Reproductive Physiology in Domestic Animals

Part one

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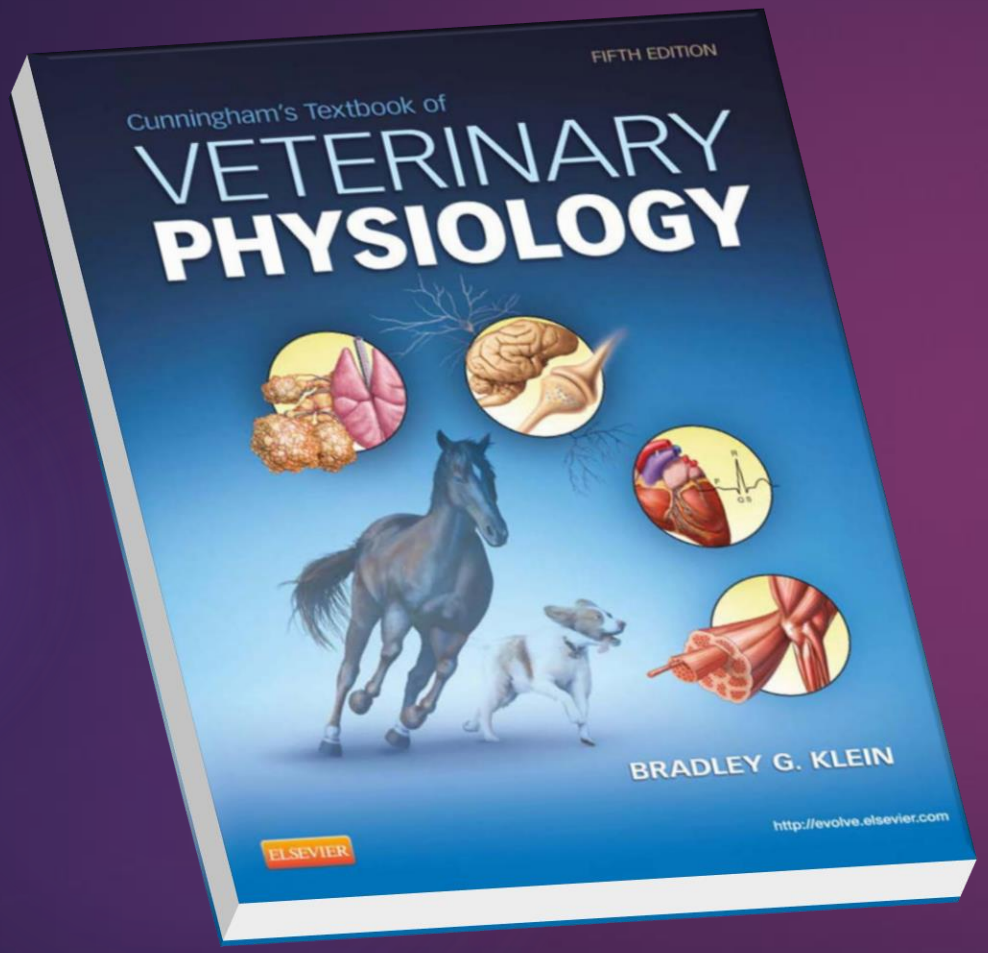
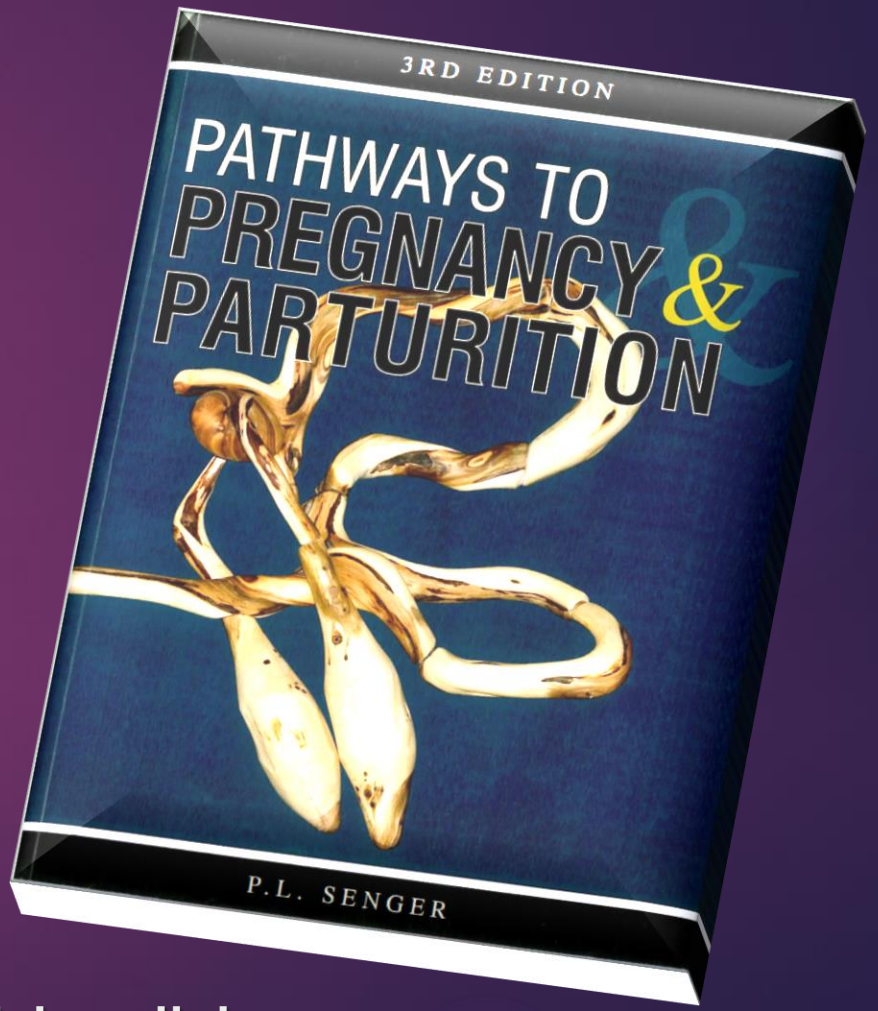
References





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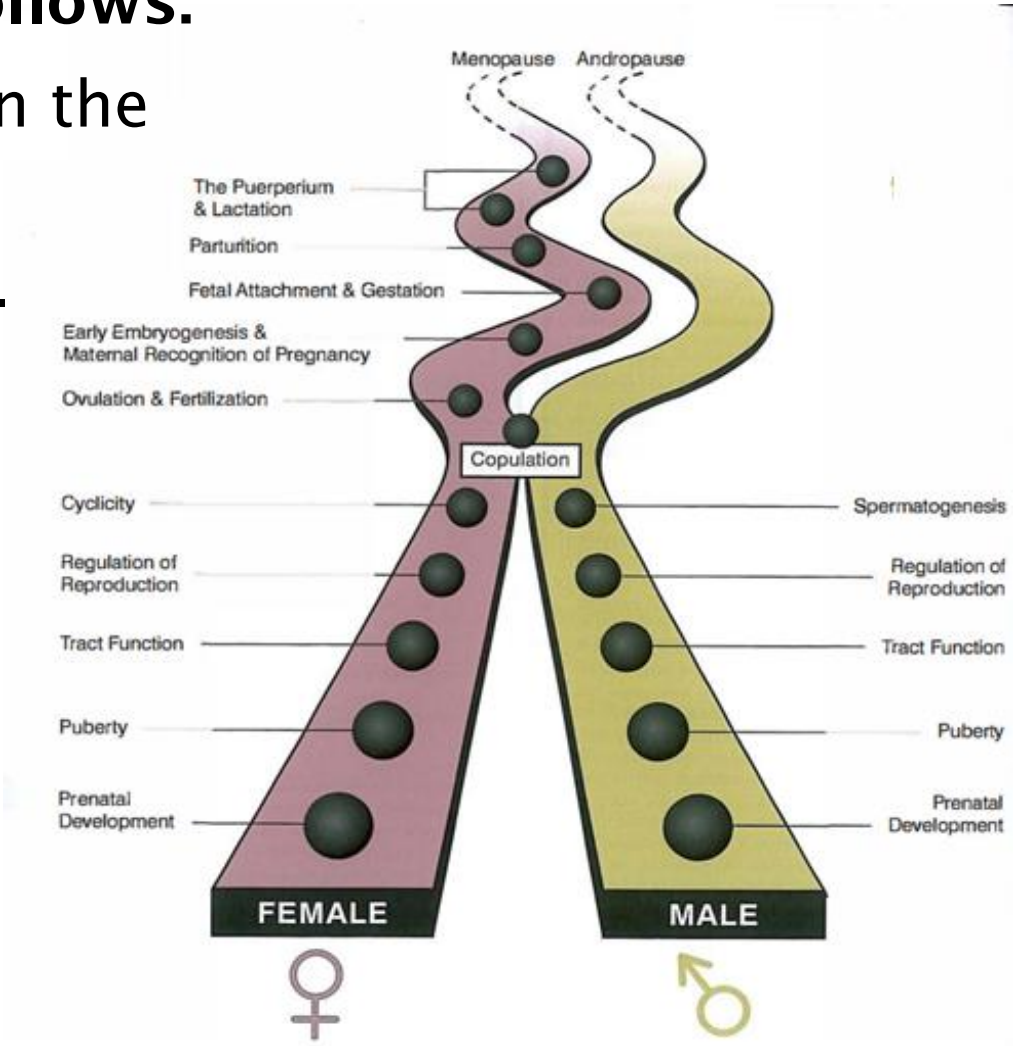
Introduction

Introduction

Reproduction is a sequence of events as follows:

- **Development** of the reproductive system in the embryo
- **Puberty**: ability to produce fertile gametes.
- **Cyclyicity**
- Reproductive **behavior** and **copulation**.
- **Fertilization**
- **Placenta** formation.
- **Parturition**.
- **Lactation**
- Reestablishing **cyclyicity**



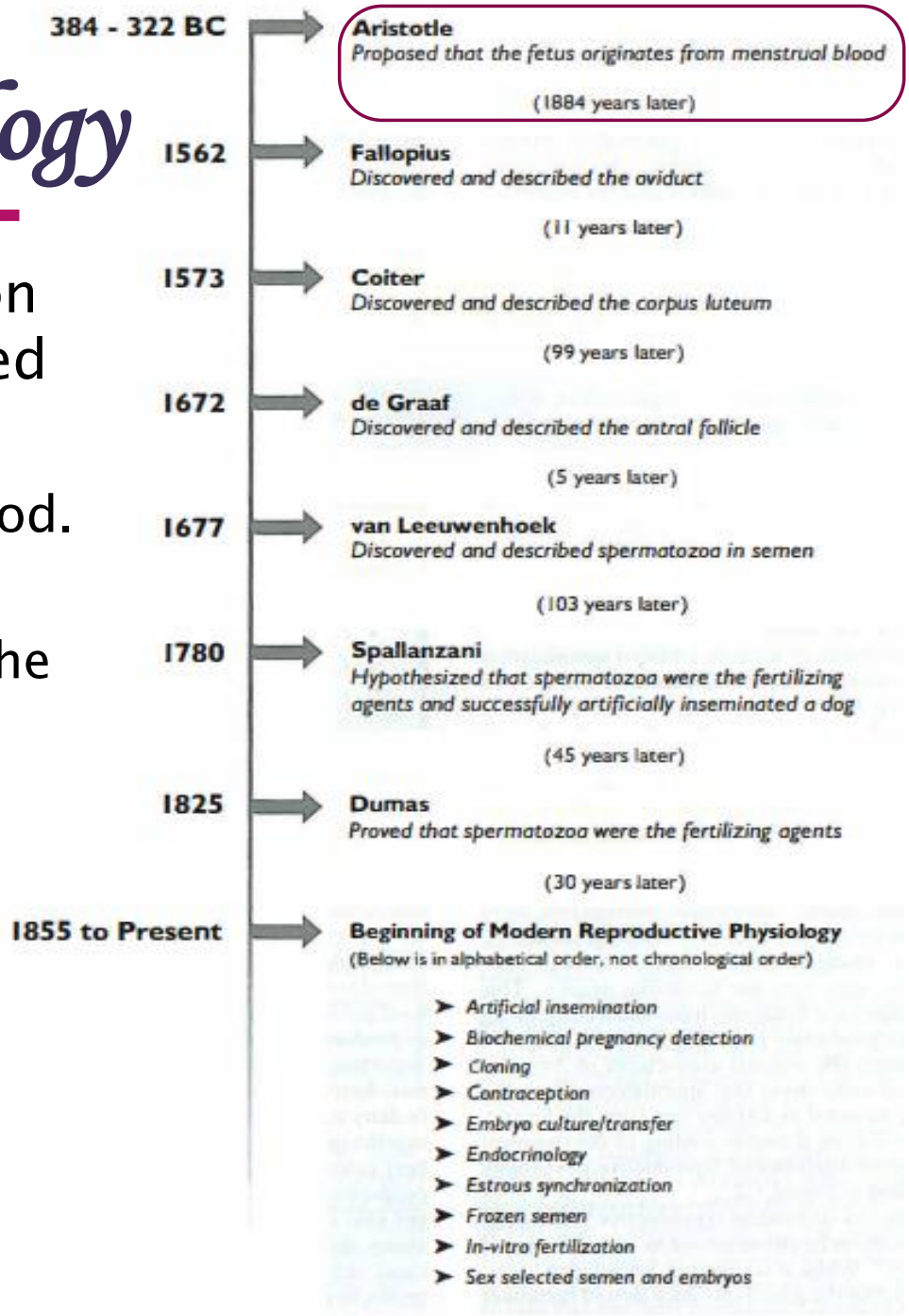
Introduction

Reproductive Science Consists of Several Subspecialties:

- **Andrology**
  - deals specifically with the study and treatment of male animals including humans.
- **Gynecology**
  - deals specifically with reproductive issues in women.
- **Theriogenology**
  - focuses on the reproductive system in animals.
- **Obstetrics**
  - a branch of reproductive physiology, veterinary medicine and/ or human medicine that specializes in the female before, during and after parturition.

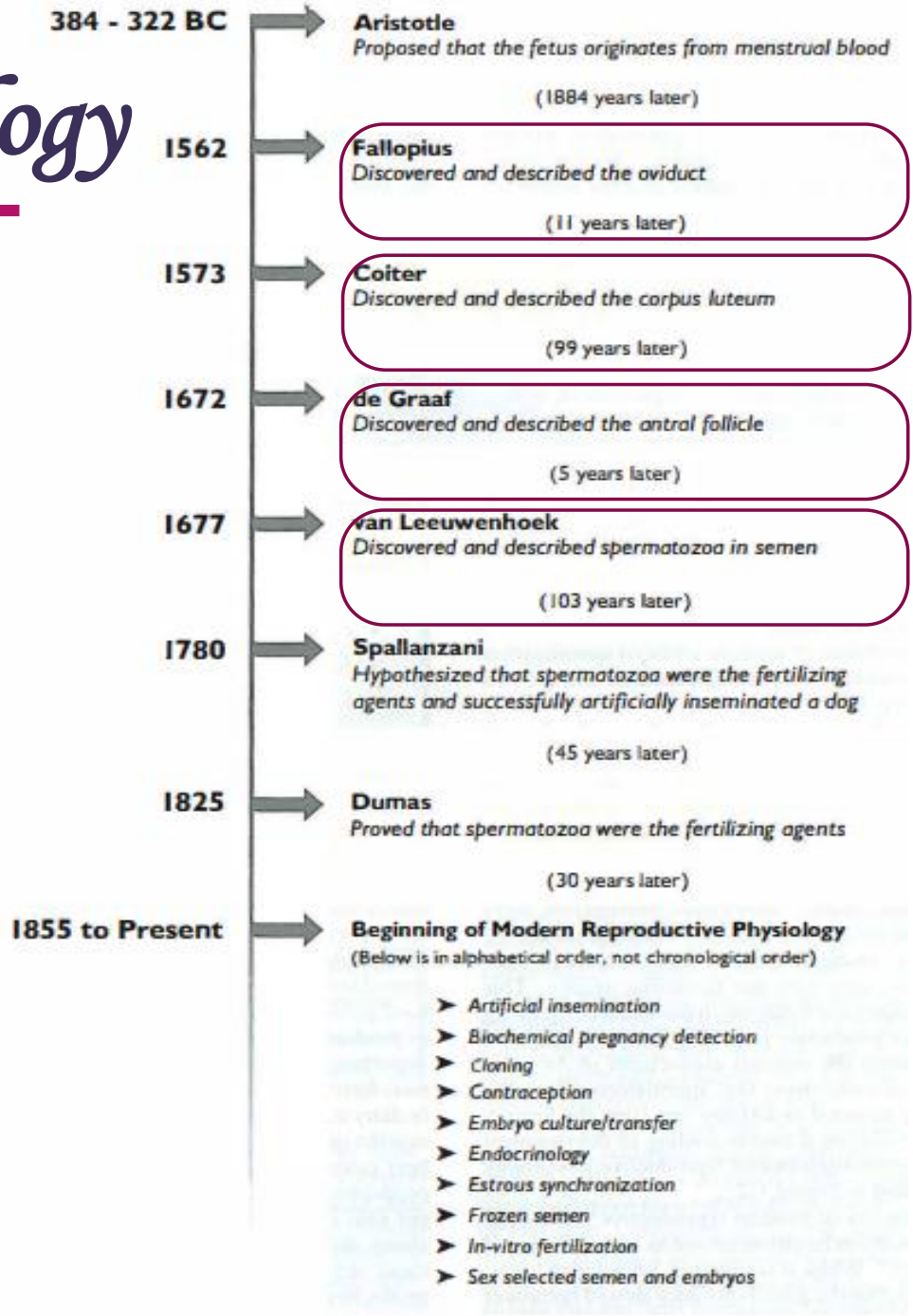
The History of Reproductive Physiology

- Aristotle provided the first recorded information on how he thought the reproductive system functioned in his book entitled "Generation of Animals".
  - He believed that the fetus arose from menstrual blood.
  - he concluded, based on the observation that menstruation did not occur during pregnancy that the fetus was derived from menstrual blood.
  - He also proposed that the conversion of menstrual blood to a fetus was initiated by seminal fluid deposited in the female during copulation.
  - Aristotle thought that semen was derived from all parts of the body and that the testes were simply pendular weights that kept the transport ducts (the ductus deferens) from becoming kinked or plugged with seminal fluid.



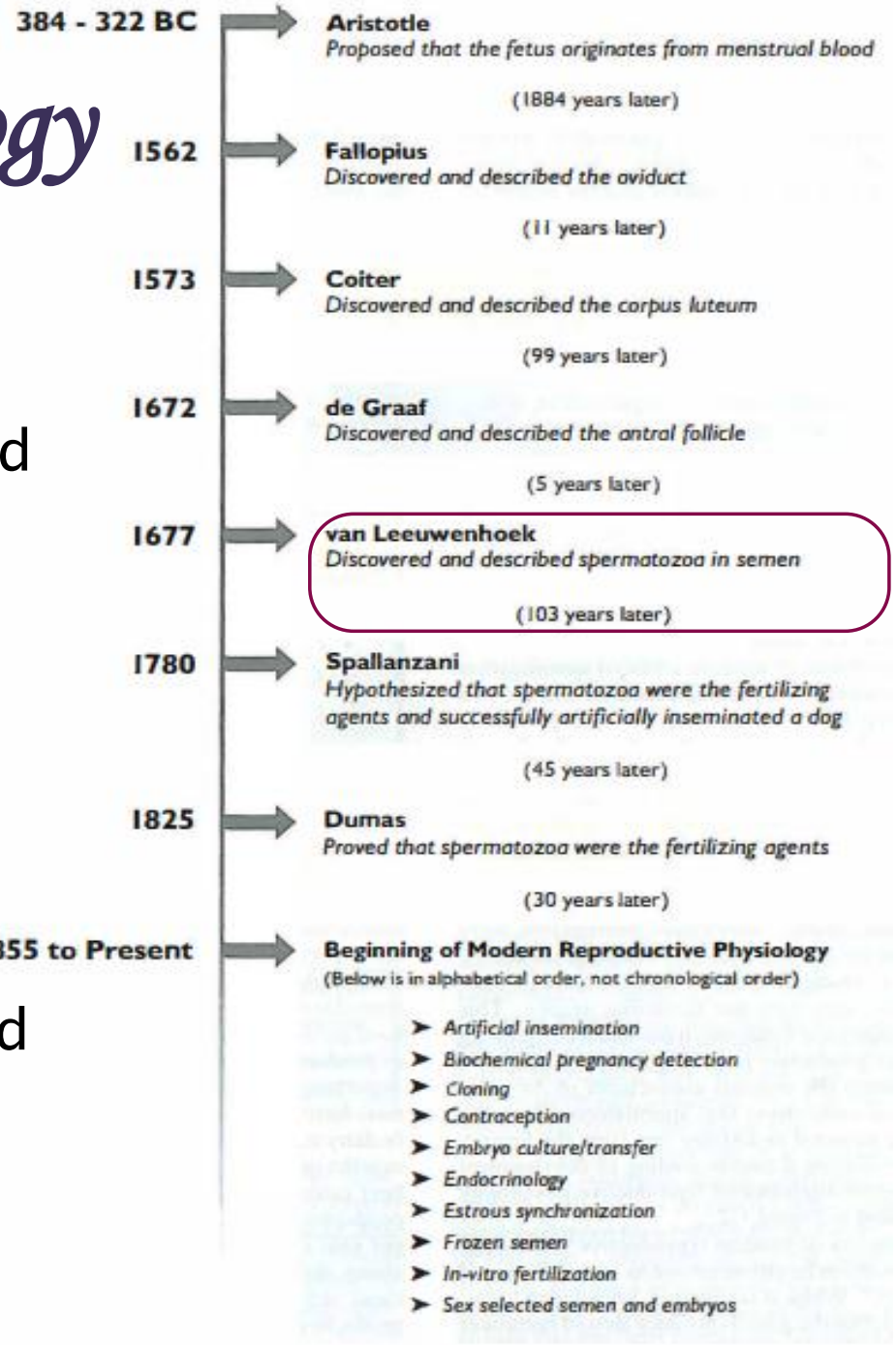
The History of Reproductive Physiology

- About 2,000 years later Fallopius described the oviducts.
  - The name Fallopian tube reflects his discovery
- A student of Fallopius, Coiter, discovered the corpus luteum in 1573
- Almost 100 years later a scientist named Regnier de Graaf described the antral follicle that has been named the Graafian follicle in honor of his discovery.
- van Leeuwenhoek developed a simple microscope in 1677 which was a major technological breakthrough.



