of blood arteries in the penis.
2. Nutritive vessels supply the tissues with oxygen and nutrient.

Helicine arteries (afferent), involved in erection, empty directly into the cavernous blood spaces.

3. Erection takes place when the cavernous blood spaces are filled with blood.
4. In the flaccid penis, the tonicity of smooth muscles in the walls of the helicine arteries and the trabeculae keeps the blood out of the cavernous spaces.
5. With sexual stimulations, the trabeculae relax, blood rushes in, and fill up the cavernous spaces. The cylinders become rigid.
6. The outflow of blood from the cavernous spaces via venous drainage (efferent) is retarded by the resistant tunica albuginea.
7. Erection is maintained when there is a greater rate of blood inflow than of outflow.
8. After ejaculation or removal of stimulus, the smooth muscles in the trabeculae tense up. The outflow of blood exceeds the inflow and the penis becomes flaccid.
9. The corpus spongiosum does not reach the same degree of rigidity as in the corpora cavernosa.
10. Return of the penis to the flaccid state is called detumescence.
11. Two chemicals control erection: nitric oxide and phosphodiesterase.
    Nitric oxide (produced by nerves in the penis) causes the relaxation of the smooth muscle cells (thus erection) in a process that involves the production of cyclic guanosine monophosphate (cGMP).
    Phosphodiesterase degrades cGMP and terminates erection.

Pericavernous Tissues of the Penis

1. There are considerable differences in these tissues among species.

2. Vascular-Type Penis, as found in stallions, contain bundles of smooth muscle interspersed with a small amount of connective tissue which run parallel to the longitudinal axis of the organ.
3. Fibrous-Type Penis, as found in ruminants and boars, has a predominance of connective tissue, and little or no smooth muscle is present.
4. Intermediate-Type Penis, as found in carnivores, has more connective tissue and less smooth muscle bundles as compared to a vascular-type penis.
5. An os penis (in dogs) or an os glandis (in cats) is continuous with the cranial corpus cavernosum.

THE URETHRA

The urethra extends from the bladder through the penis. It can be subdivided into different sections, depending on the structure it is coursing through.

Prostatic urethra

1. Passes through the prostate.
2. It is in this portion that you find the colliculus seminalis and the utriculus masculinus.
3. The ejaculatory ducts and prostatic ducts open into the prostatic urethra.
4. The epithelium is mainly transitional but becomes pseudostratified or stratified columnar at the distal portion.

There are two layers of smooth muscles around the prostatic urethra, inner longitudinal and outer circumferential. The outer layer is highly developed at the internal urethral orifice, where it becomes part of the internal sphincter of the bladder.

Membranous urethra

1. Very short structure line by stratified columnar epithelium.
2. Smooth muscle layer thinner.
3. It is in the membranous urethra that striated muscle fibers of the urogenital diaphragm surround the urethra. These fibers comprise the sphincter muscle of the urethra, forming the external sphincter of the bladder.

Cavernous urethra spongiose or penile urethra

1. The longest portion of the urethra expands at the bulb of the corpus spongiosum (bulb of the urethra) and expands again in the glans penis (terminal fossa).
2. Epithelium is stratified columnar. At the distal portion, from the fossa outward, it becomes stratified squamous nonkeratinized and in turn becomes continuous with the stratified squamous keratinized epithelium that covers the glans penis.
3. Located in the penile periurethral tissue are many small glands that contain mucus secretory cells. These are the glands of Littre and the secretion helps to lubricate the urethra.

4. In the ruminants and the stallion, the terminal portion of the urethra protrudes incompletely (bull) or completely (stallion, ram and buck) above the glans penis to form the urethra process (processus urethrae).

THE PREPUCE

1. This is a retractable fold of skin covering made of connective tissue and smooth muscles.
2. The external layer reflects inward to form the internal layer.
3. The epithelium resembles that of a mucous membrane.
4. Sebaceous glands are present at the preputial opening.
5. Long bristle-like hairs are found in the external layer of the prepuce in ruminants and the boar. In the stallion, ruminants, boar and the dog, fine hairs, sebaceous and sweat glands are located over a variable distance in the internal layer.
6. The skin changes to a cutaneous mucosa toward the preputial fornix.
7. A diverticulum is present in the dorsal prepuce of boars, lined by stratified squamous epithelium.

THE SEMEN

1. This is a complex fluid derived from the testis and the accessory glands.
2. The prostate contributes a thin, milky emulsion.
3. The testis and the excurrent ducts contribute a fluid with a high concentration of sperms.
4. The seminal vesicles (when present) contribute a fluid that is high in fructose and prostaglandins.
5. In the boar, the bulbourethral glands may contribute as much as 15 to 30% of the volume of the ejaculate.