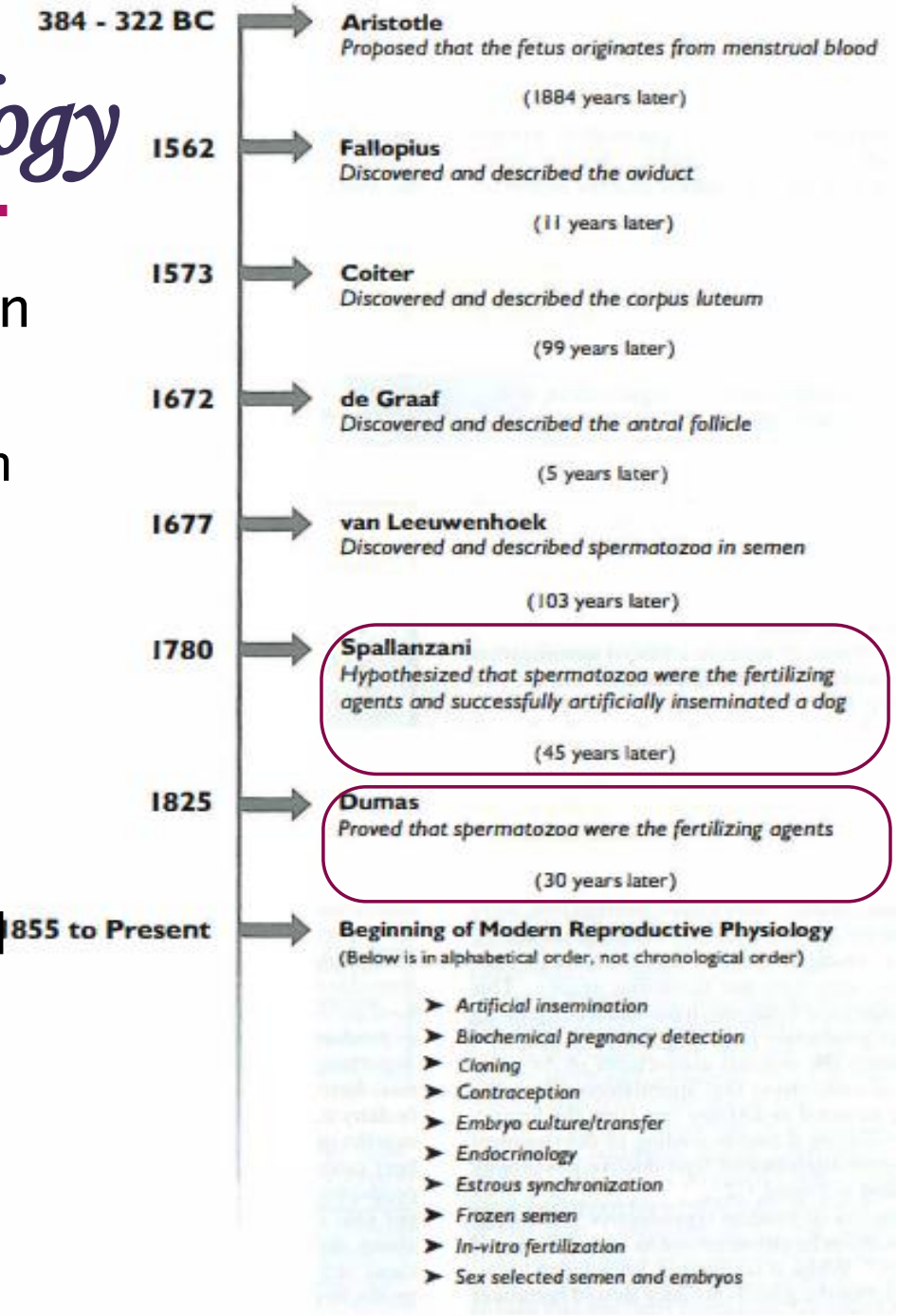
The History of Reproductive Physiology

- A medical student suggested to van Leeuwenhoek that semen might contain living cells. Using his microscope, van Leeuwenhoek observed semen and discovered that it contained small particles that moved about. He referred to these particles as "animalcules".
  - van Leeuwenhoek found that similar "animalcules" were present in semen from males of many species and published a paper on his observations in 1677.
- The most widely accepted speculation of the day was that the "animalcules" (spermatozoa) contained fully fanned individuals within their cellular confines. In other words, the sperm head was thought to contain a microscopic, yet fully formed individual



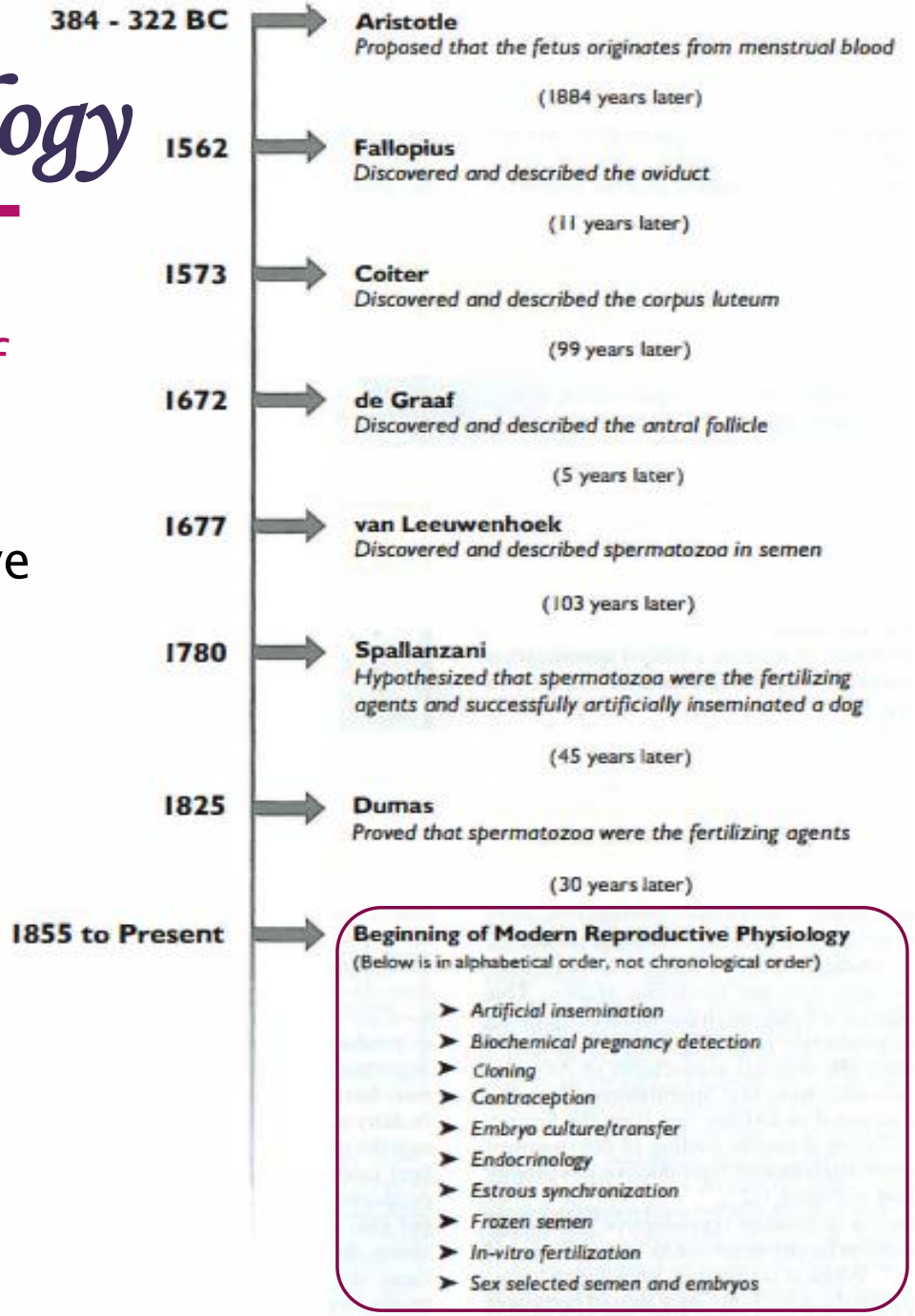
The History of Reproductive Physiology

- The father of modem artificial insemination was an Italian priest named Spallanzani.
  - He showed that one drop of dog semen diluted with 25 pounds of fluid retained its ability to fertilize. Using the dog, he performed the first artificial insemination.
- A scientist named Dumas collected bodies about I mm in diameter from rabbit follicles. He discovered that follicles contained ova and were precursors to the early embryo. This discovery led Dumas to conclude that the "animalcules," now called spemrntozoa, were responsible for uniting with the ovum and producing an embryo.
  - This early description of fertilization marked the beginning of modern reproductive physiology



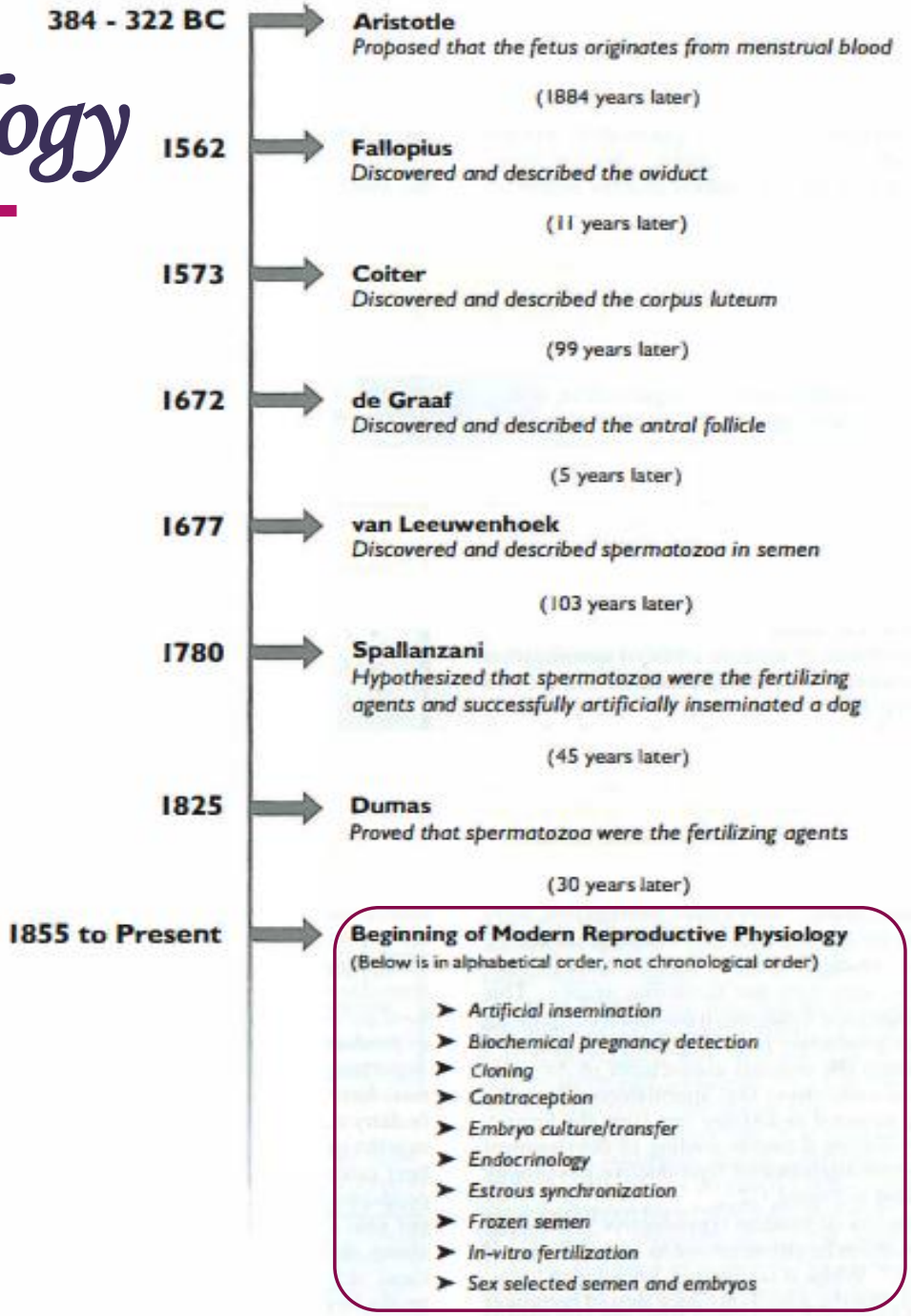
The History of Reproductive Physiology

- The era of modern reproductive physiology that followed can be characterized as an "explosion of knowledge."
  - recognition that the gonads produce steroid hormones that alter the function of the reproductive tissues and that the anterior pituitary controls the function of the gonads were major milestones of discovery.
  - The understanding that females experience reproductive cyclicity and that they ovulate with predictable frequency continued the explosion of knowledge.
  - Development of the radioimmunoassay for the measurement of hormones enabled the precise description of hormonal profiles in both the male and female



The History of Reproductive Physiology

- These discoveries opened the door for the development of methods for artificial manipulation of reproductive processes.
  - In the 1940's and I 950's, understanding spermatozoal physiology and how these cells function in test-tube environments led to successful artificial insemination in several species.
  - It wasn't until the 1960's that it was understood that prostaglandin $F_{2\alpha}$ regulated the length of the estrous cycle in most mammalian females.
  - The discovery that natural prostaglandin $F_{2\alpha}$ caused destruction of the corpus luteum made it possible to manipulate and alter estrous cycles and to control the time of ovulation.
- Such application is now commonplace in dairy and beef enterprises throughout the world.



Eng. Name	Per. name	Family	Female name	Male name	Birth proc.	M&F n.b. name	Male n.b. name	Fem. n.b. name	Cast. male name
Cattle	گاو	Bovine	Cow	Bull	Calving (گوساله زایی)	Calf (گوساله)	Bull calf	Heifer (تلیسه)	Steer
Goat	بز	Caprine	Doe (Nanny)	Buck (Billy)	Kidding (بزغاله زایی)	Kid (بزغاله)	Bucklin g	Doelin g	Wether
Sheep	گوسفند	Ovine	Ewe (میش)	Ram (قوچ)	Lambing (بره زایی)	Lamb (بره)	Ram lamb (بره قوچ)	Ewe lamb (بره میش)	Wether
Horse	اسب	Equine	Mare	Stallion	Foaling	Foal (کره اسب)	Colt	Filly	Geling
Swine (pig)	خوک	Porcine	Sow	Boar	Farrowin g	Piglet (litter)	Boar	Gilt	Barrow
Dog	سگ	Canine	Bitch	Dog	Whelping	Puppy (litter)	-	-	-
Cat	گربه	Feline	Queen	Tom	Kindling	Kitten (litter)	-	-	-

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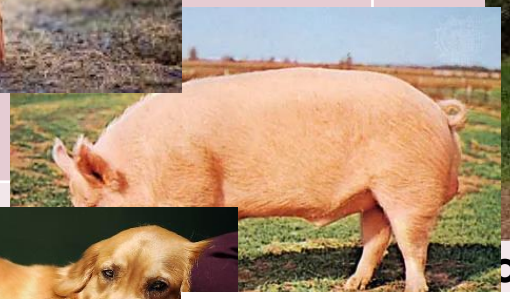
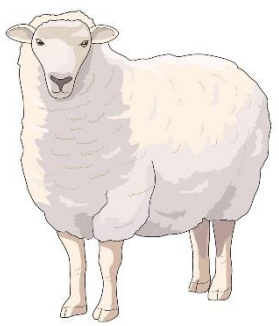
							(بره قوچ)	Ewe lamb (بره میش)	Wether
H					on	Foalin		Filly	Geling
S (					w		Boar	Gilt	B
Dog	سگ	Canine			oi				
Cat	گربه	Feline	Queen	Tom	Kindling	Kitten (litter)			

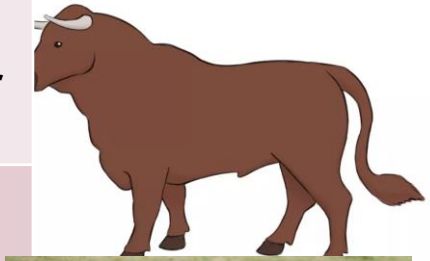



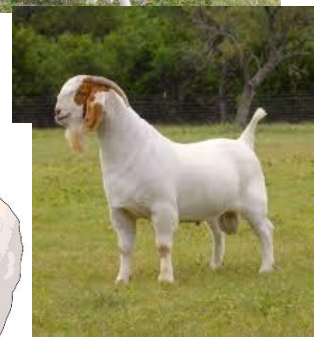












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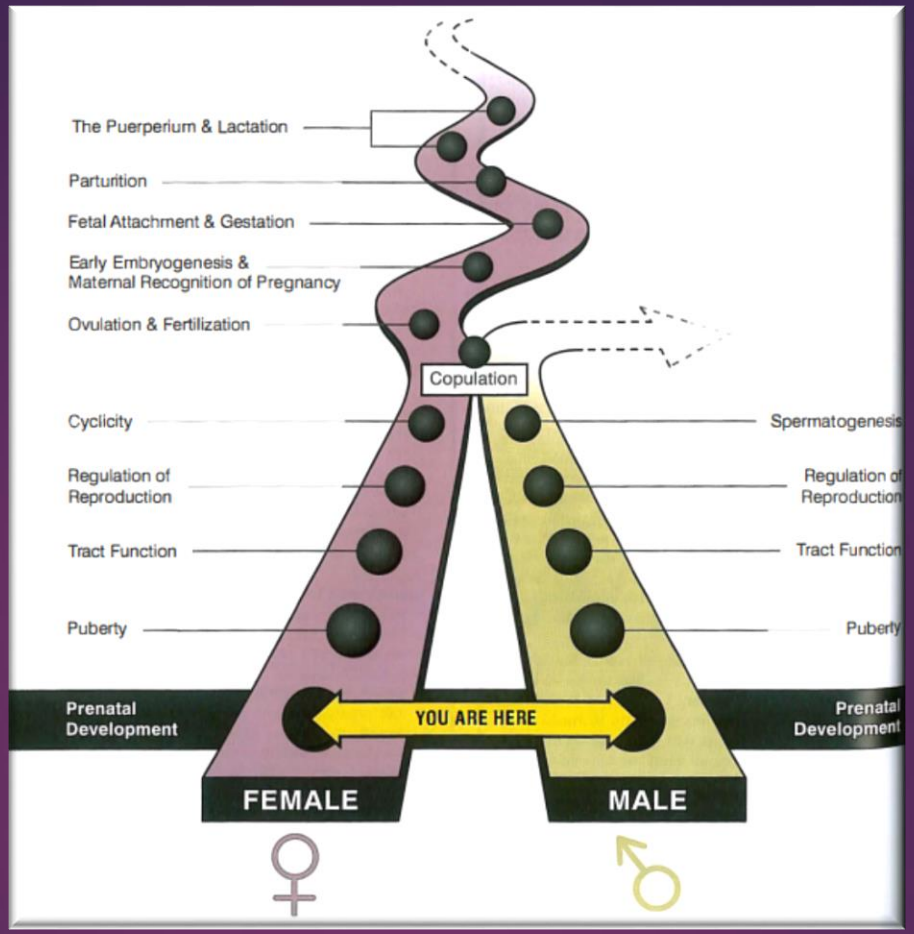
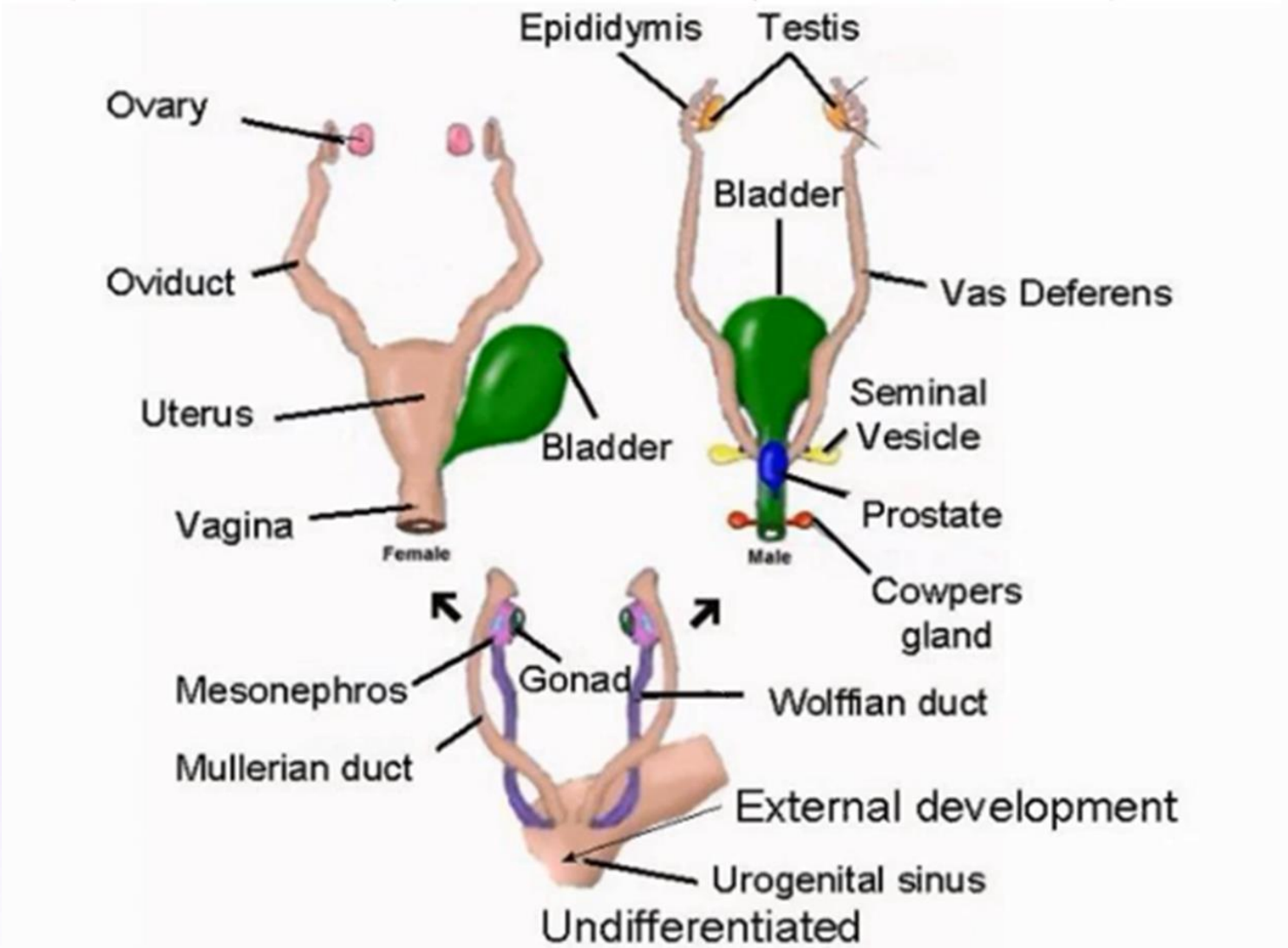


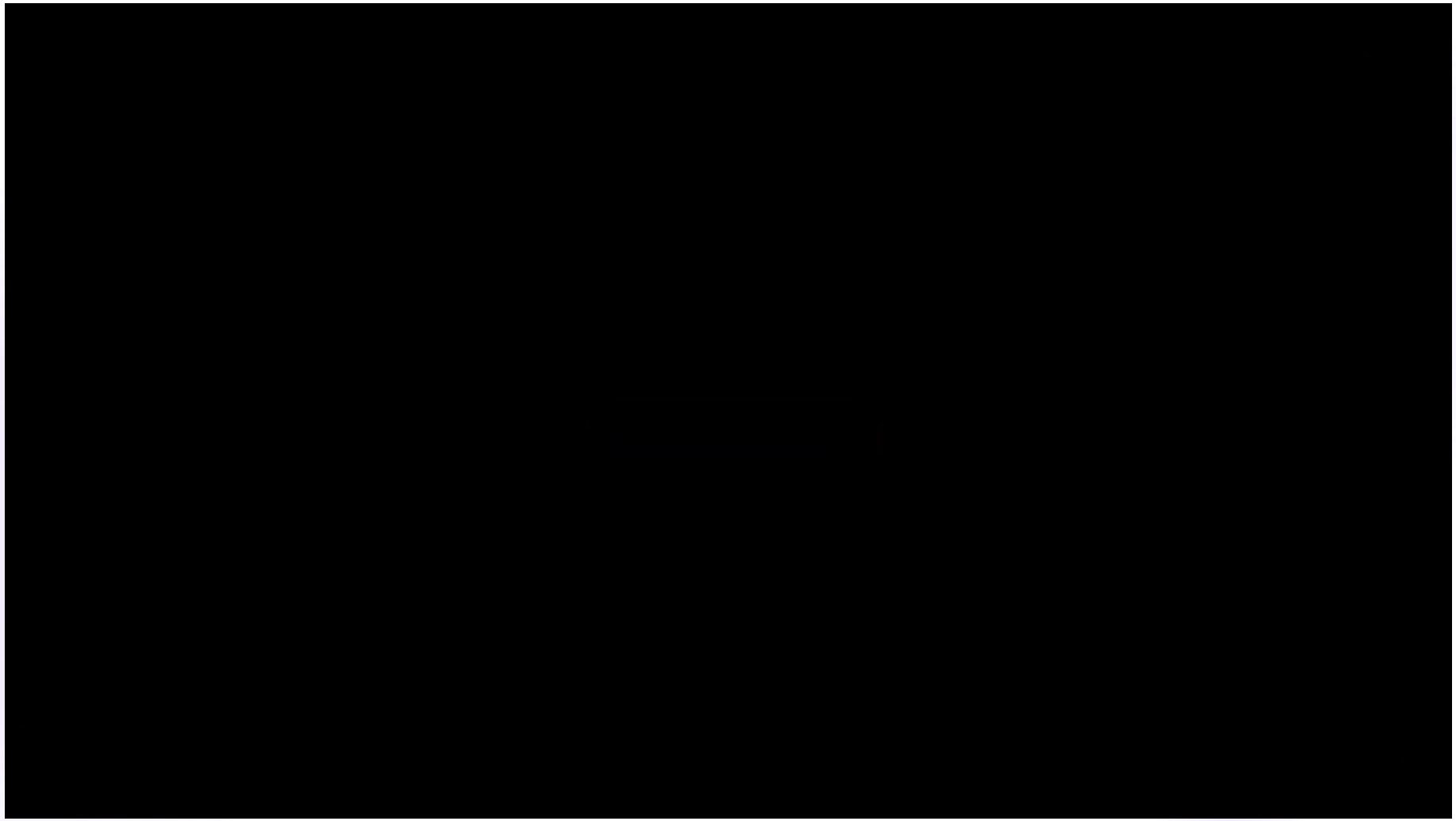
Section I

Prenatal Development

Ontogenesis of the Female Genitalia



Sex Determination and Differentiation



Sex Determination and Differentiation

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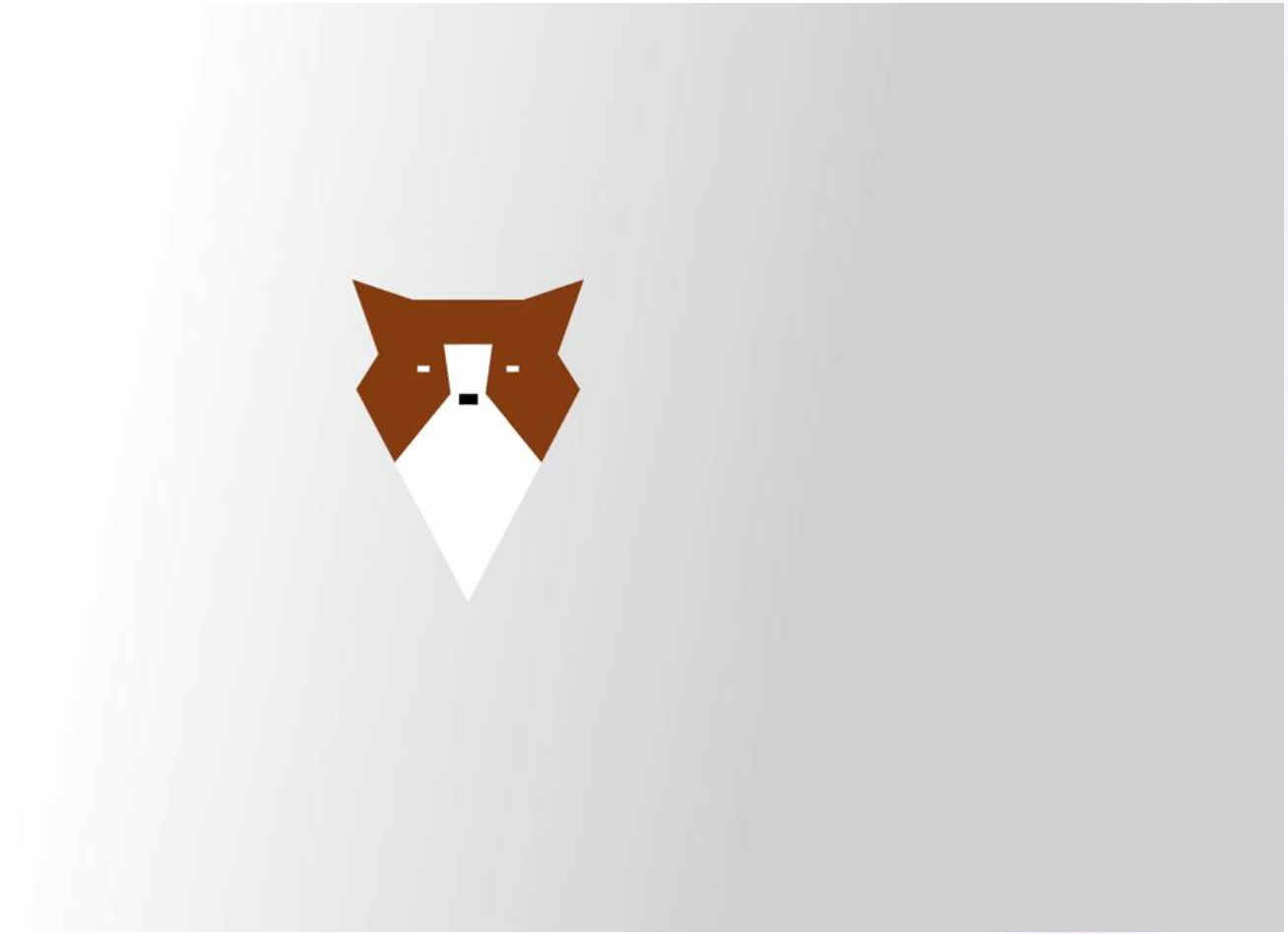
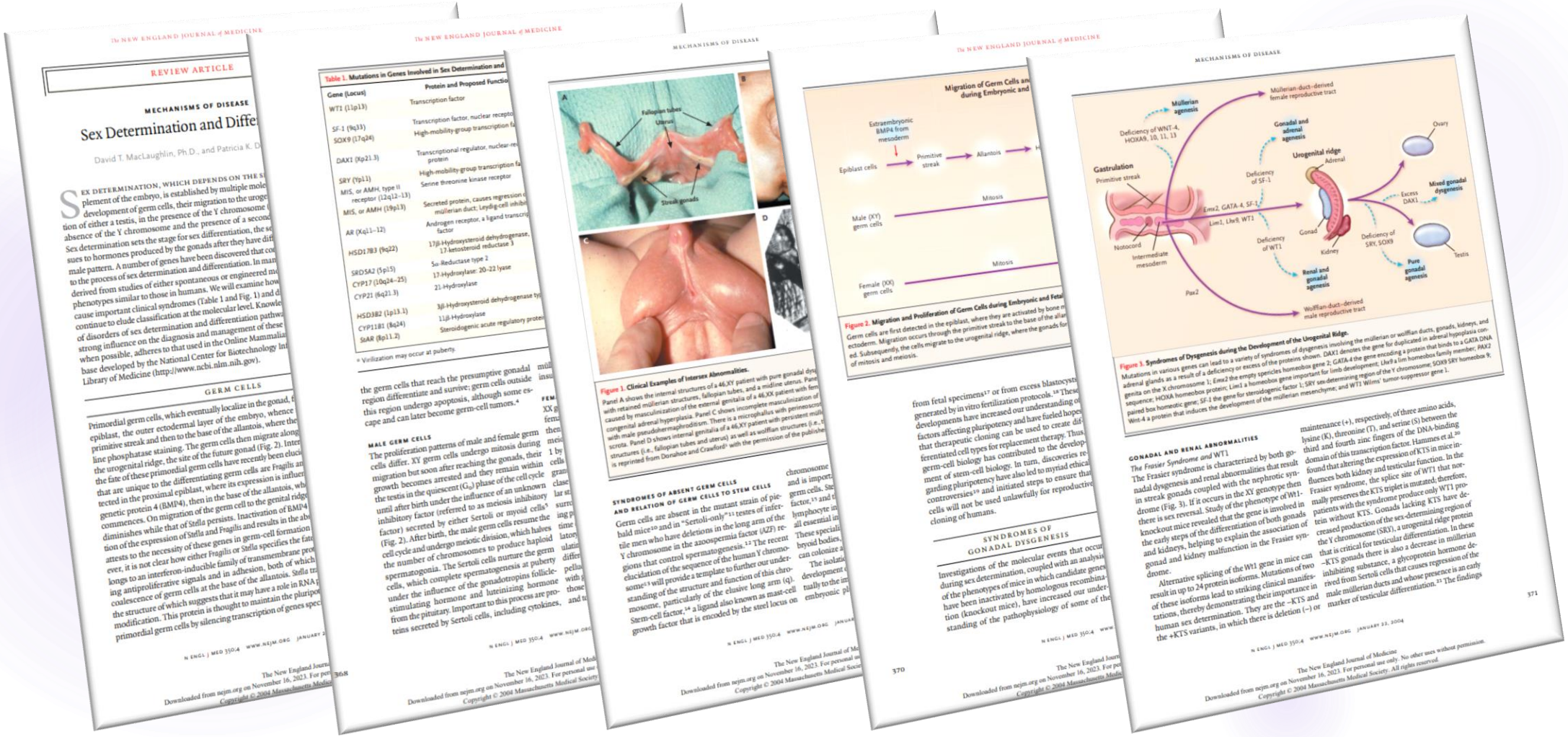


Journal Club (for more reading)

- https://www.nejm.org/doi/pdf/10.1056/NEJMra022784?articleTools=true



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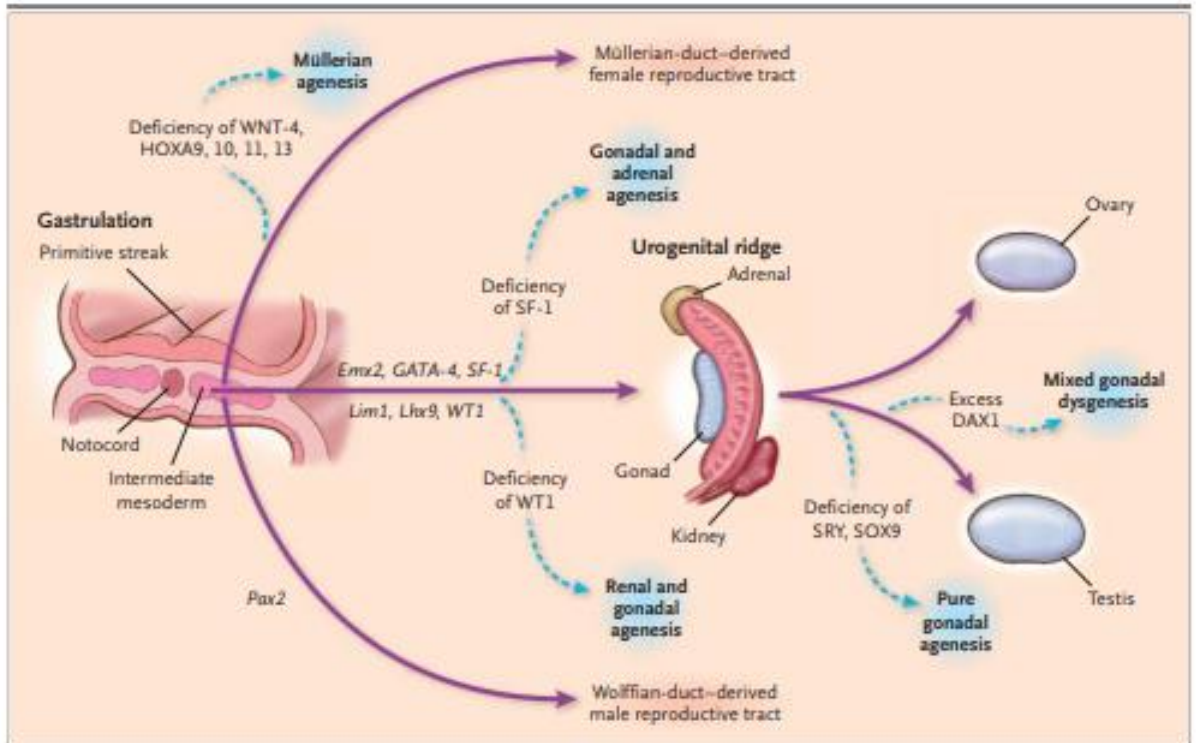


Figure 3. Syndromes of Dysgenesis during the Development of the Urogenital Ridge.

Mutations in various genes can lead to a variety of syndromes of dysgenesis involving the müllerian or wolffian ducts, gonads, kidneys, and adrenal glands as a result of a deficiency or excess of the proteins shown. *DAX1* denotes the gene for duplicated in adrenal hypoplasia congenita on the X chromosome 1; *Emx2* the empty spericles homeobox gene 2; *GATA-4* the gene encoding a protein that binds to a GATA DNA sequence; HOXA homeobox protein; *Lim1* a homeobox gene important for limb development; *Lhx9* a lim homeobox family member; *PAX2* paired box homeotic gene; *SF-1* the gene for steroidogenic factor 1; SRY sex-determining region of the Y chromosome; SOX9 SRY homeobox 9; Wnt-4 a protein that induces the development of the müllerian mesenchyme; and *WT1* Wilms' tumor-suppressor gene 1.

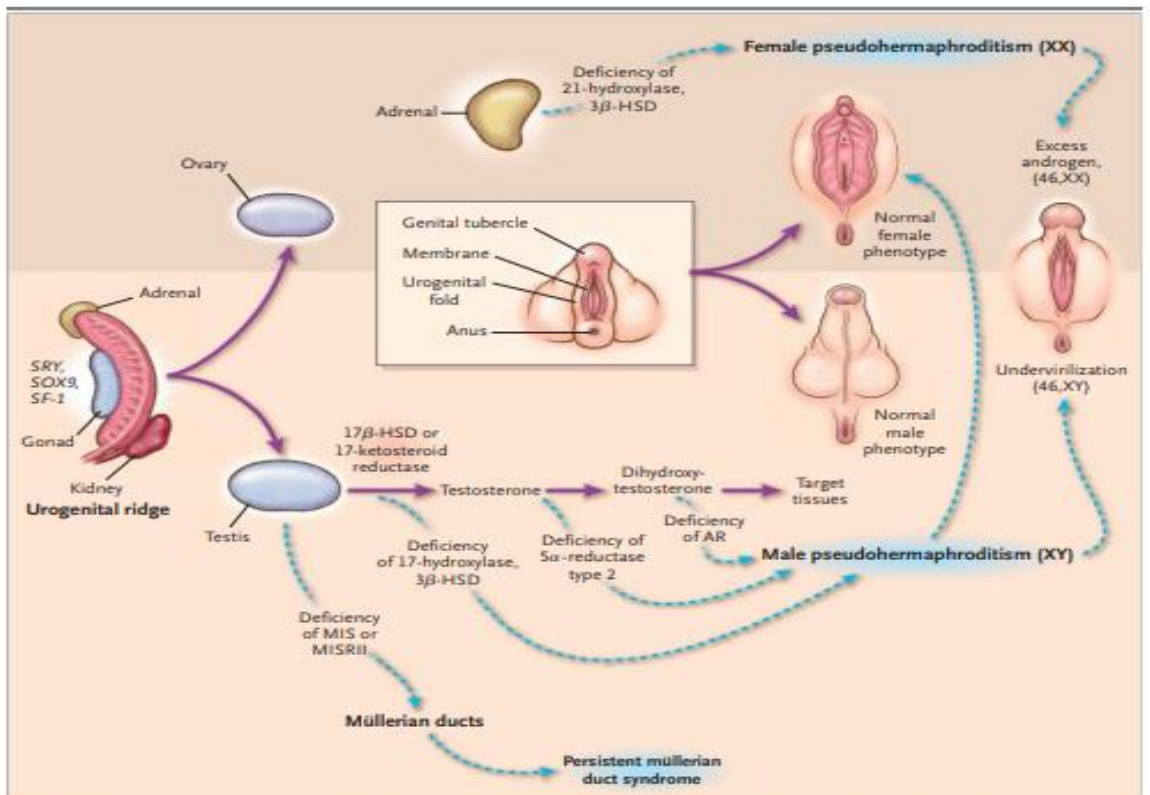
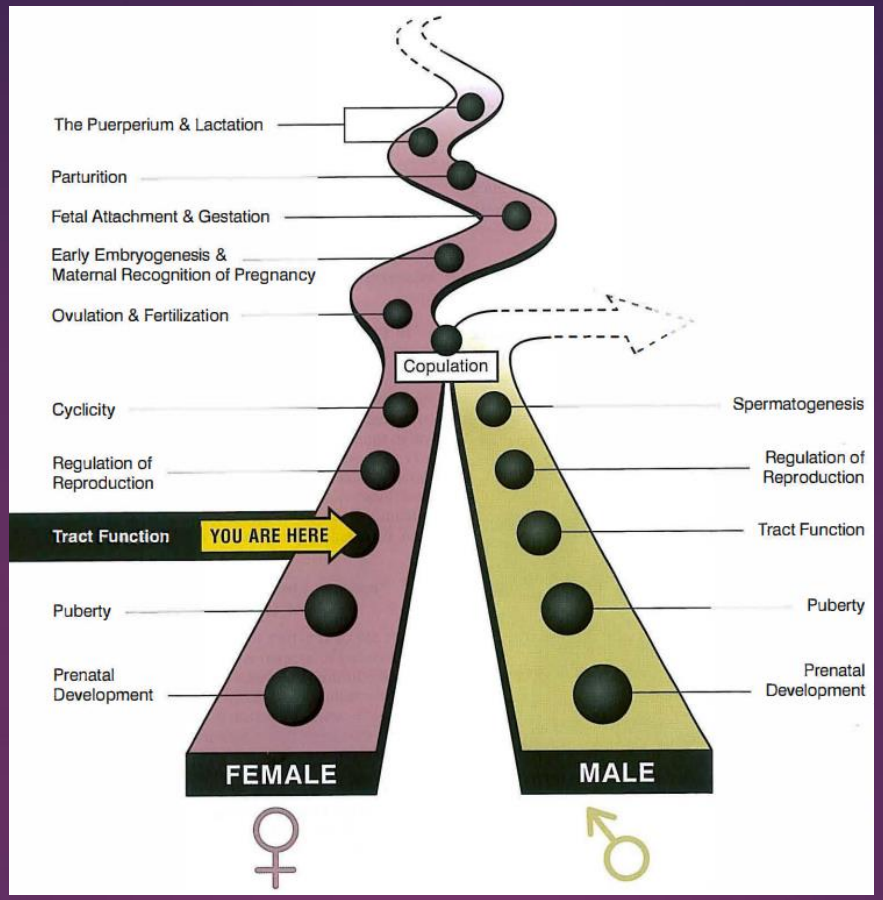


Figure 4. Functional Abnormalities of the Synthesis and Action of Hormones.

After the gonads have formed, reduced hormonal activity or signaling of specific receptors can lead to functional abnormalities of the reproductive tract, including persistent müllerian duct syndrome; male pseudohermaphroditism, causing undervirilization; and müllerian agenesis. After adrenal development, reduced enzymatic activity can result in female pseudohermaphroditism with excessive virilization. HSD denotes hydroxysteroid dehydrogenase, MIS müllerian inhibiting substance, MISRII müllerian inhibiting substance type II receptor, *SF-1* the gene for steroidogenic factor 1, *SRY* the gene for the sex-determining region of the Y chromosome, *SOX9* the gene for SRY homeobox 9, and AR androgen receptors.

Sex and Gender (for more reading)



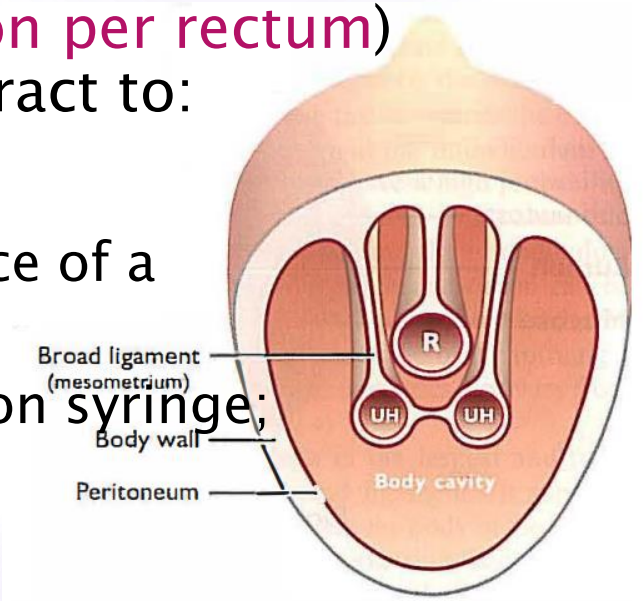
Section II

The Organization and Function of the Female Reproductive Tract

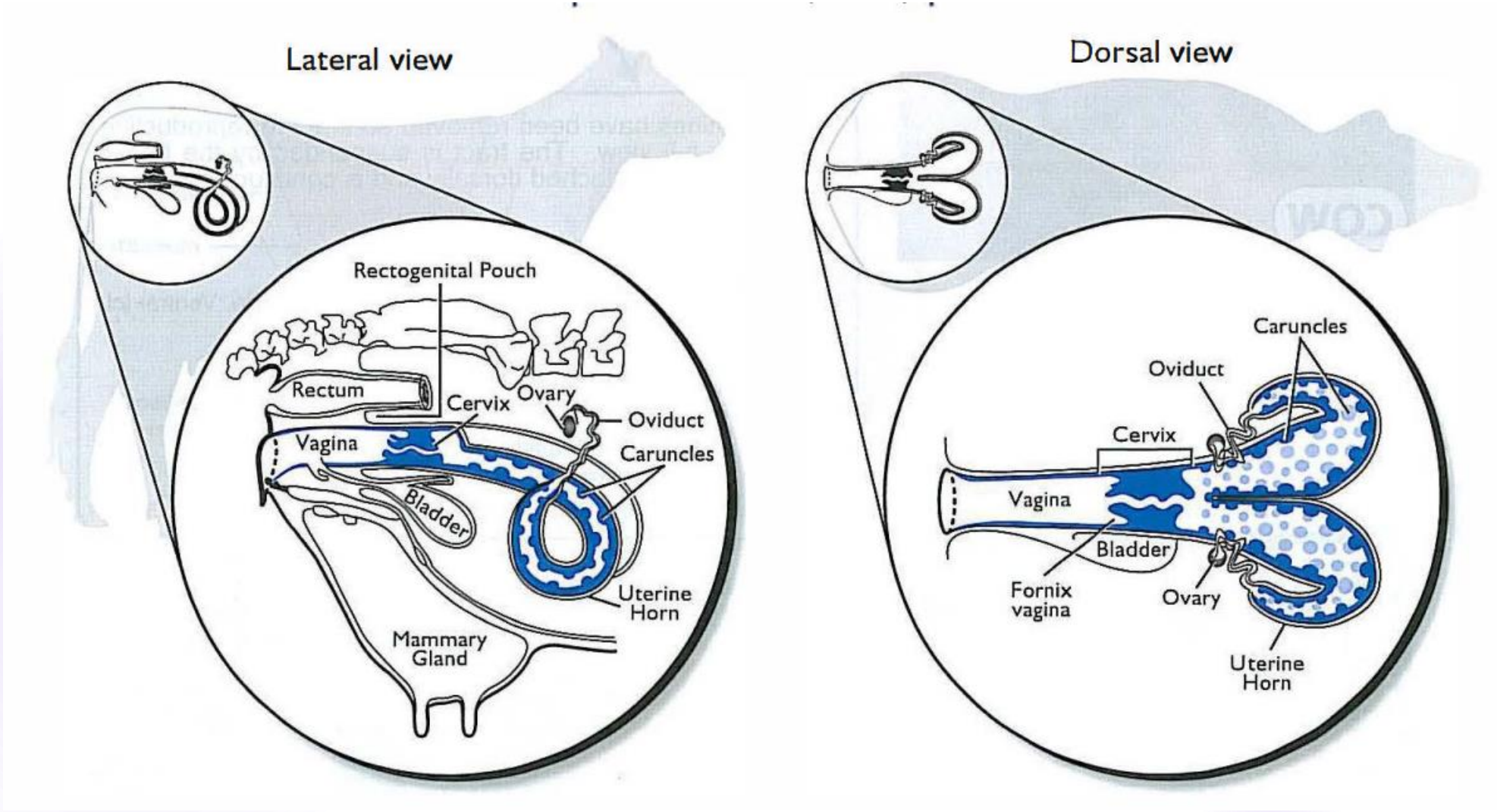
Female Reproductive Tract

II

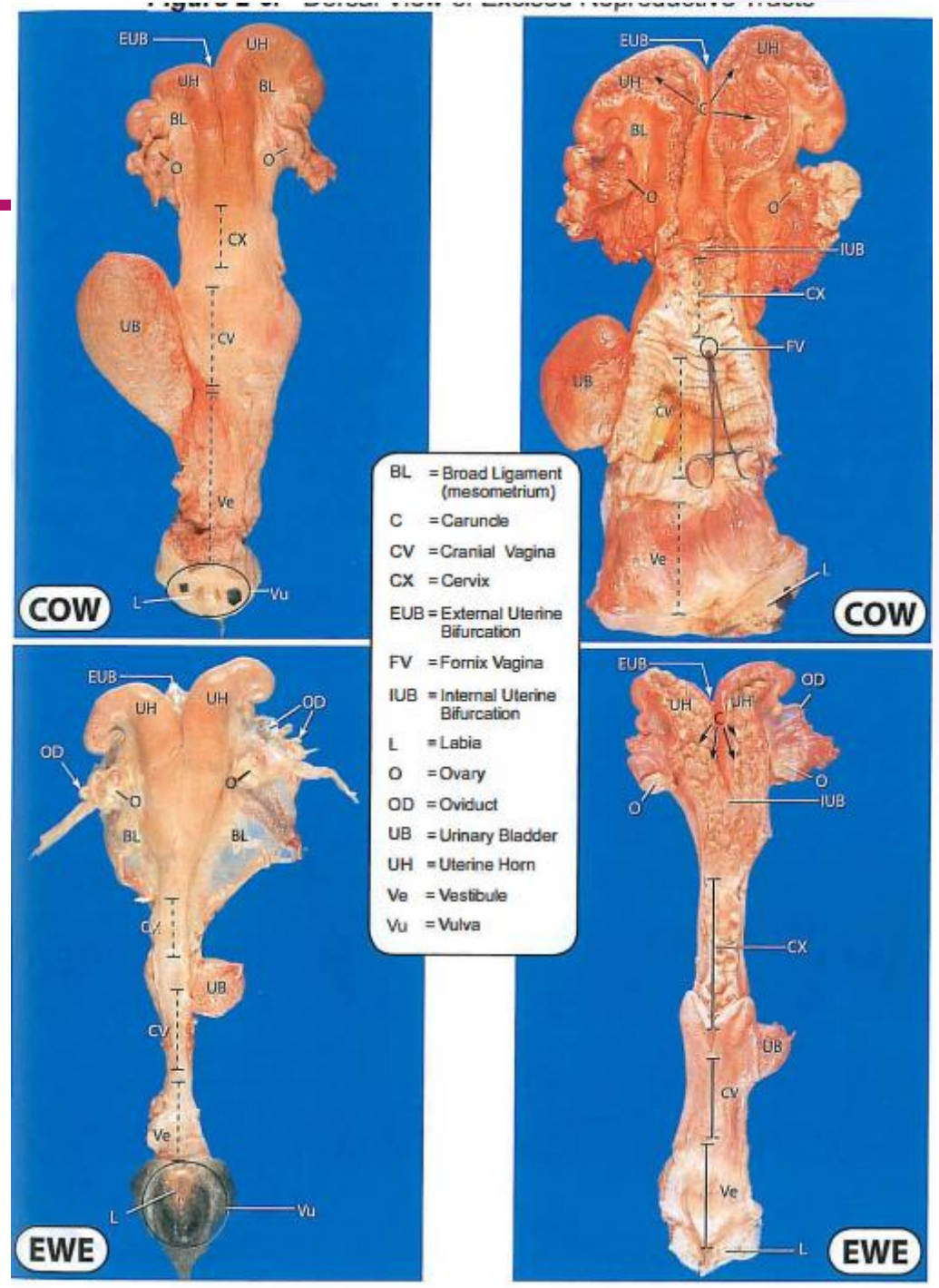
- The major structures of the female reproductive tract include the ovaries (the female gonads), oviducts, uterus, cervix, vagina and external genitalia. Each of these organs may be subdivided into components that represent specific anatomical regions.
- In all domestic species, the reproductive tract lies directly beneath the rectum and is separated from it by the rectogenital pouch.
- In the cow, mare, and camel this fortuitous anatomical relationship provides the opportunity for manual palpation (manipulation per rectum) and/or ultrasonic examination of the female reproductive tract to:
  - 1) diagnose the ovarian status of the female;
  - 2) diagnose pregnancy by determining the presence or absence of a fetus or of fetal membranes located within the uterus;
  - 3) manipulate the tract for insertion of an artificial insemination syringe;
  - 4) recover embryos using nonsurgical techniques
  - 5) identify reproductive tract abnormalities



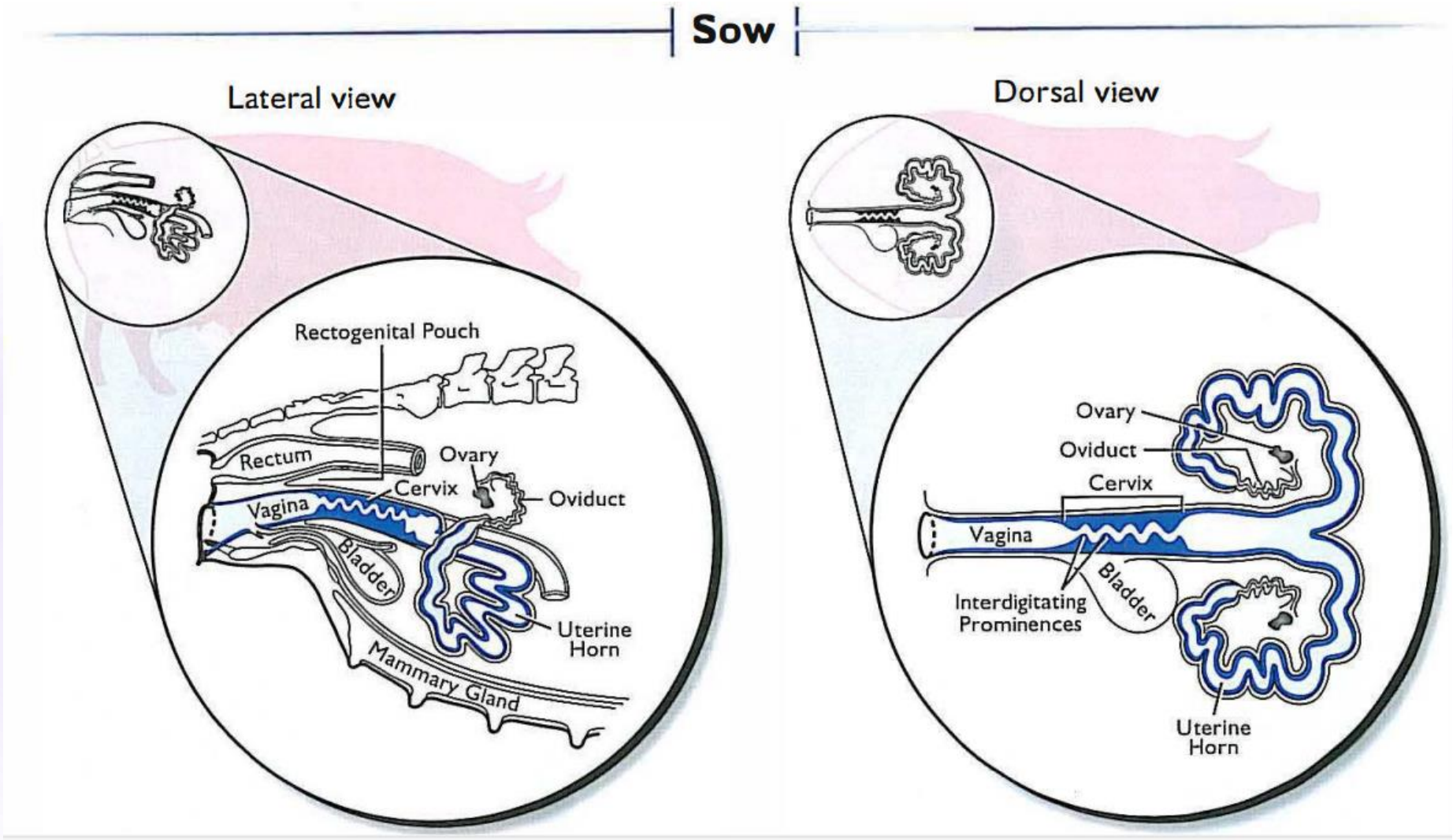
Ruminant (Cow)



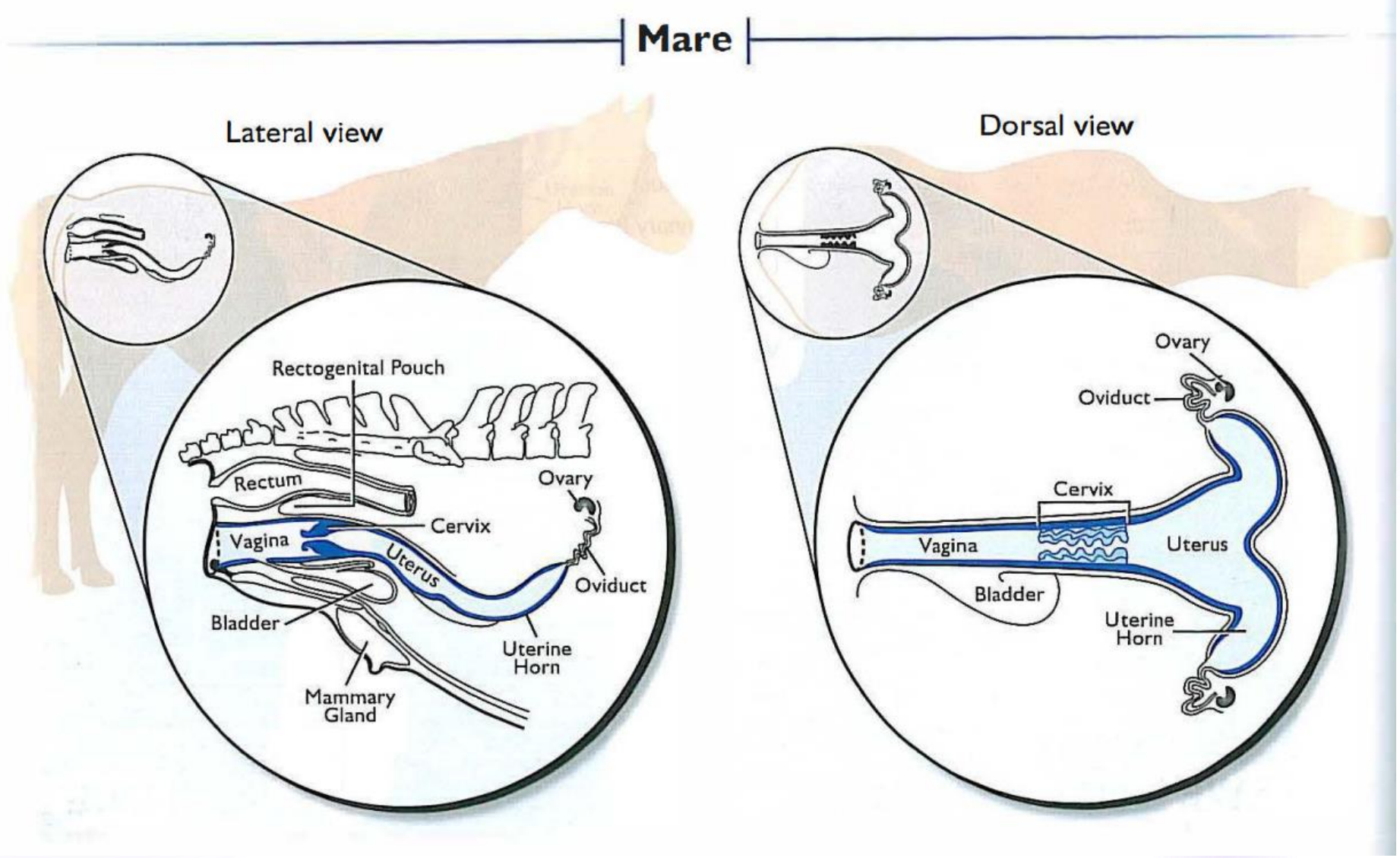
Ruminant


EUB
UH
BL
O
CX
UB
CV
Ve
Vu
L
COW
IUB
FV
C
OD
EWE
BL = Broad Ligament (mesometrium)
C = Carunde
CV = Cranial Vagina
CX = Cervix
EUB = External Uterine Bifurcation
FV = Fornix Vagina
IUB = Internal Uterine Bifurcation
L = Labia
O = Ovary
OD = Oviduct
UB = Urinary Bladder
UH = Uterine Horn
Ve = Vestibule
Vu = Vulva

Sow


Sow
Lateral view
Rectogenital Pouch
Rectum
Ovary
Cervix
Oviduct
Vagina
Bladder
Uterine Horn
Mammary Gland
Dorsal view
Ovary
Oviduct
Cervix
Vagina
Interdigitating Prominences
Bladder
Uterine Horn

Mare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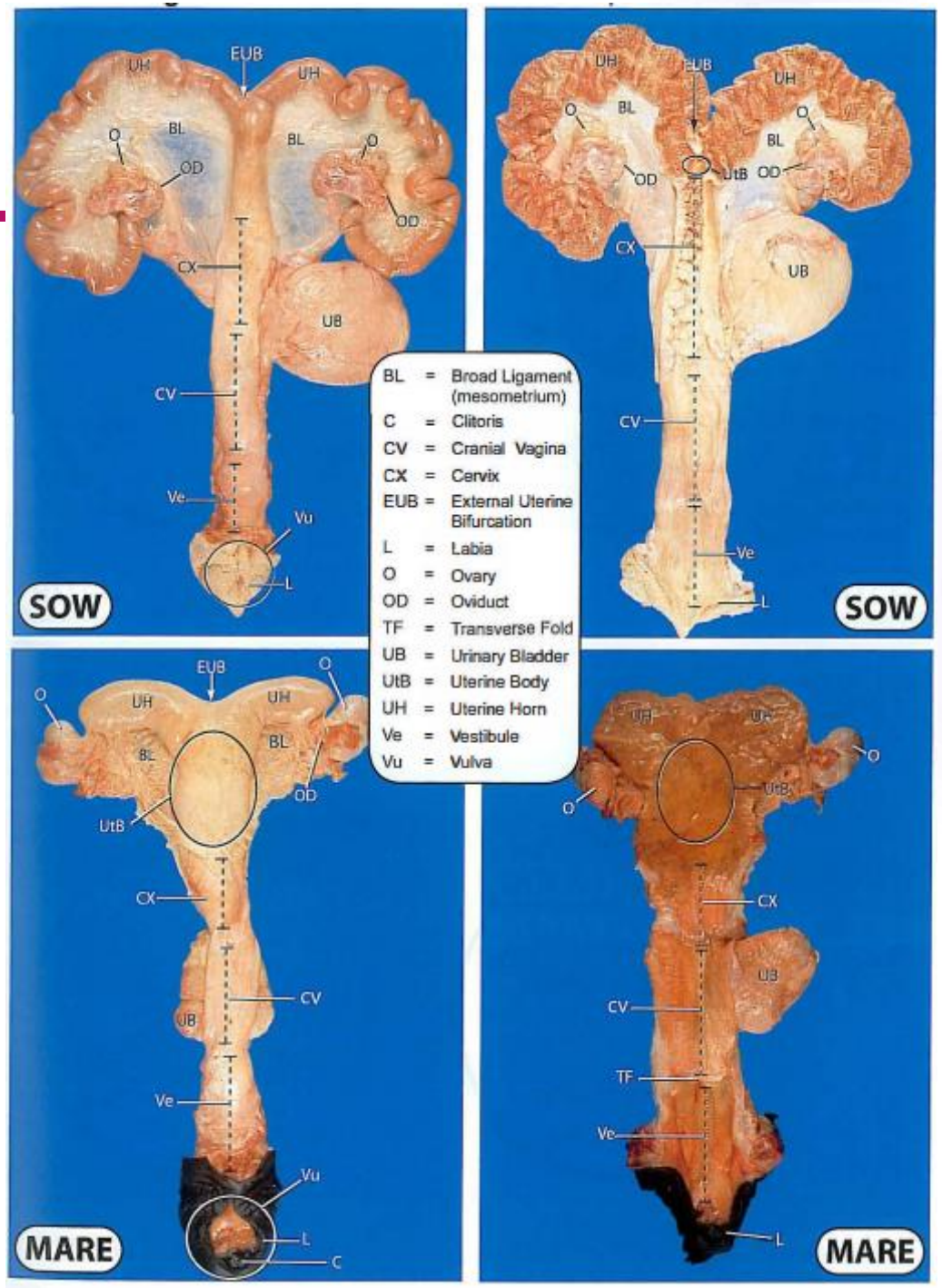
Uterus
Oviduct
Bladder
Uterine Horn
Mammary Gland
Dorsal view
Ovary
Oviduct
Cervix
Vagina
Uterus
Bladder
Uterine Horn

Sow and Mare


EUB
UH
UH
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BL
O
O
OD
OD
CX
UB
CV
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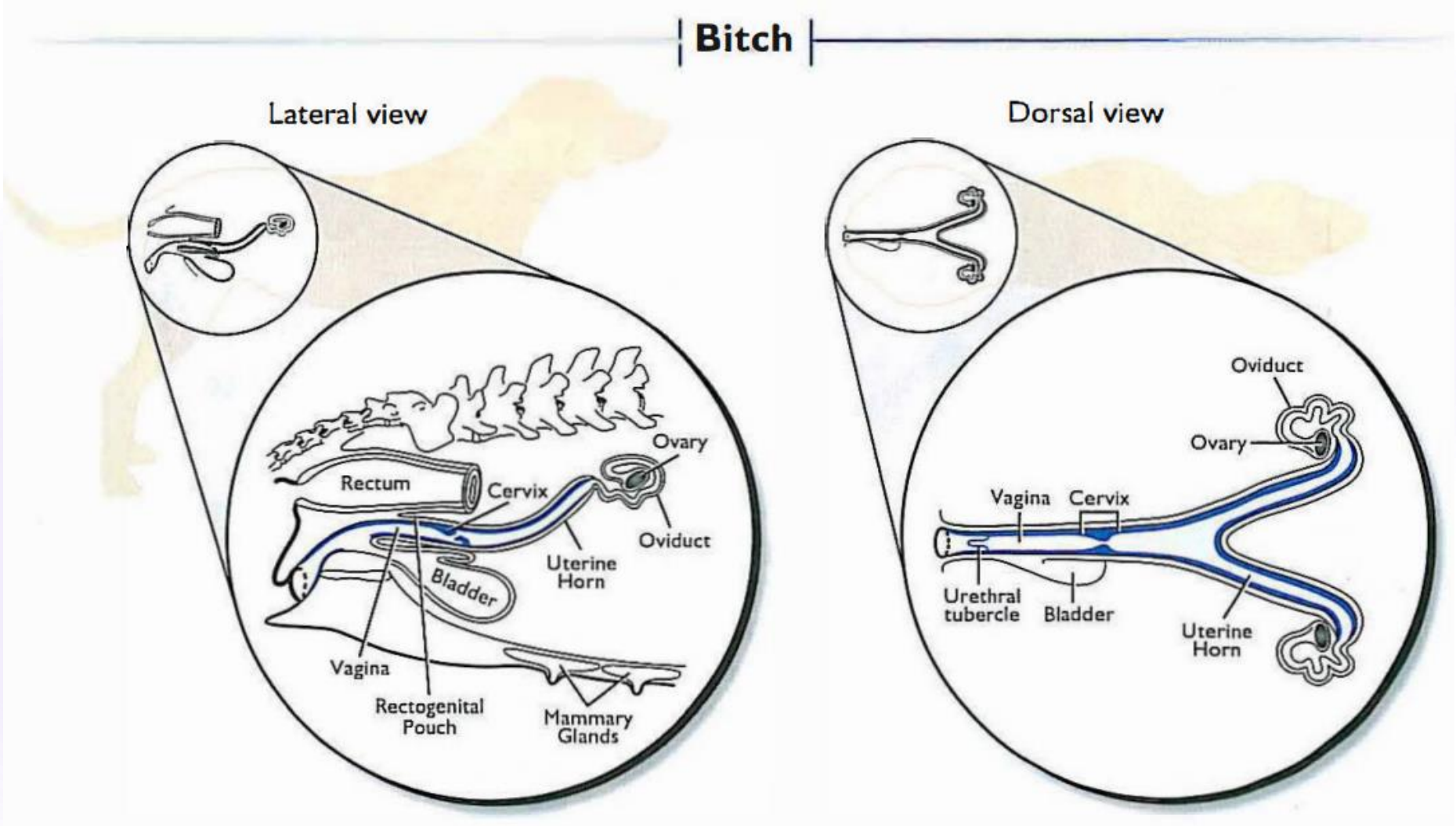
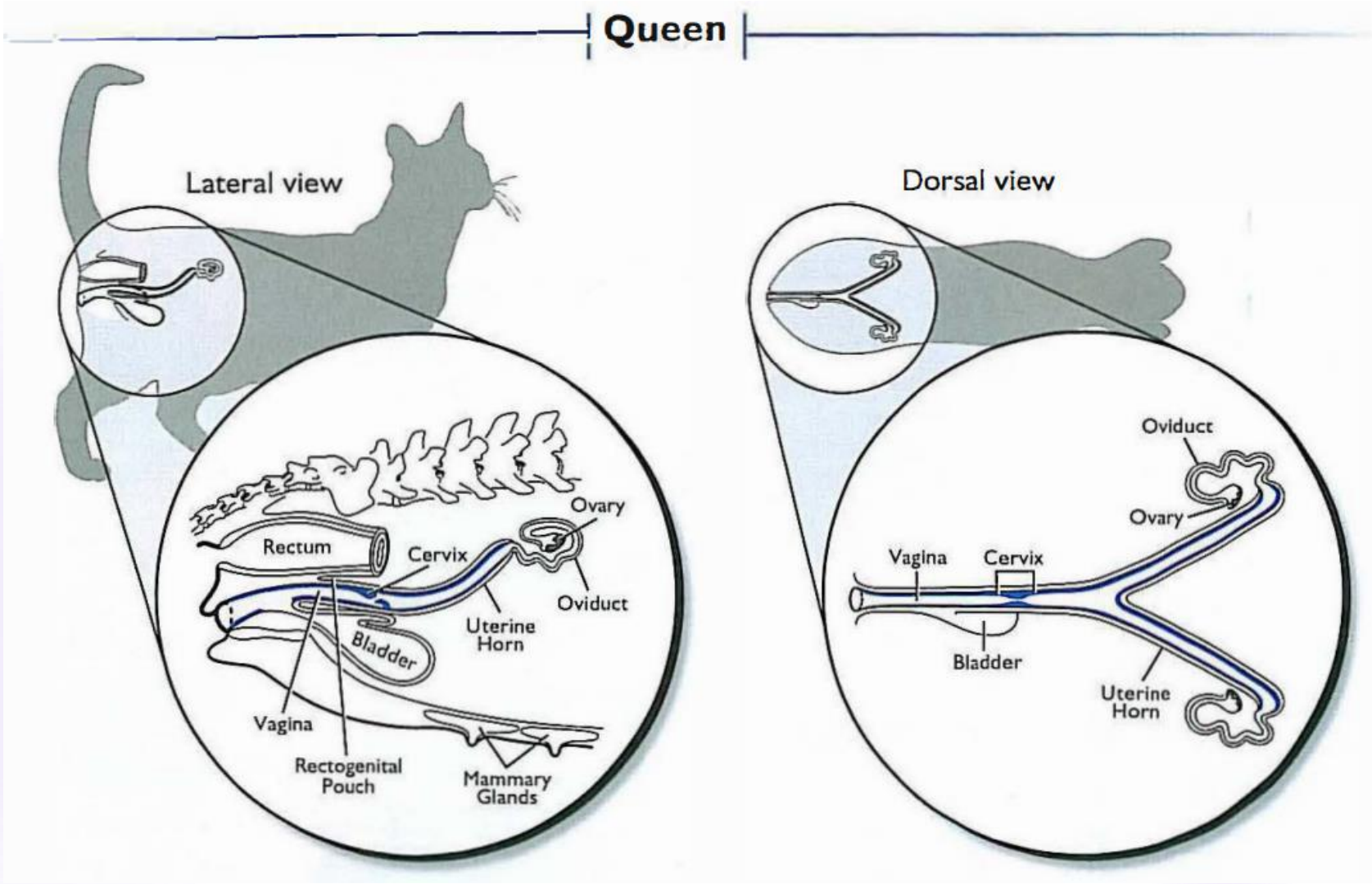
L
SOW
BL = Broad Ligament (mesometrium)
C = Clitoris
CV = Cranial Vagina
CX = Cervix
EUB = External Uterine Bifurcation
L = Labia
O = Ovary
OD = Oviduct
TF = Transverse Fold
UB = Urinary Bladder
UtB = Uterine Body
UH = Uterine Horn
Ve = Vestibule
Vu = Vulva
UtB
TF
C
MARE

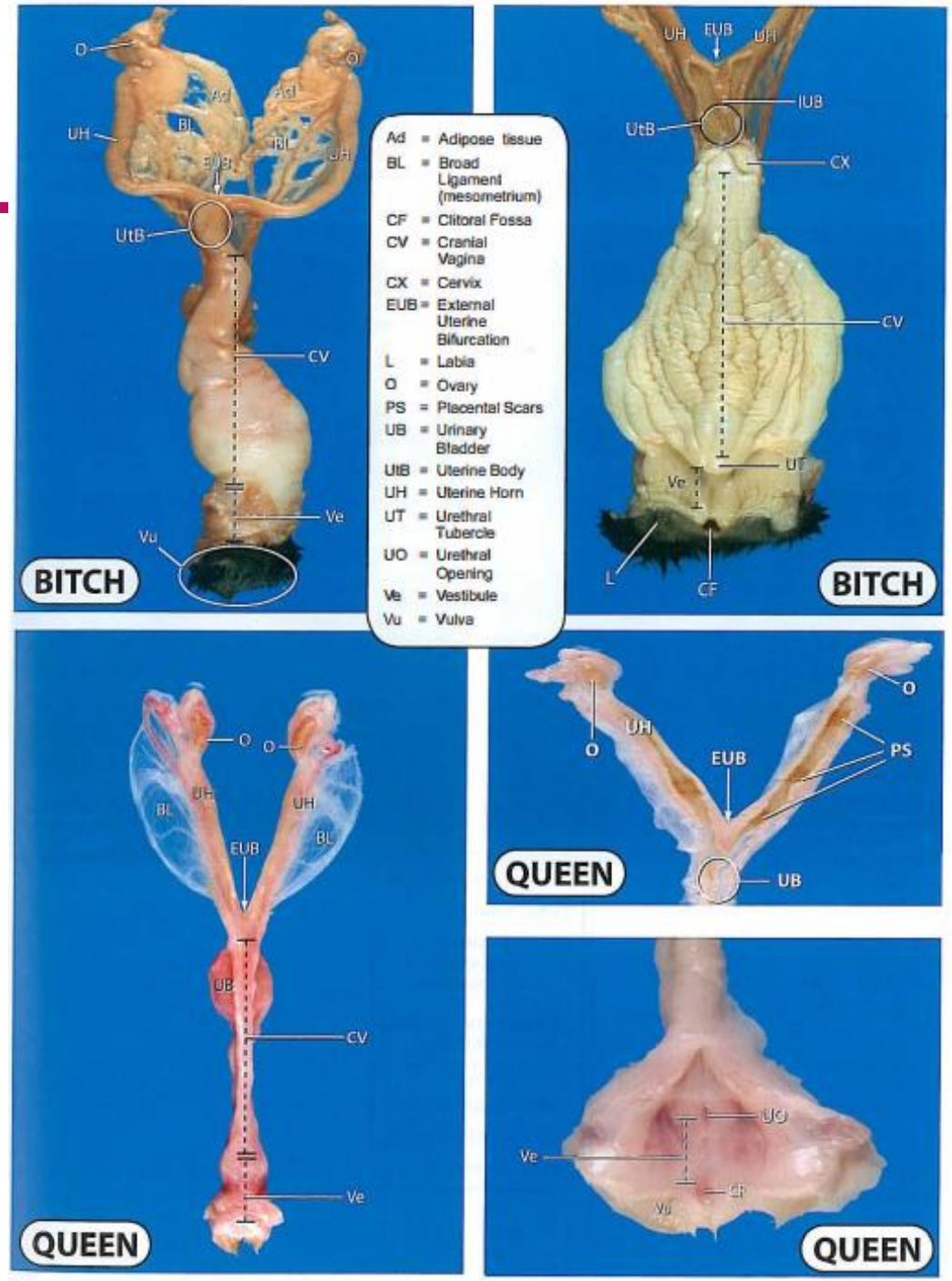
Carnivores (Bitch)



Carnivores (Queen)

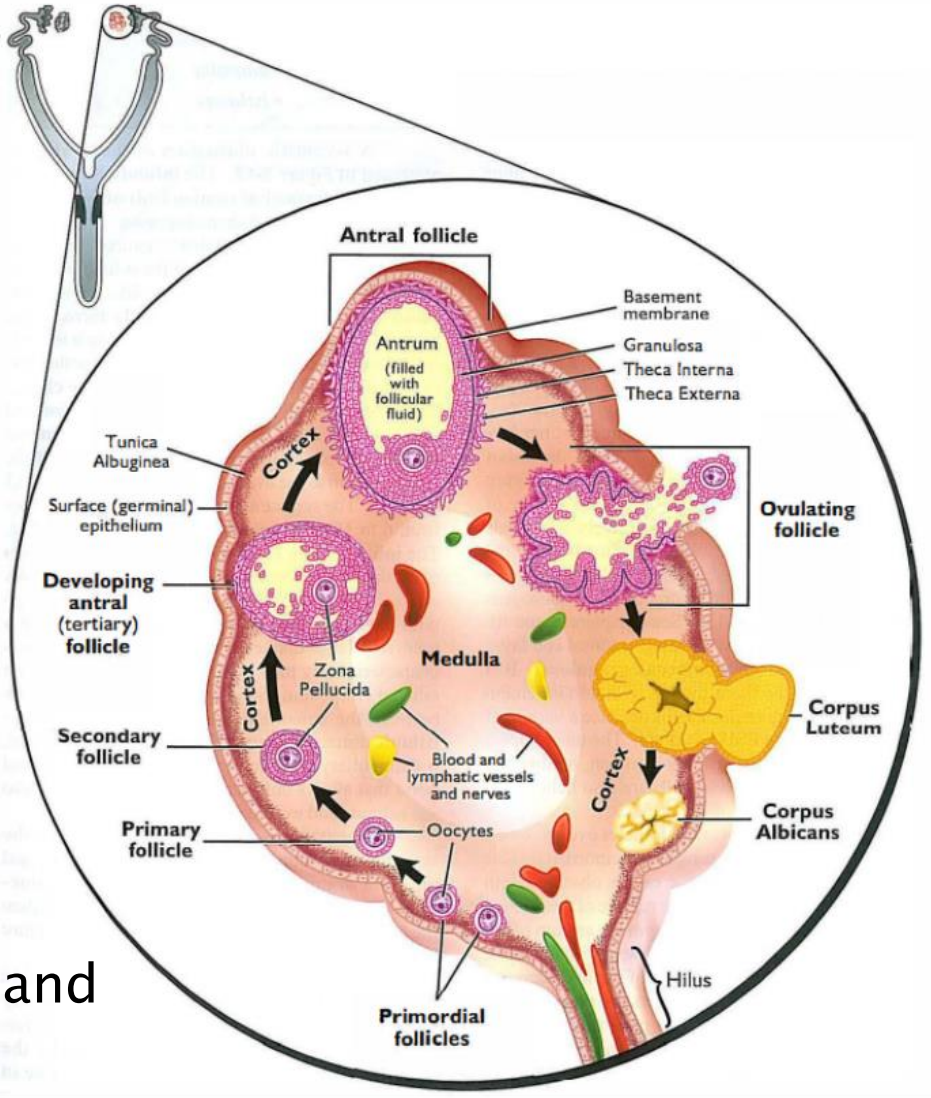


Bitch and Queen



The ovary

- The ovary is an ovoid relatively dense structure, the primary functions of which are to produce female gametes (ova) and the hormones estrogen and progesterone. The corpus luteum also produces oxytocin, relaxin, inhibin and activin.
- The ovary is composed of:
  - Outer connective tissue surface called the tunica albuginea
  - Single layer of cuboidal cells called the germinal epithelium (wrongly named)
  - The ovarian cortex houses the population of oocytes
    - follicles that will mature and eventually ovulate.
    - corpus luteum (CL)
    - corpus albicans
  - The ovarian medulla: vasculature, nerves, lymphatics and relatively dense connective tissue.



The ovary

II

- Ovarian follicles: The process whereby immature follicles develop into more advanced follicles and become candidates for ovulation is referred to as folliculogenesis.
  - Primordial follicles that are microscopic, are the most immature and are the smallest encountered in the ovarian cortex. The oocyte (egg) within the primordial follicle is surrounded by a single layer of flattened (squamous) cells.
  - Primary follicle is characterized by having an oocyte that is Surrounded by a single layer of cuboidal or follicular cells.
    - they either develop into a more advanced secondary follicle or they degenerate.
  - Secondary follicle, is characterized as having two or more layers of follicle cells, but without an antrum or cavity.
    - the oocyte within a secondary follicle is characterized as being surrounded by a relatively thick translucent layer called the zona pellucida.

The ovary

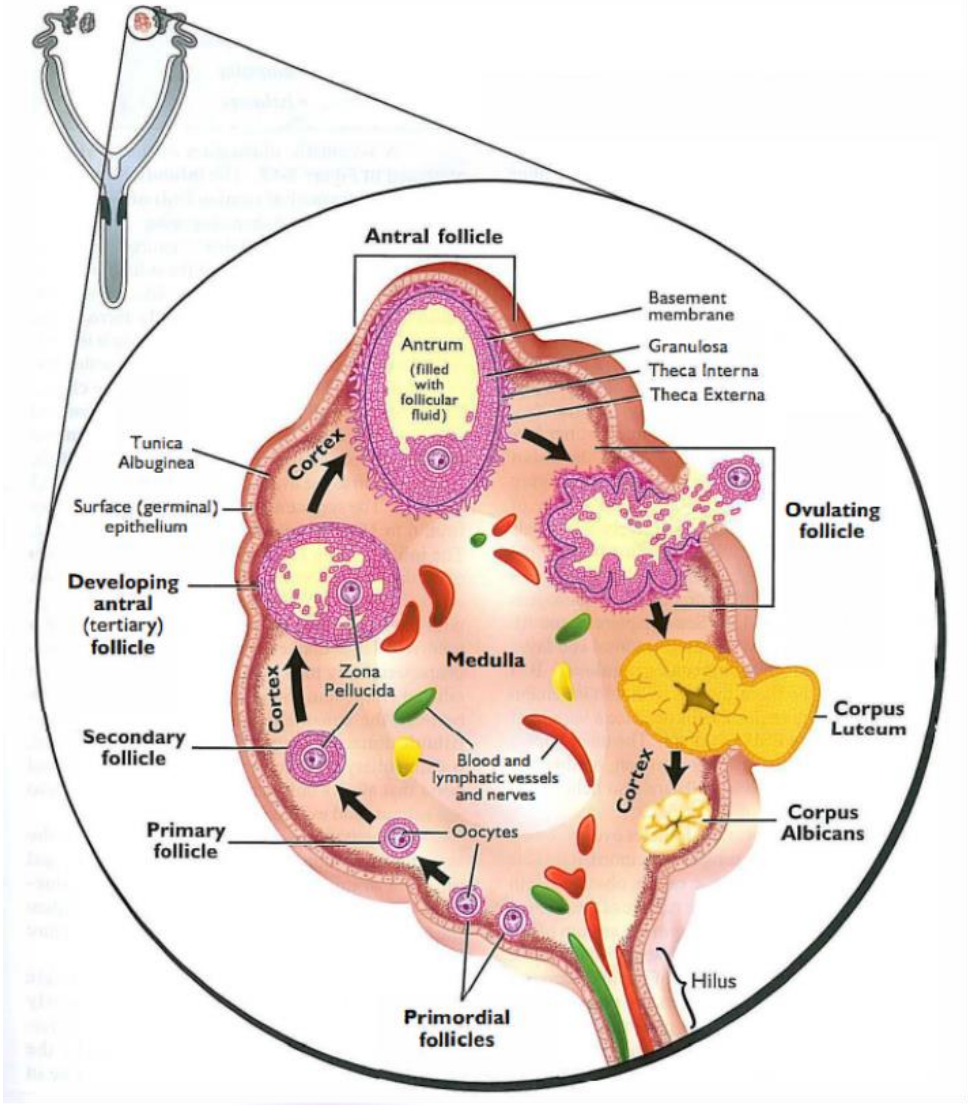
II

- Antral follicle is characterized by a fluid-filled cavity called the antrum. The fluid within the antrum is called follicular fluid. Sometimes the antral follicle is referred to as a tertiary follicle.
- Grafian follicle is the dominant tertiary preovulatory follicle.
  - Antral follicles consist of three distinct layers. Theca externa, the theca interna and the granulosal cell layer.
    - The theca externa: loose connective tissue that completely surrounds and supports the follicle.
    - the theca interna: responsible for the production of androgens under the influence of LH.
    - The granulosal cells: produce a variety of materials and have FSH receptors. The most important products of these cells are estrogen, inhibin and follicular fluid. Granulosal cells are also believed to govern the maturation of the oocyte

The ovary

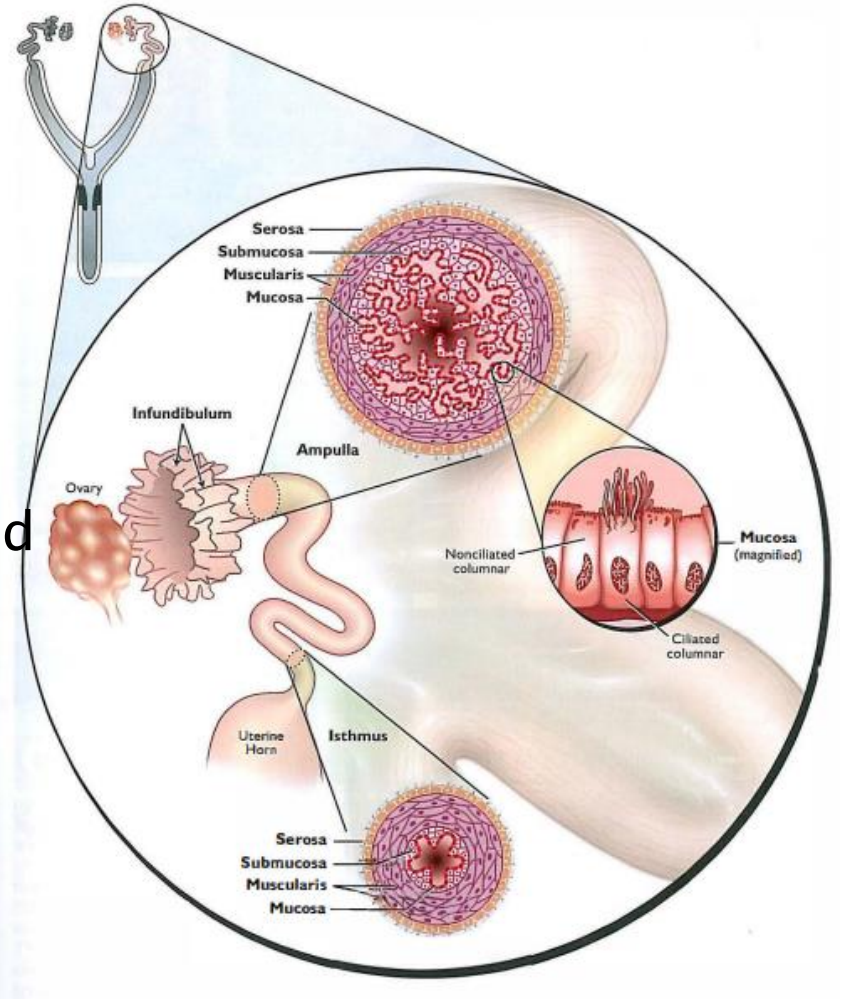
II

- corpus hemorrhagicum forms When dominant antral follicles ovulate and small blood vessels rupture, causing local hemorrhage.
- After the formation of the corpus hemorrhagicum ("bloody body"), the cells of the theca interna and the granulosal cells differentiate into luteal cells to form a corpus luteum.



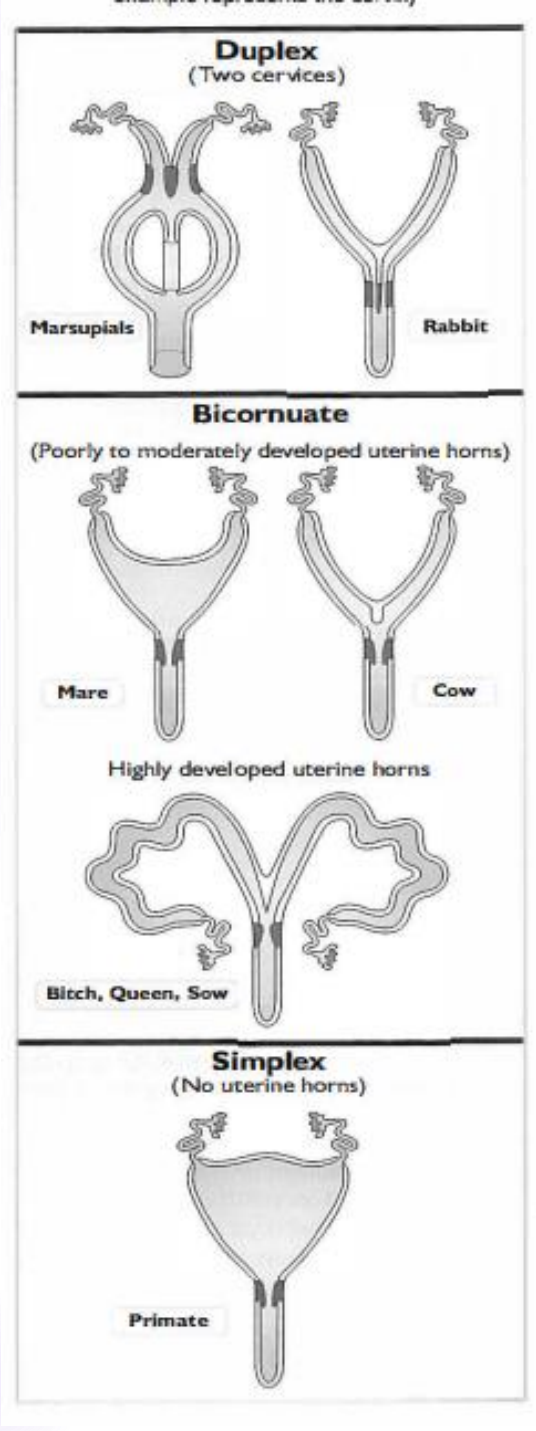
The Oviduct

- The infundibulum is the terminal end (cranial or ovarian end) of the oviduct and consists of a funnel-shaped opening that "captures" the newly ovulated oocyte.
  - The surface of the infundibulum is covered with many velvety, finger-like projections called fimbriae.
- The ampulla occupies one-half or more of the oviductal length and merges with the isthmus of the oviduct
  - The ampullary-isthmus junction (AIJ) is generally ill-defined and serves as a control point that allows only fertilized oocytes to pass into the isthmus and eventually into the uterus.
- The isthmus is smaller in diameter than the ampulla, thicker muscular wall and has fewer mucosal folds.



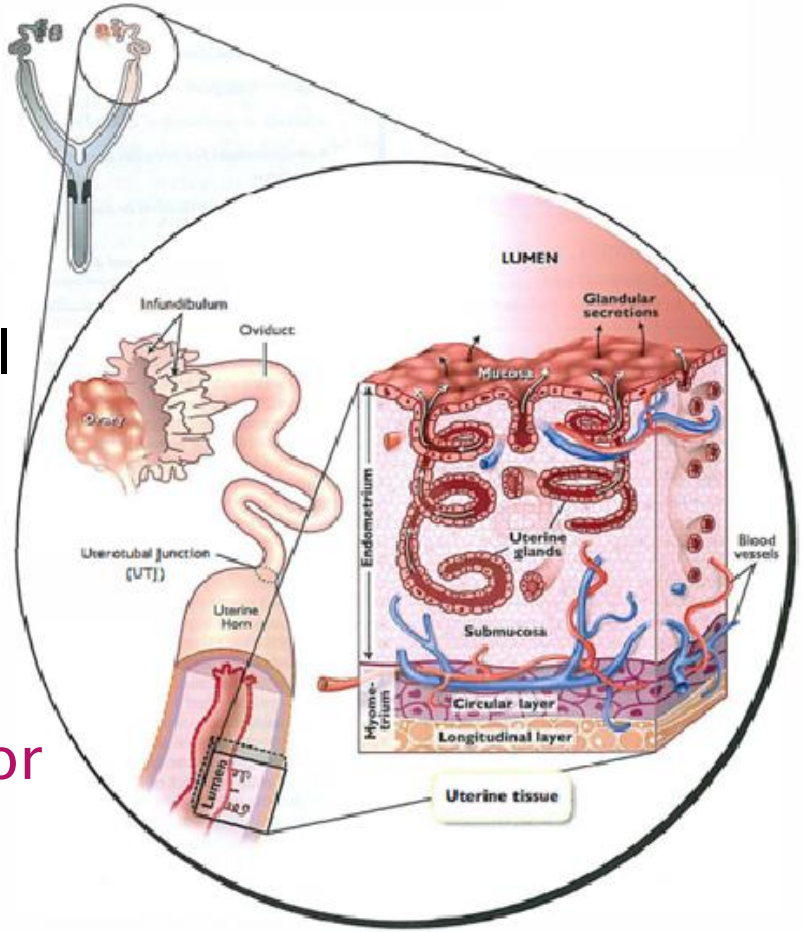
The Uterus

- The uterus connects the oviducts to the cervix. In most mammals, the uterus consists of two uterine horns or cornua.
- there are three distinct anatomical types of uteri:
  - Duplex uterus, characterized as having two cervical canals.
  - Bicornuate uterus is characterized by having two uterine horns and a small uterine body
  - Simplex uterus is characterized as having a single uterine body



The Uterus

- The uterus consists of a serosal layer called the perimetrium that is part of the peritoneum.
- The myometrium consists of two layers of outer longitudinal and inner circular muscle layers.
  - Motility of the uterus a high degree of tone (a partial state of contraction) when estrogen is the predominant steroidal hormone.
  - Under the influence of progesterone, the myometrium has a low degree of tone
  - During parturition, the myometrium becomes a major driving force for expulsion of the fetus and fetal membranes.

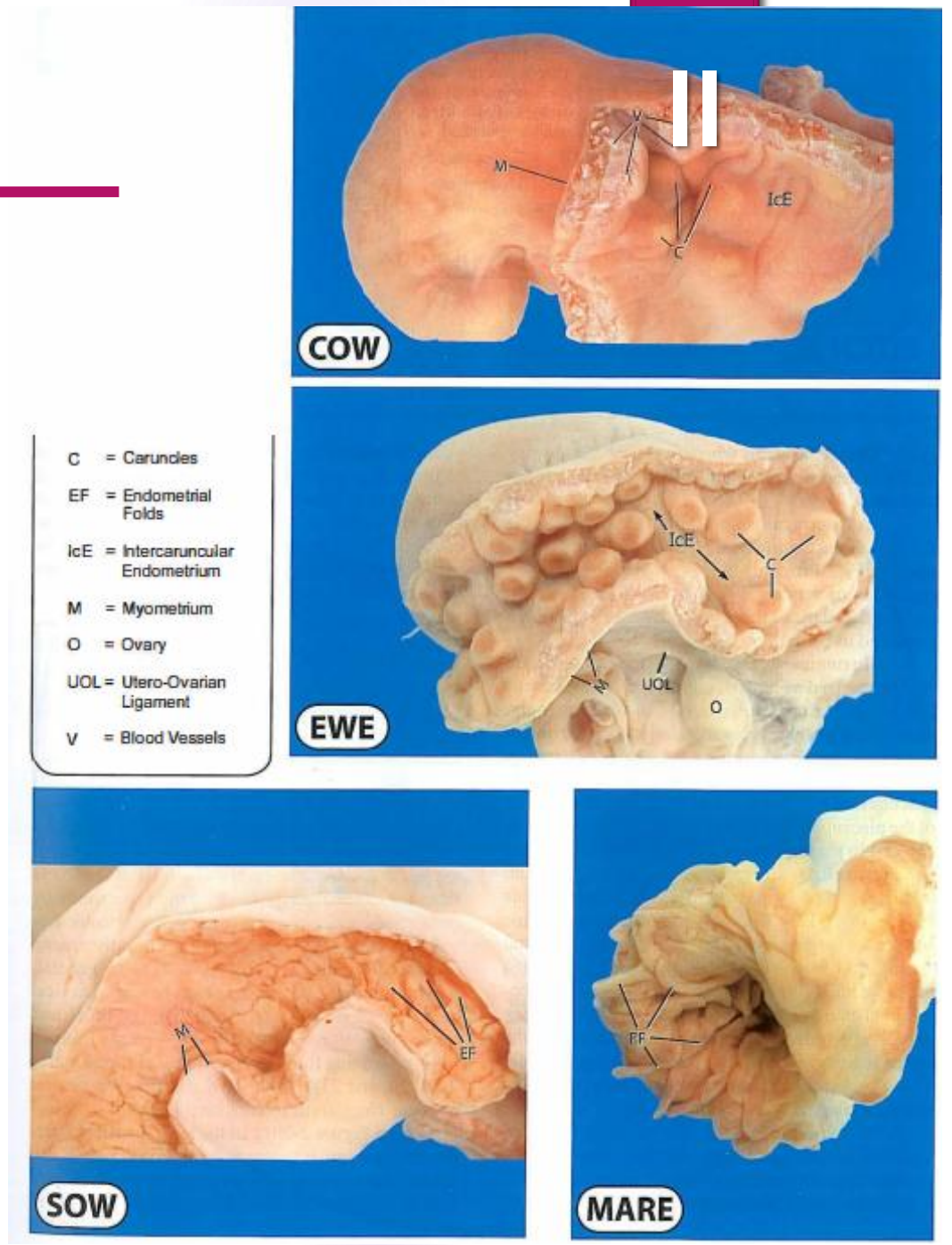


The Uterus

- The inner portion of the uterus is composed of the mucosa and submucosa called the endometrium.
  - The mucosal epithelium is responsible for secreting materials into the lumen of the uterus that enhance embryo development and sperm viability.
  - A distinct difference between lower mammals and primates, particularly humans, is that the endometrium of the uterus in the human is sloughed to the exterior.
  - At a critical time during the estrous cycle the cells of the uterine endometrium produce prostaglandin $F_{2\alpha}$.
    - $PGF_{2\alpha}$ causes luteolysis or regression of the corpus luteum if the animal is not pregnant.
- The primary functions of the uterus are: 1)sperm transport, 2)luteolysis and control of cyclicity, 3)environment for preattachment embryo, 4)maternal contribution to the placenta, 5)expulsion of the fetus and fetal placenta

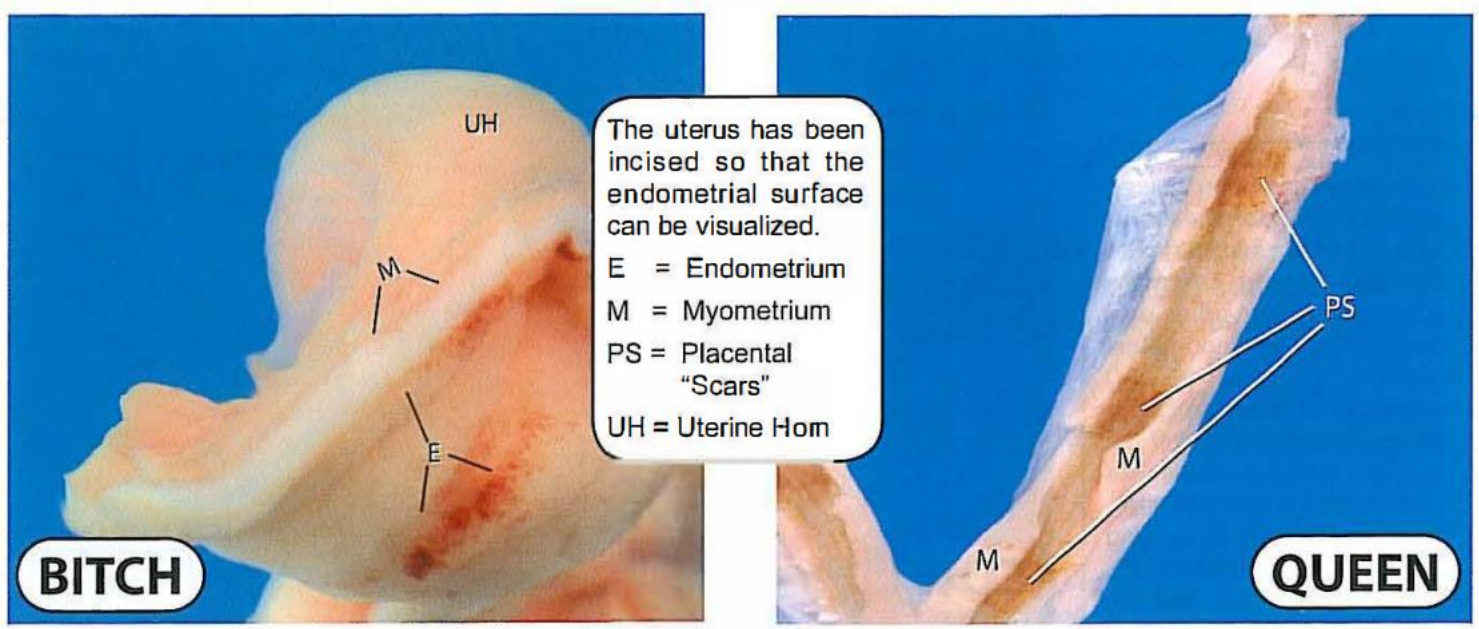
The Uterus

- The uterus has been incised so that the endometrial surface can be visualized.
  - In the cow and the ewe, caruncles (C) can be observed as protrusions from the endometrial surface. Blood vessels (V) are white, cord-like structures located beneath the surface of each caruncle.
  - The endometrium of the sow and mare is characterized as having many endometrial folds (EF).
  - Both the caruncles and the endometrial folds contribute to the maternal placenta if pregnancy occurs



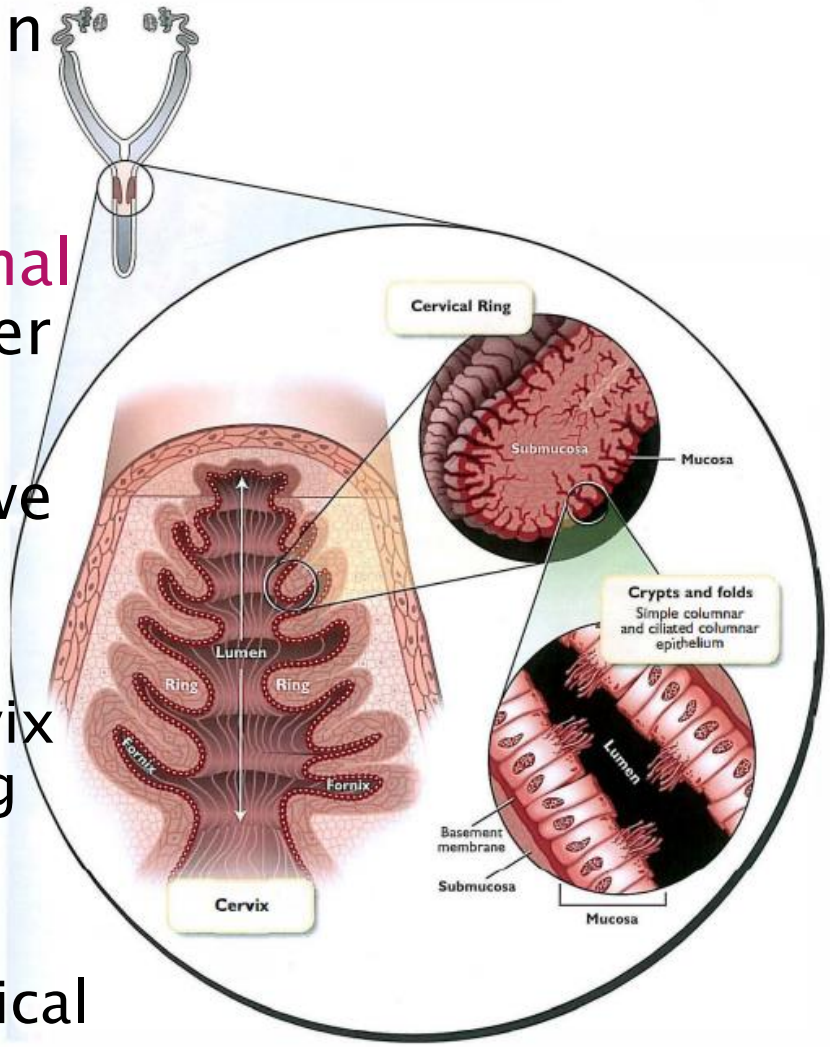
The Uterus

- Placental "scars" in the uterus of the queen represent sites of previous placental attachment. These sites are not true scars that are permanent fibrous replacements of normal tissue.
  - They are useful to wildlife biologists who use them in postmortem evaluation of wild animals to approximate the number of young produced by a female within a certain period of time.



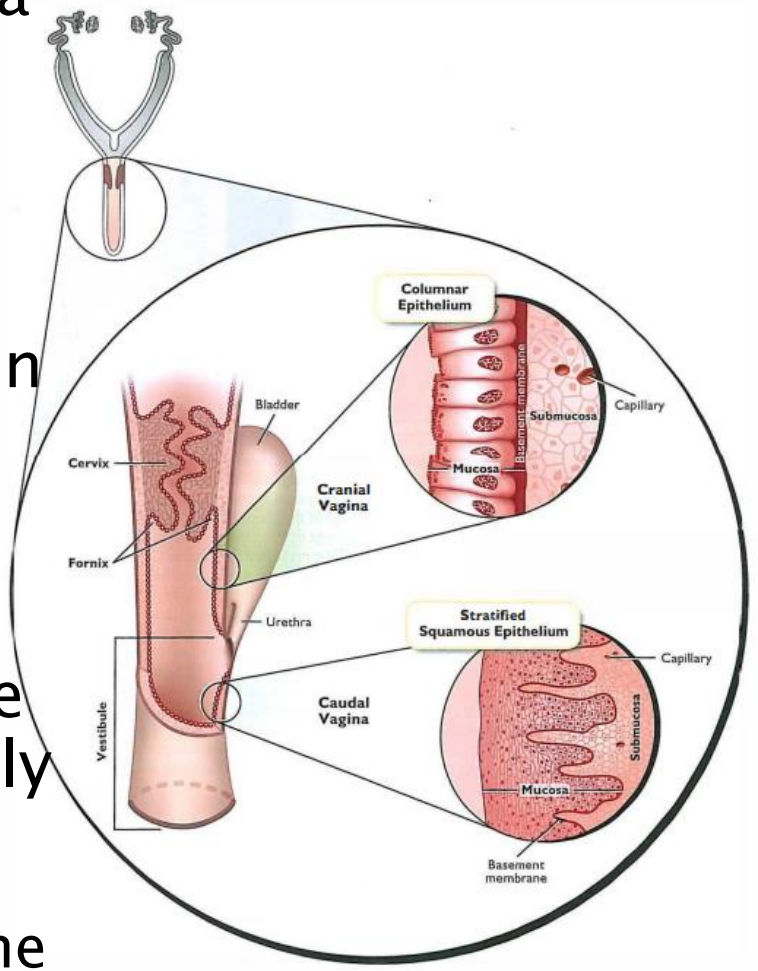
The Cervix

- The cervix is a relatively thick-walled, noncompliant organ that serves as a barrier to sperm transport in the ewe, cow, bitch and queen but not in the sow and mare.
- The cervix also isolates the uterus from the external environment during pregnancy by forming a barrier consisting of highly viscous mucus.
- A primary function of the cervix in the cow and ewe is to produce mucus during estrus.
  - In the sow and mare, a much smaller quantity of mucus is produced. This mucus flows from the cervix toward the exterior and lubricates the vagina during copulation.
  - Foreign material introduced during copulation (including sperm) is flushed out of the tract by cervical mucus.

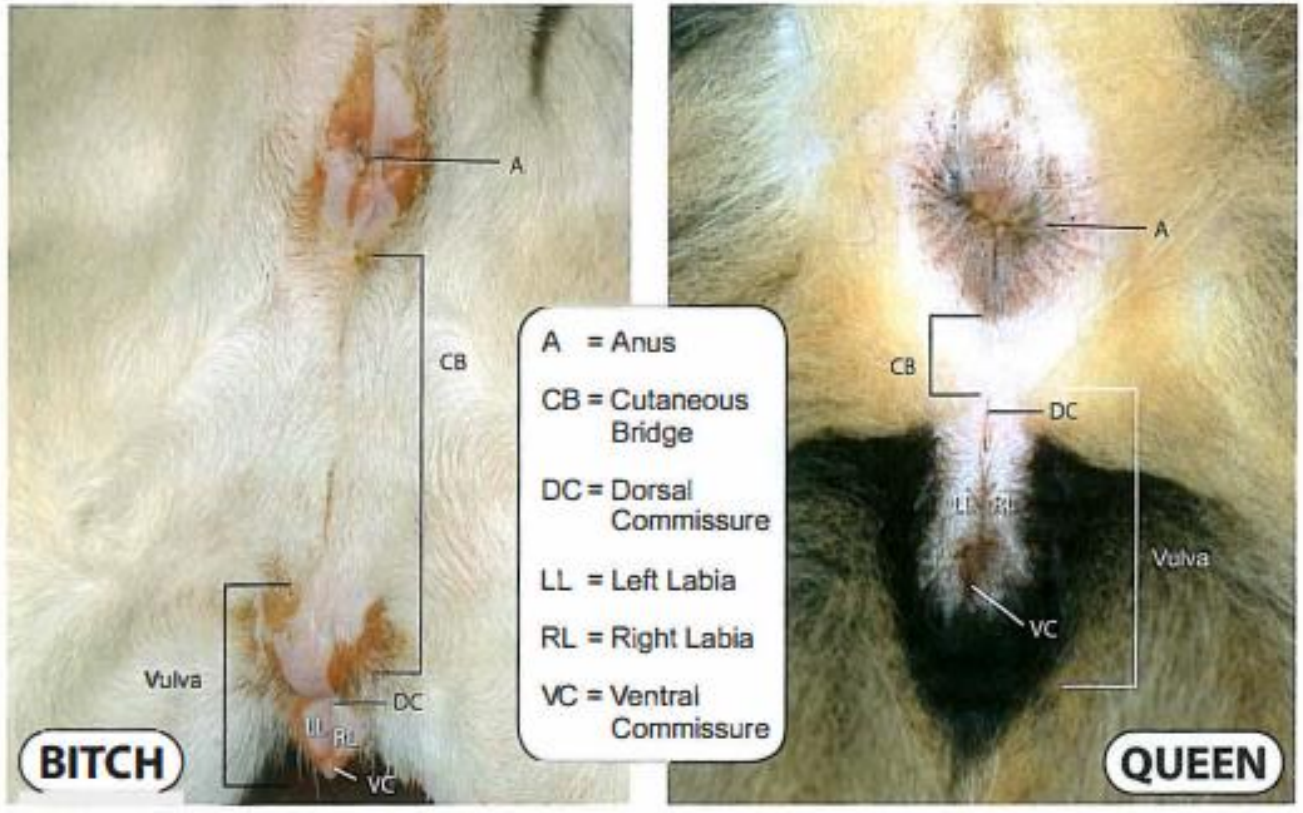


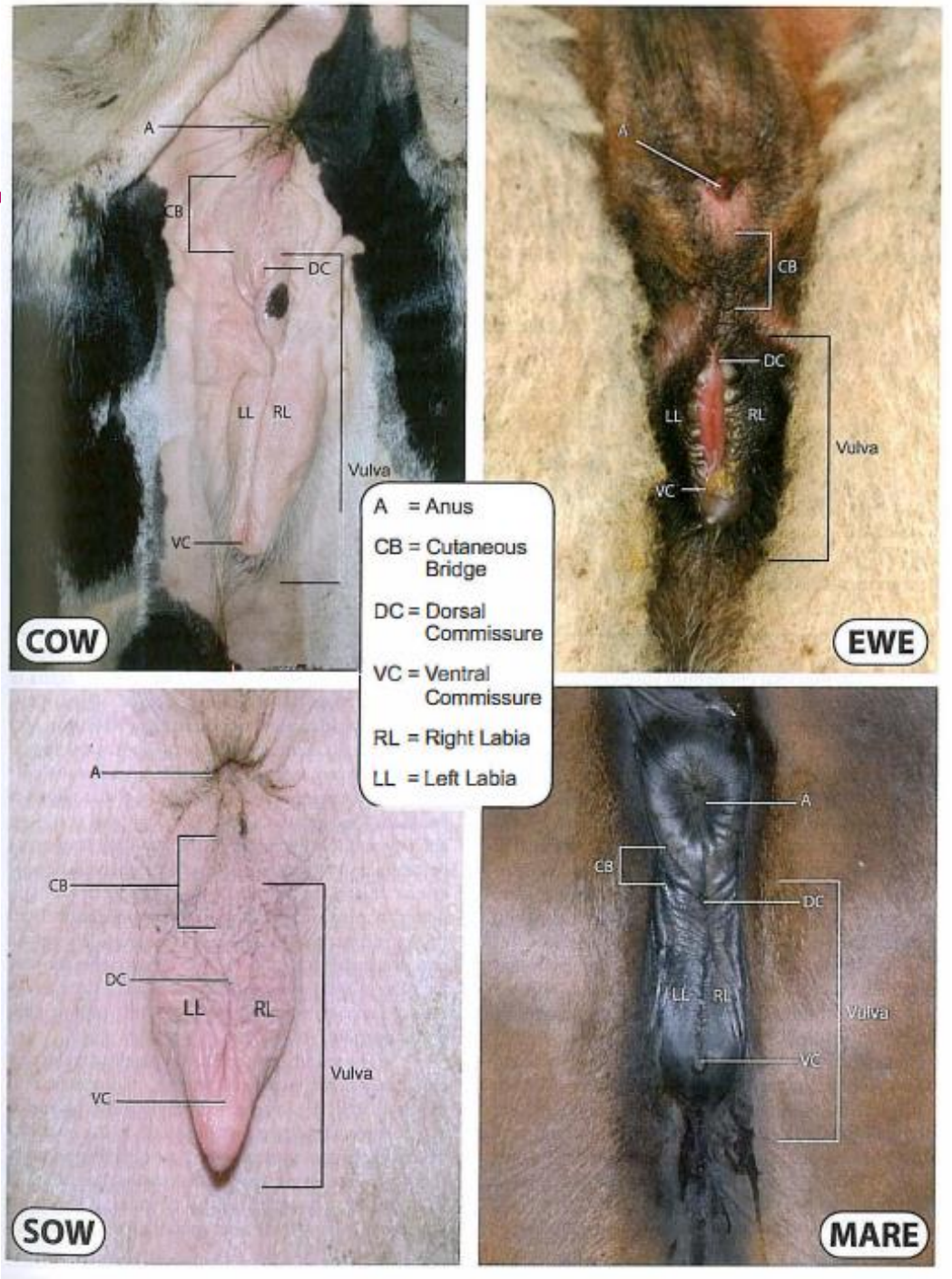
The Vagina

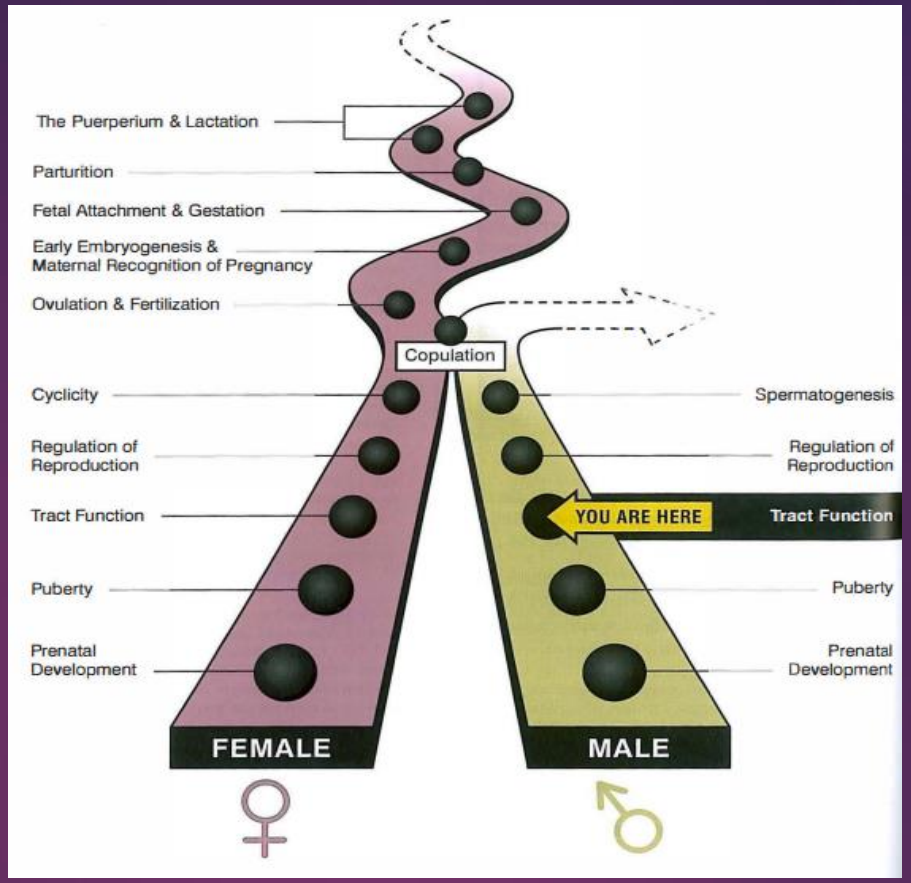
- The primary function of the vagina is to serve as: 1)a copulatory organ, 2)the site for expulsion of urine during micturition 3)a passive birth canal during parturition.
- The luminal epithelium near the cervix (cranial vagina) is generally columnar and highly secretory in nature.
- The caudal vagina is characterized as having stratified squamous epithelium
- During the time of estrogen dominance (estrus), the stratified squamous epithelium thickens dramatically
  - it mechanically protects the vagina during copulation
  - prevents microorganisms from gaining entrance to the vasculature in the submucosa.



The External Genitalia





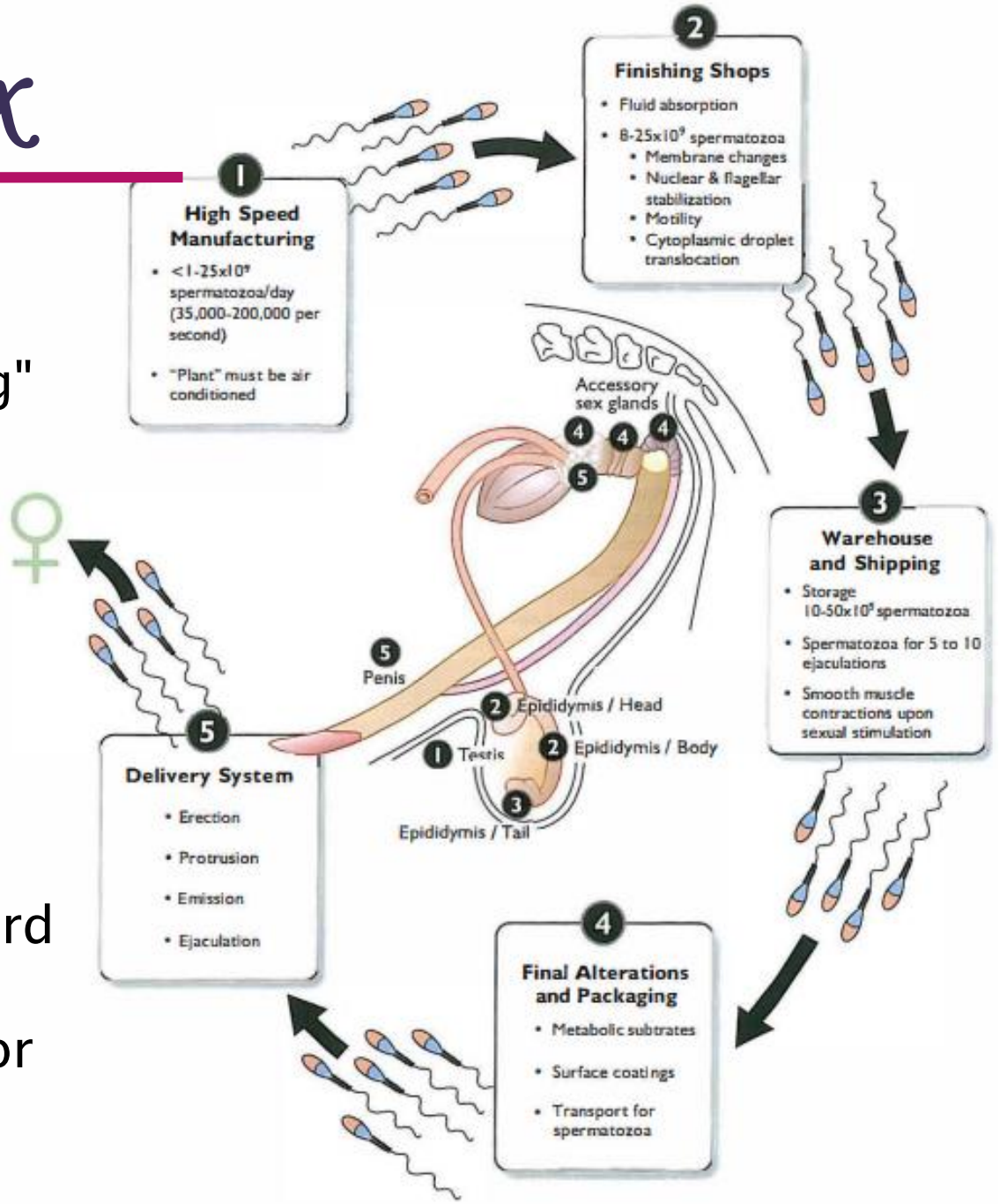


Section III

The Organization and Function of the Male Reproductive Tract

A Manufacturing Complex

- The male reproductive system is analogous to a manufacturing complex.
- The primary products of the "manufacturing" process are fertile spermatozoa.
- Hormones (such as testosterone) and other secretory products (epididymal fluid and seminal plasma) of the male system contribute to the efficiency of the overall manufacturing and delivery process
- The basic components of the male reproductive system are the: 1)spermatic cord 2)scrotum 3)testis 4)excurrent duct system 5)accessory sex glands 6)penis 7)muscles for protrusion, erection and ejaculation



The Spermatic Cord

CM = Cremaster Muscle

DD = Ductus Deferens

HE = Head of Epididymis

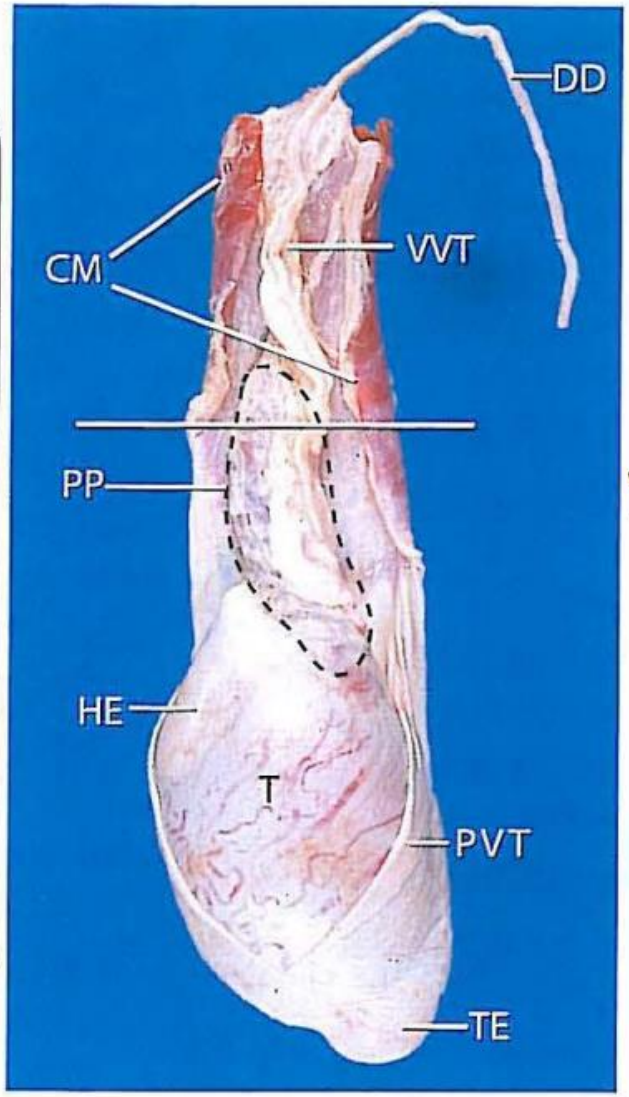
PP = Pampiniform Plexus

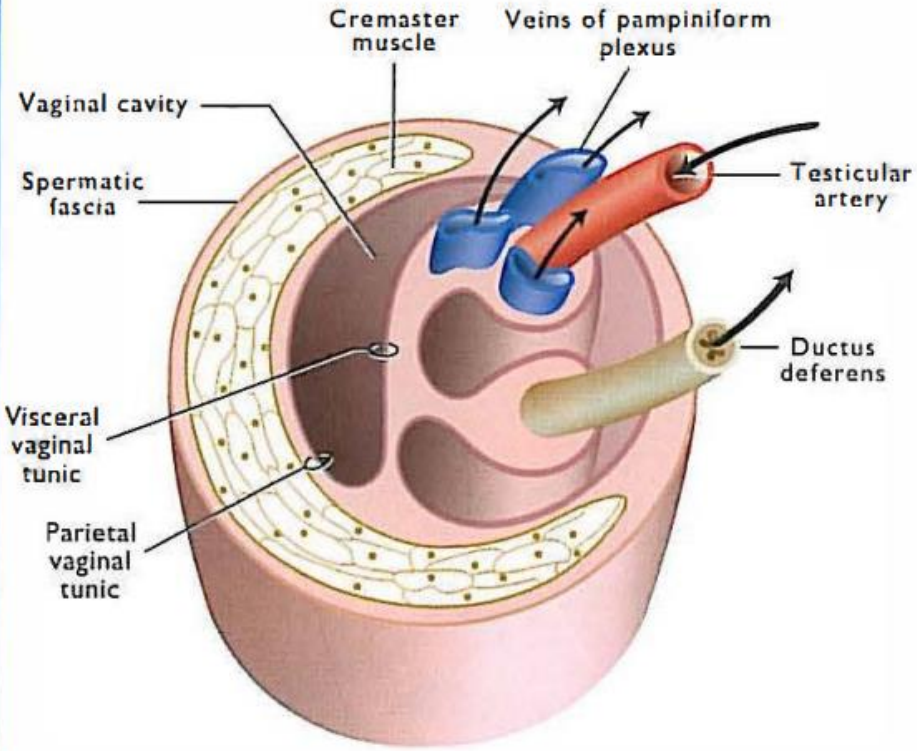
PVT = Parietal Vaginal Tunic

T = Testis

TE = Tail of the Epididymis

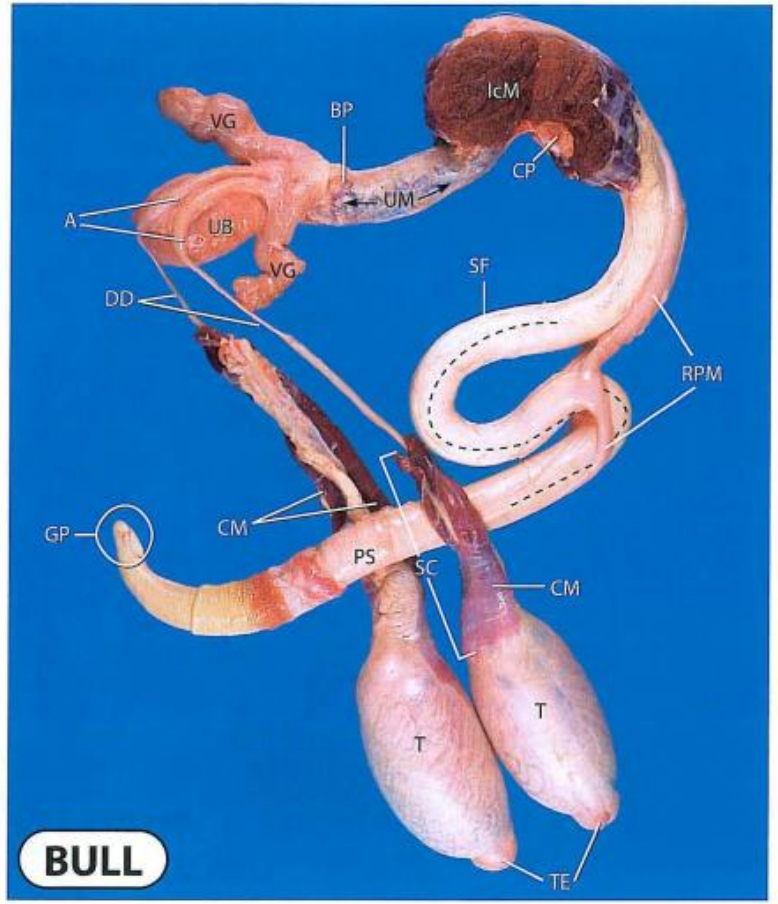
VVT = Visceral Vaginal Tunic



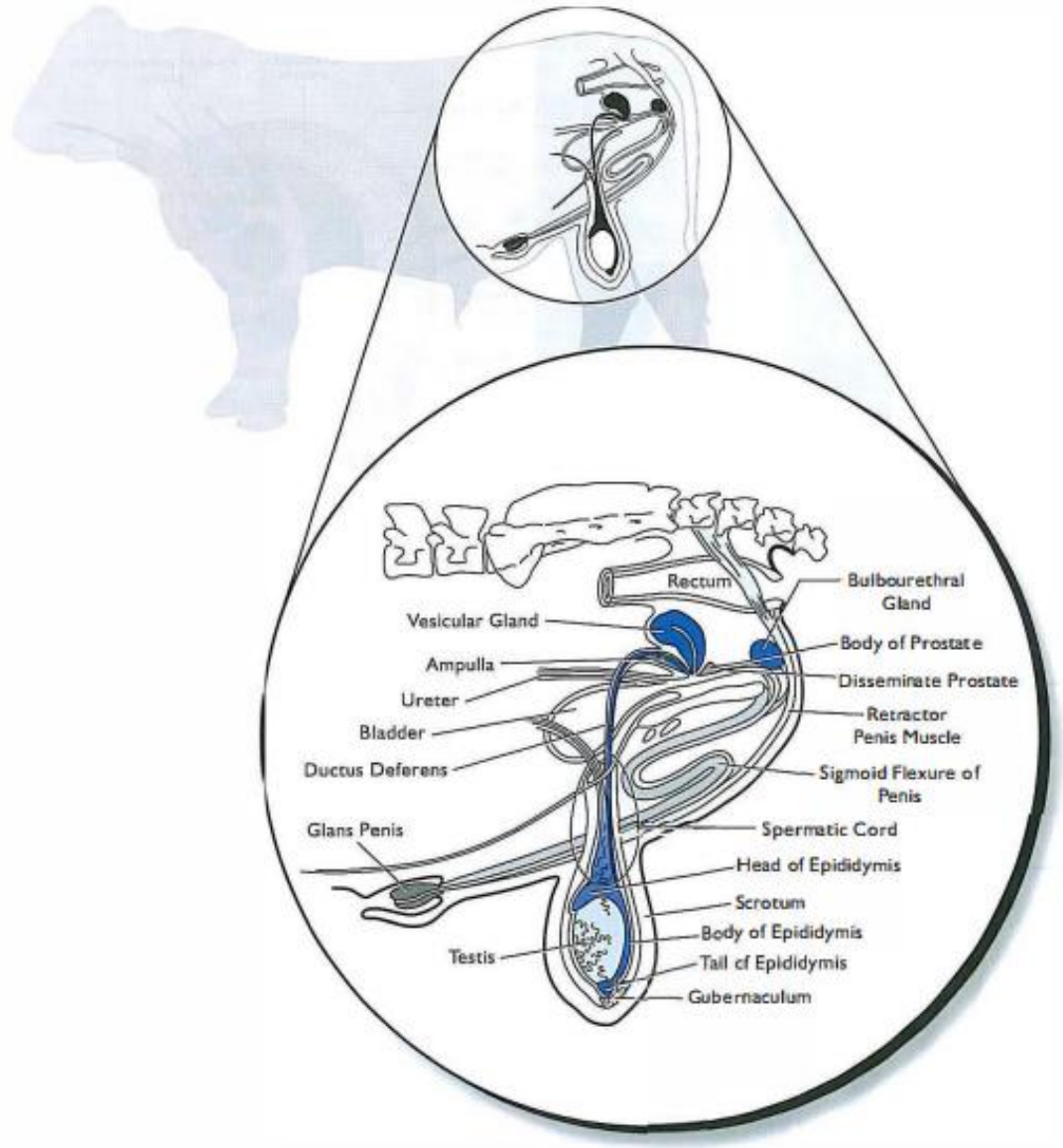


The line across the excised spermatic cord (photo at left) indicates the approximate plane of the cross-sectional schematic. Arrows indicate direction of fluid flow.

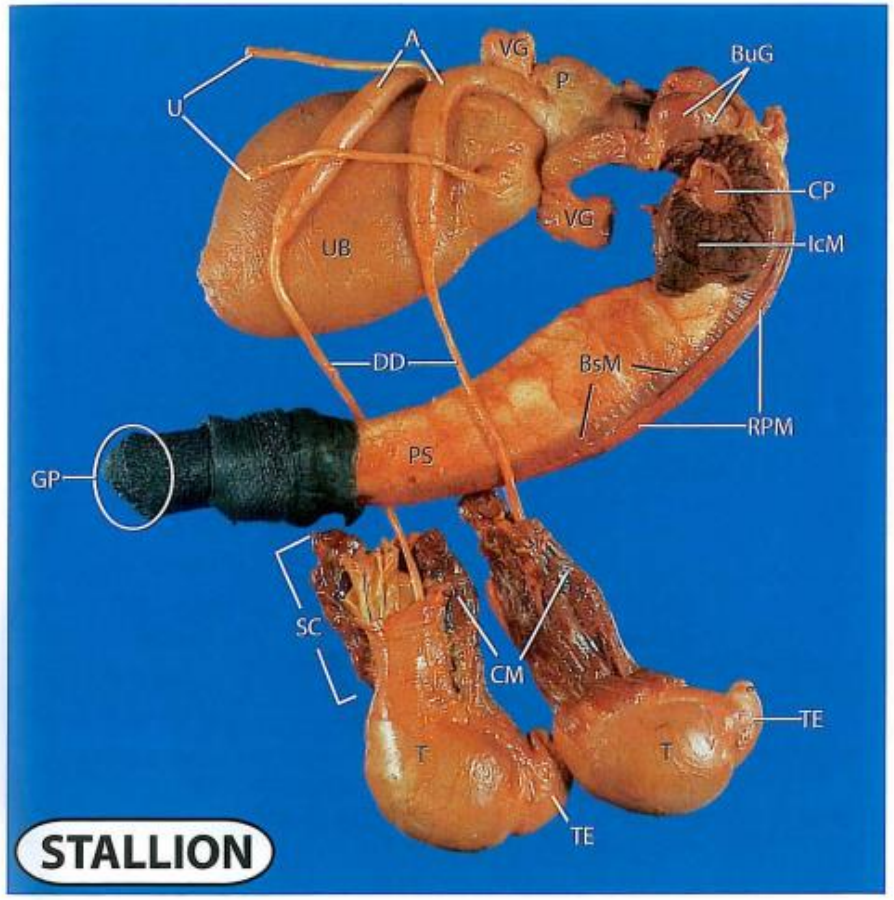
Bull



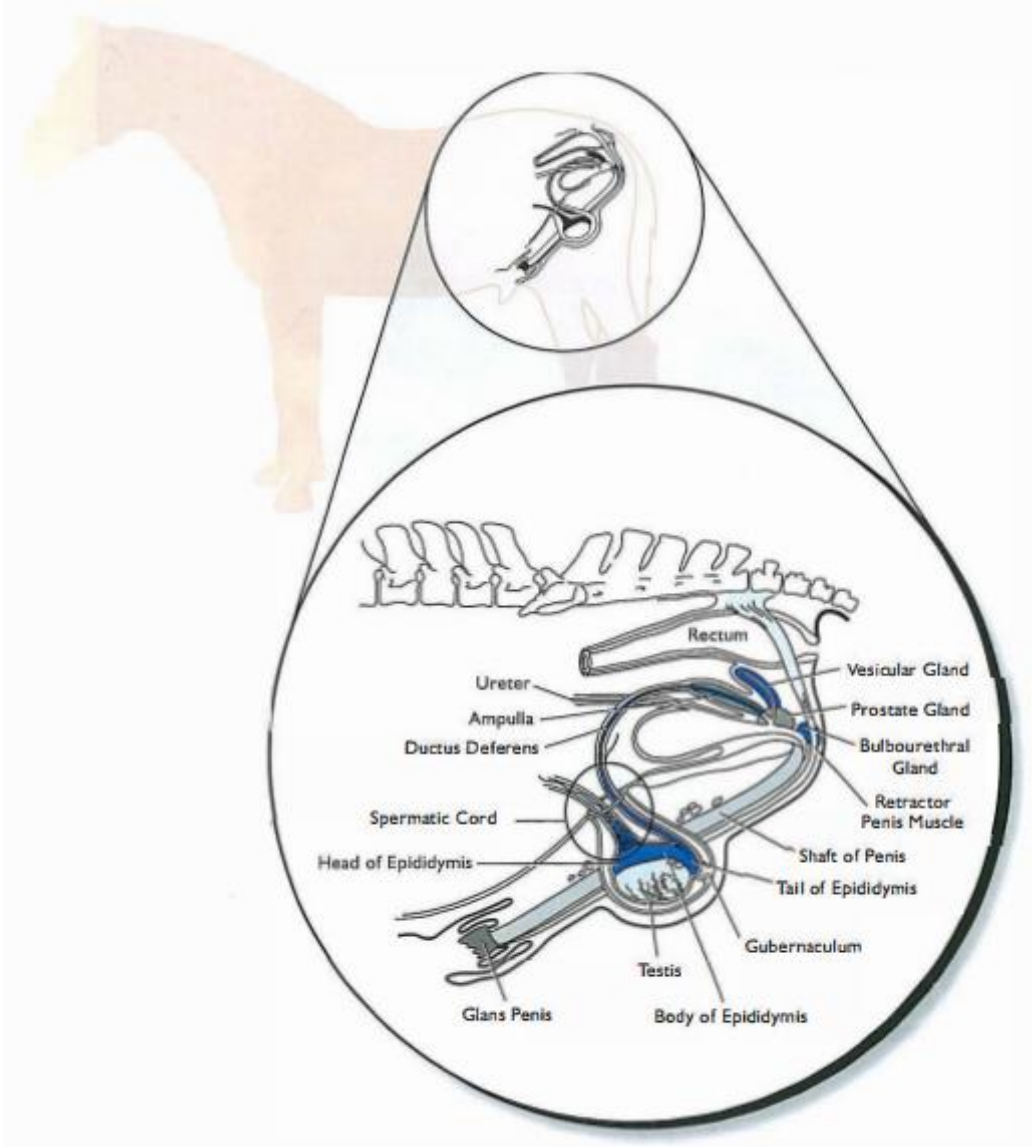
A	= Ampulla	IcM	= Ischiocavernosus Muscle	TE	= Tail of Epididymis
BP	= Body of Prostate	PS	= Penile Shaft	UB	= Urinary Bladder
CM	= Cremaster Muscle	RPM	= Retractor Penis Muscle	UM	= Urethralis Muscle
CP	= Crus Penis	SC	= Spermatic Cord	VG	= Vesicular Gland
DD	= Ductus Deferens	SF	= Sigmoid Flexure		
GP	= Glans Penis	T	= Testis		



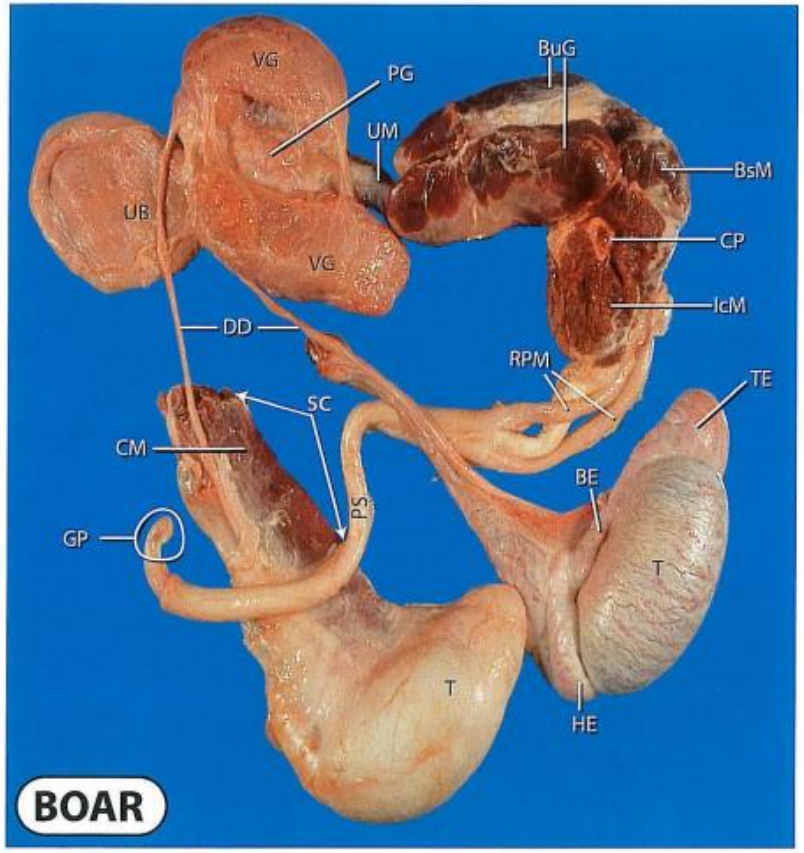
Stallion



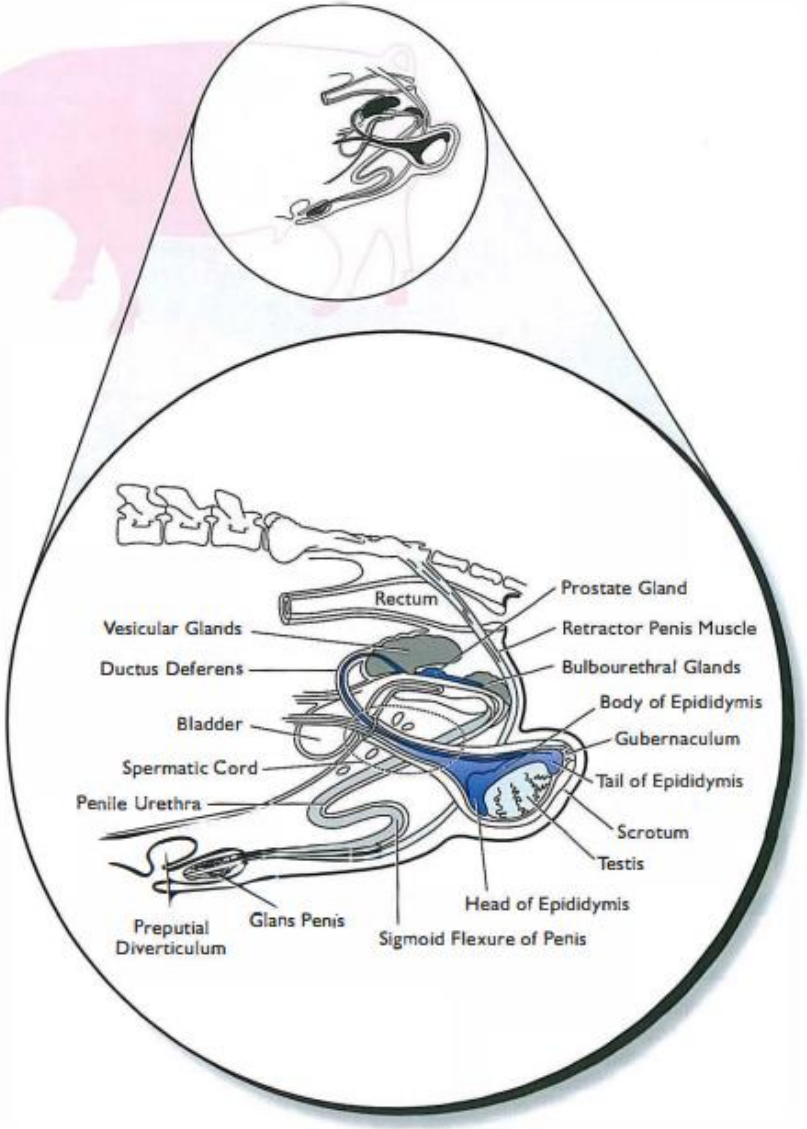
A = Ampulla	GP = Glans Penis	T = Testis
BsM = Bulbospongiosus Muscle	IcM = Ischiocavernosus Muscle	TE = Tail of Epididymis
BuG = Bulbourethral Gland	P = Prostate	U = Ureters
CM = Cremaster Muscle	PS = Penile Shaft	UB = Urinary Bladder
CP = Crus Penis	RPM = Retractor Penis Muscle	VG = Vesicular Gland
DD = Ductus Deferens	SC = Spermatic Cord	



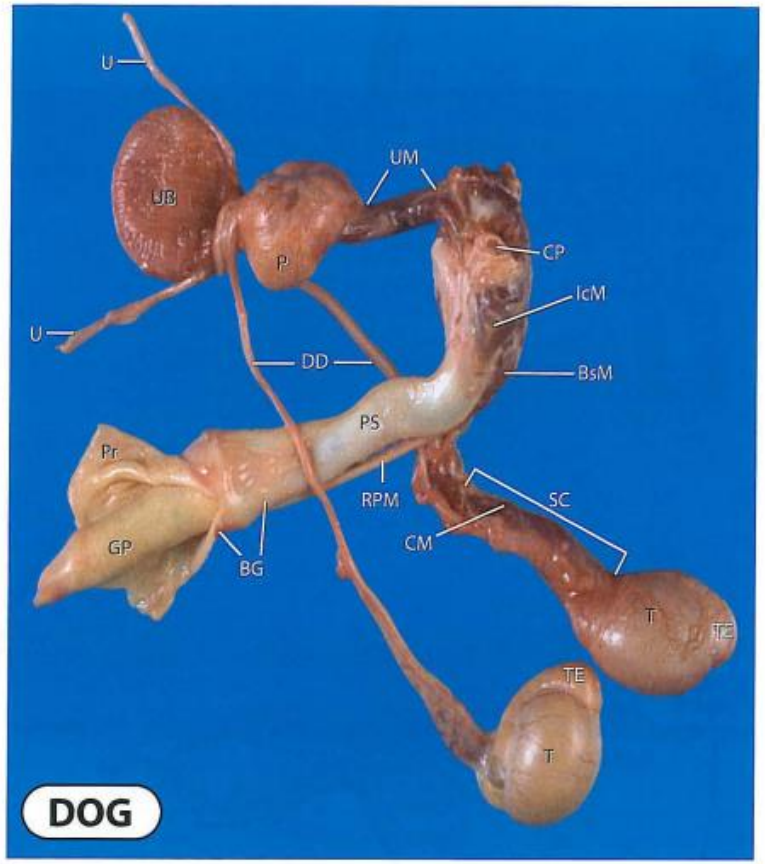
Boar



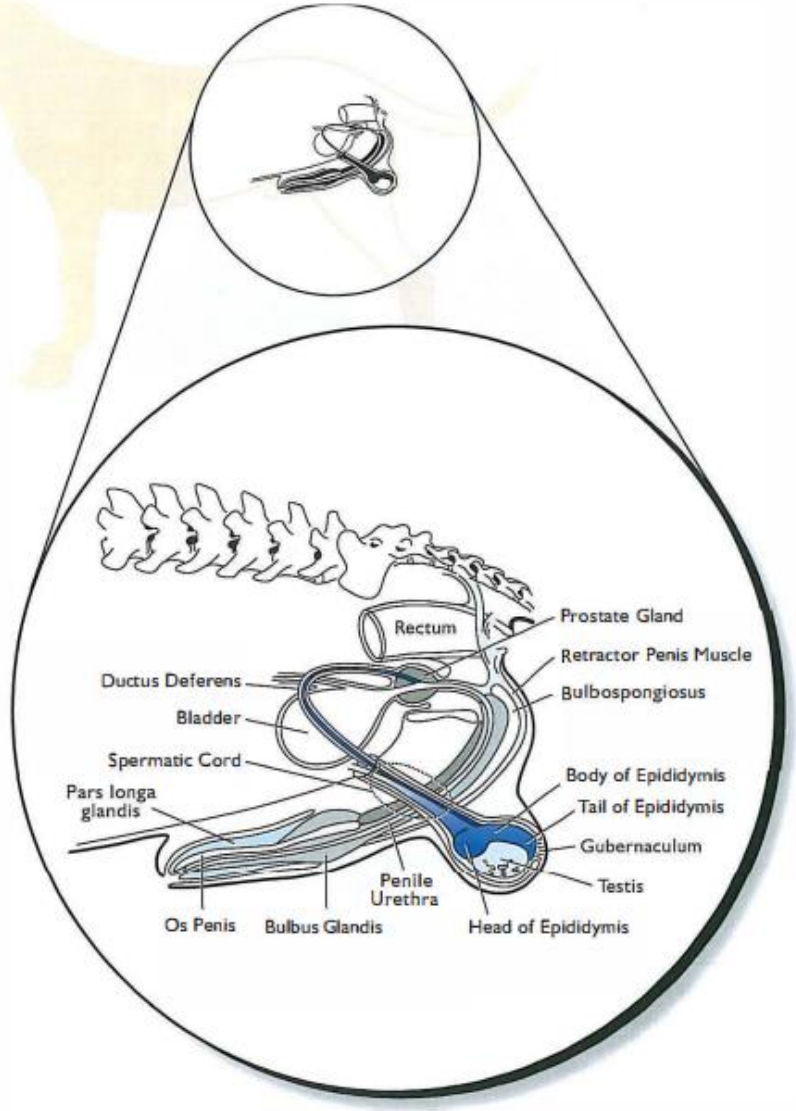
BE = Body of Epididymis	HE = Head of Epididymis	TE = Tail of Epididymis
BsM = Bulbospongiosus Muscle	IcM = Ischiocavernosus Muscle	UB = Urinary Bladder
BuG = Bulbourethral Gland	PG = Prostate Gland	UM = Urethralis Muscle
CM = Cremaster Muscle	PS = Penile Shaft	VG = Vesicular Gland
CP = Crus Penis	RPM = Retractor Penis Muscle	
DD = Ductus Deferens	SC = Spermatic Cord	
GP = Glans Penis	T = Testis (left T-parietal vaginal tunic intact; right T-parietal vaginal tunic removed)	



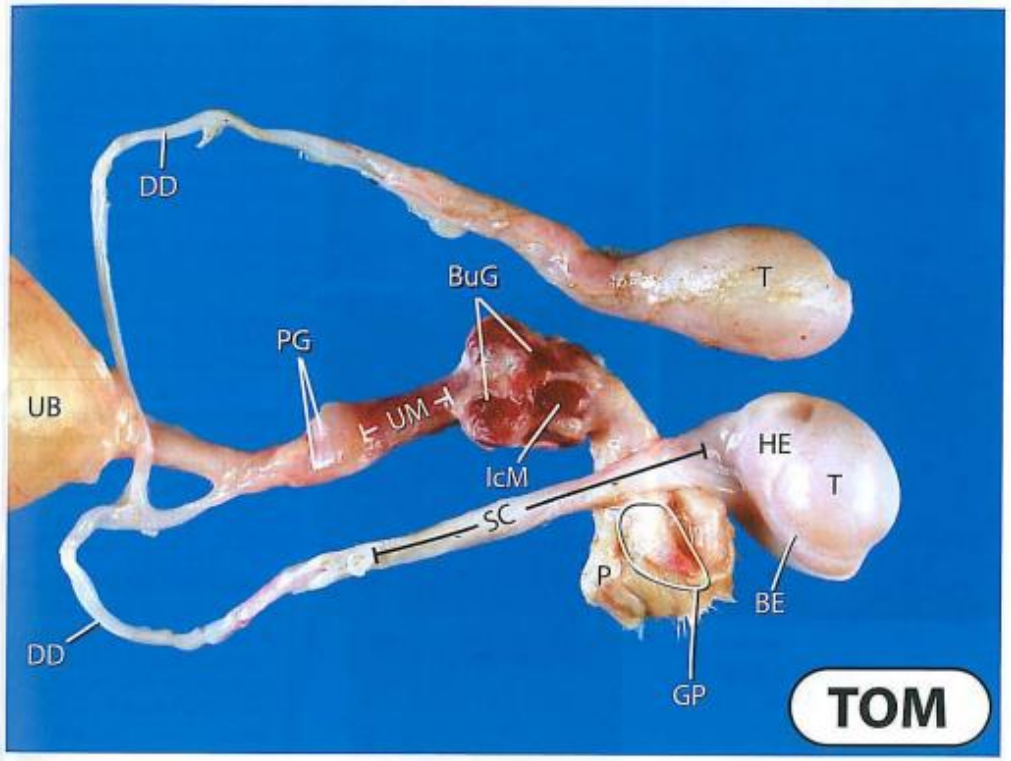
Dog



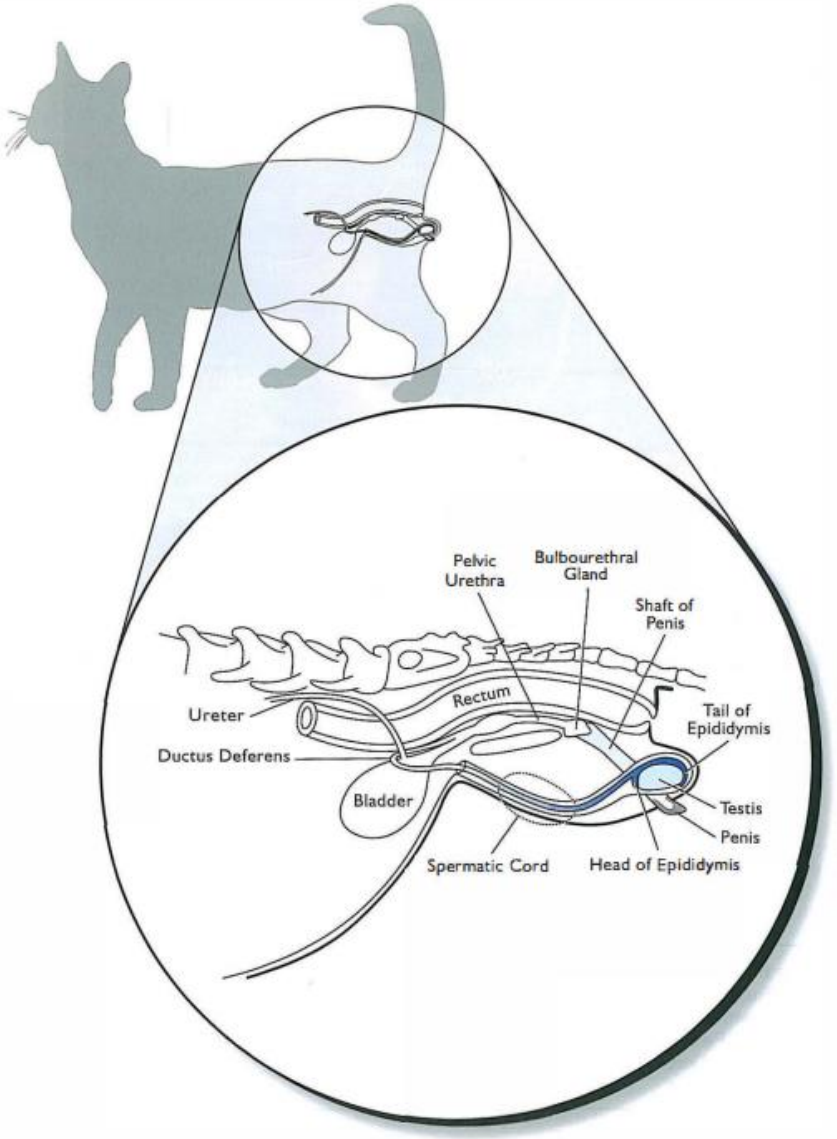
BG = Bulbus Glandis
BsM = Bulbospongiosus Muscle
CM = Cremaster Muscle
CP = Crus Penis
DD = Ductus Deferens
GP = Glans Penis
IcM = Ischiocavernosus Muscle
P = Prostate Gland
PS = Penile Shaft
PR = Prepuce
RPM = Retractor Penis Muscle
SC = Spermatic Cord
T = Testis
TE = Tail of Epididymis
U = Ureter
UB = Urinary Bladder
UM = Urethralis Muscle



Tom



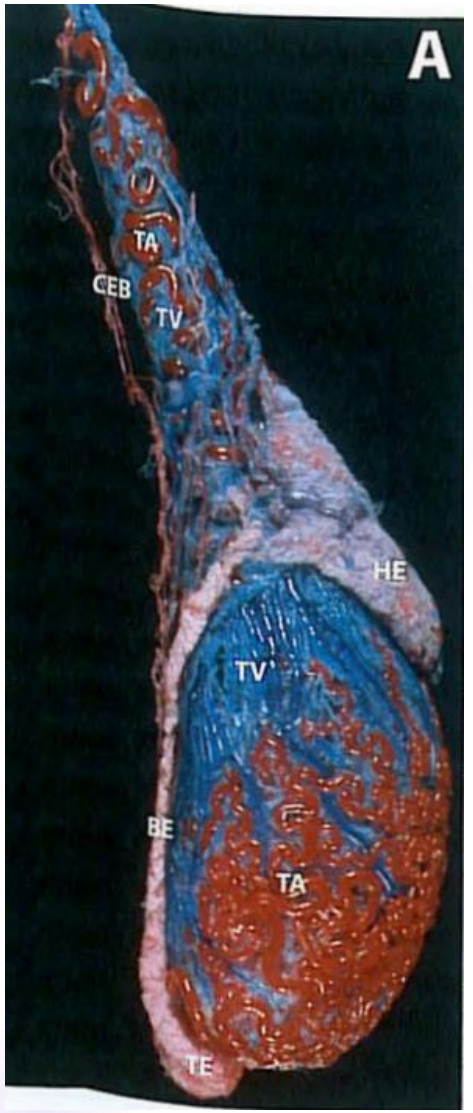
BE = Body of Epididymis	HE = Head of Epididymis	SC = Spermatic Cord
BuG = Bulbourethral Glands	IcM = Ischiocavernosus Muscle	T = Testis
DD = Ductus Deferens	P = Prepuce	U = Urinary Bladder
GP = Glans Penis	PG = Prostate Gland	UM = Urethralis Muscle



The pampiniform plexus

III

- The testicular artery (TA) is highly convoluted and passes through the spermatic cord and surrounds the testis in the ventromedial area.
- In the spermatic cord, the testicular veins (TV) are in close proximity lo the torturous testicular artery. The testicular veins (TV) seen on the surface of the testicle return venous blood to the spermatic cord.
  - A branch of the testicular artery, the caudal epididymal branch (CEB) can be observed. The head of the epididymis (HE), body of the epididymis (BE) and tail of the epididymis (TE) can be seen.

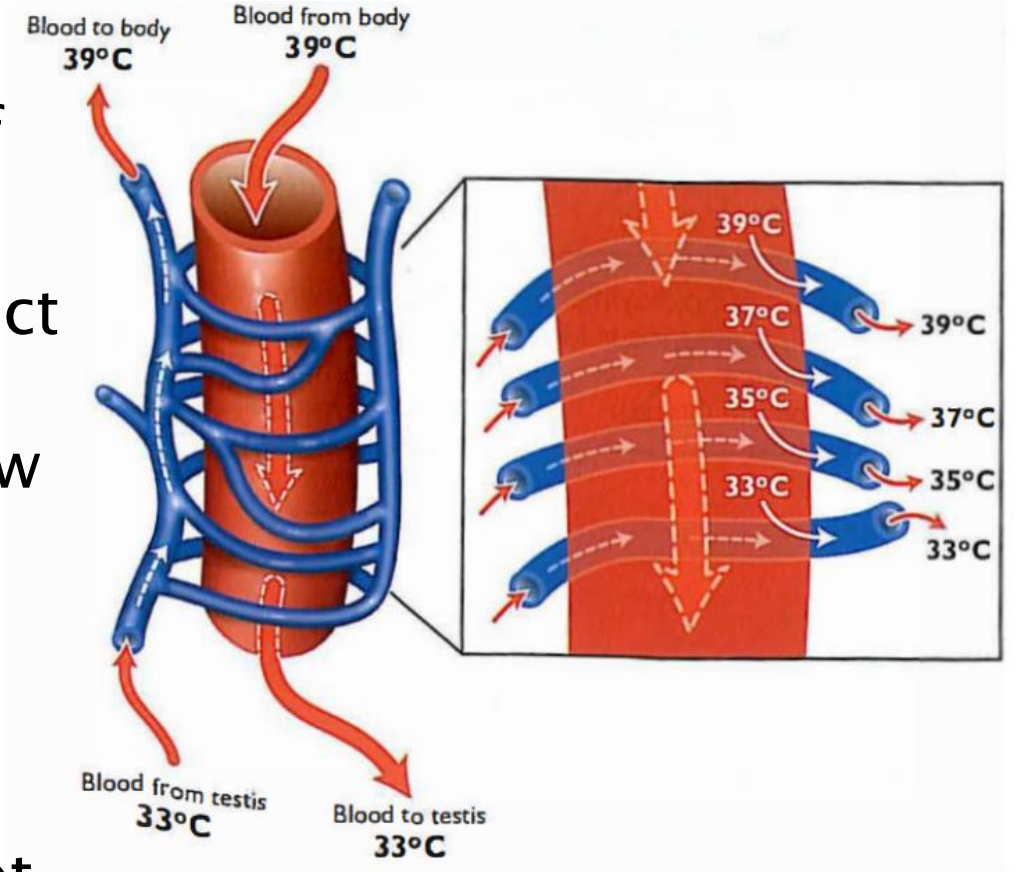


The pampiniform plexus

- An enlarged view of a portion of the vascular cone.
- The highly convoluted testicular artery (TA) has an intimate relationship with the veins of the pampiniform plexus (PP).
- A highly enlarged photograph showing the intimate relationship of the pampiniform plexus with the testicular artery (TA).
- Notice the finger-like "wrappings" (arrows) of the pampiniform plexus surrounding the testicular artery (TA). This intimate relationship provides the anatomical basis for the countercurrent heat exchanger.

The pampiniform plexus

- Heat from the warm (39°C) arterial blood from the body is transferred to the cooler (33°C) venous blood leaving the surface of the testes.
- This venous blood has been cooled by direct heat loss from the testicular veins through the skin of the scrotum. Maintenance of low testicular temperature is obligatory for spermatogenesis in domestic animals and man.
- Disruption or modification of this cooling mechanism will severely compromise, if not completely suppress, spermatogenesis.

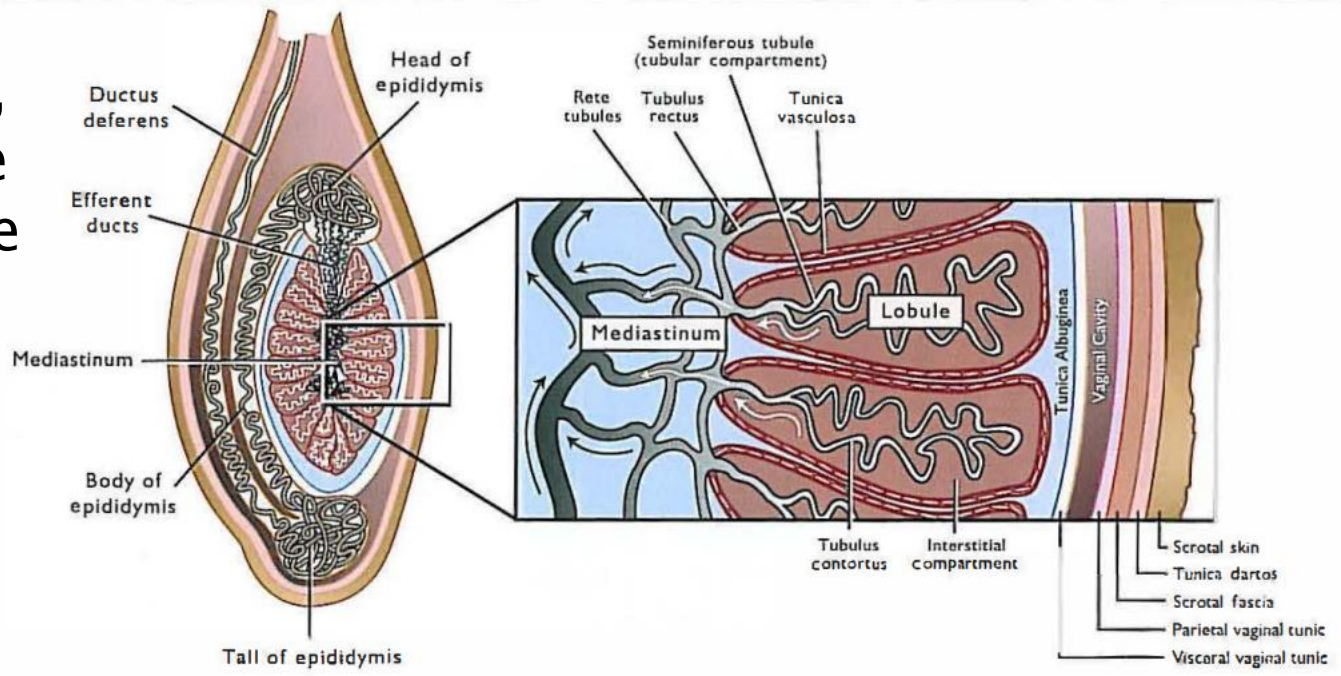


The Testes

- The testes are paired organs that vary considerably in size and shape among species.
- They are considered the primary reproductive organs in the male because they produce both spermatozoa and the androgen testosterone.
- In addition, they produce inhibin, estrogens and a variety of proteins believed to be important to spermatozoal function.
- They also produce fluid that originates primarily from the seminiferous tubules. This fluid serves as a vehicle in which spermatozoa are suspended and facilitates their removal from the testes. The fluid produced by the testes (sometimes called rete fluid) also contains products synthesized by the Sertoli cells.

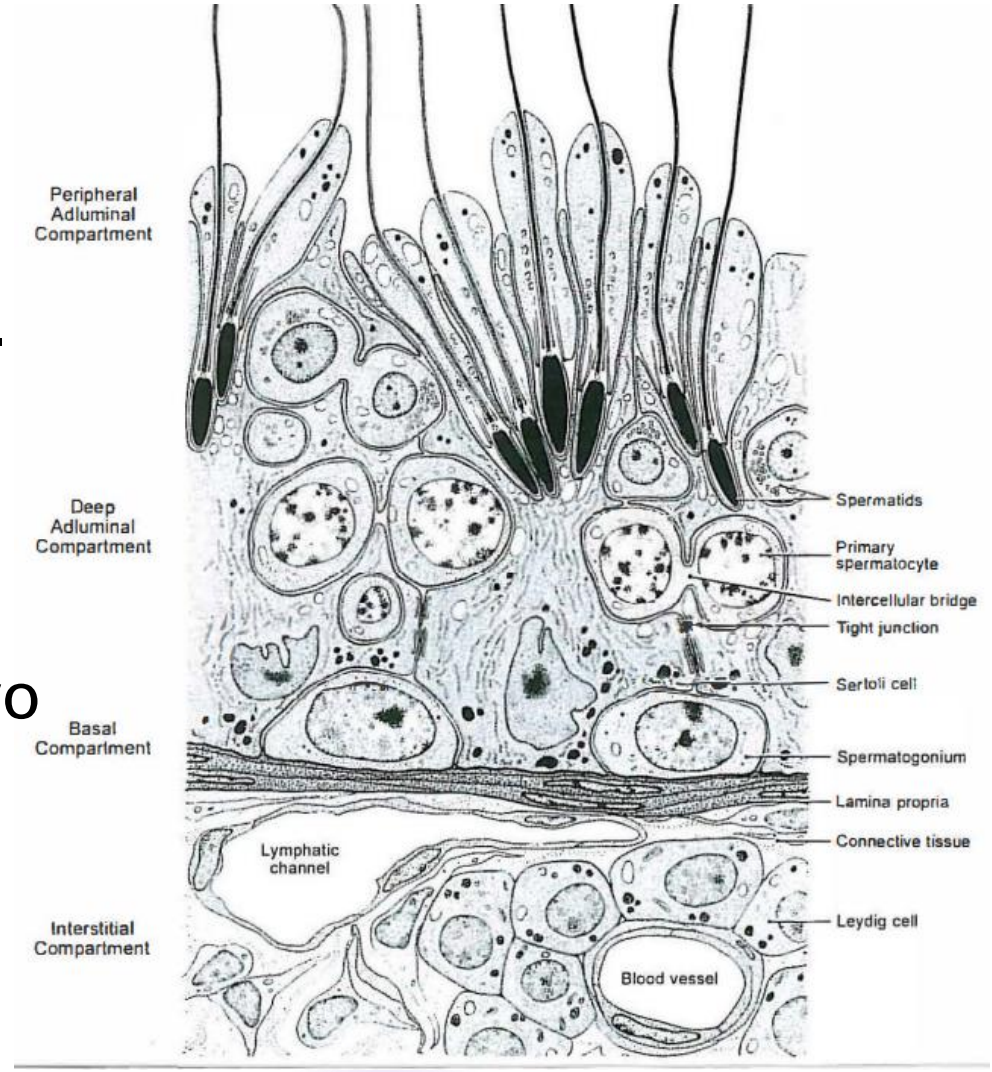
The Testes

- The word parenchyma refers to the specific cellular mass of a gland or organ that is supported by a connective tissue network
  - Tubular parenchyma: seminiferous tubules and all of the cells and material inside them.
  - Interstitial parenchyma: consists of all cells and materials outside the seminiferous tubules, such as blood vessels, connective tissue, lymphatics, nerves and the interstitial cells of Leydig, that produce testosterone.



The Testes

- The seminiferous tubule is composed of a basement membrane and a layer of seminiferous epithelium (also called the germinal epithelium). The tubule is surrounded by contractile peritubular cells. Their contraction and the flow of fluid secreted by Sertoli cells allows newly formed spermatozoa to move into the rete tubules .
- The seminiferous epithelium consists of two major regions known as the basal compartment and the adluminal compartment. Sertoli cells are anchored to the basement membrane and surround the developing population of germ cells



Seminiferous tubule

Peripheral Adluminal Compartment

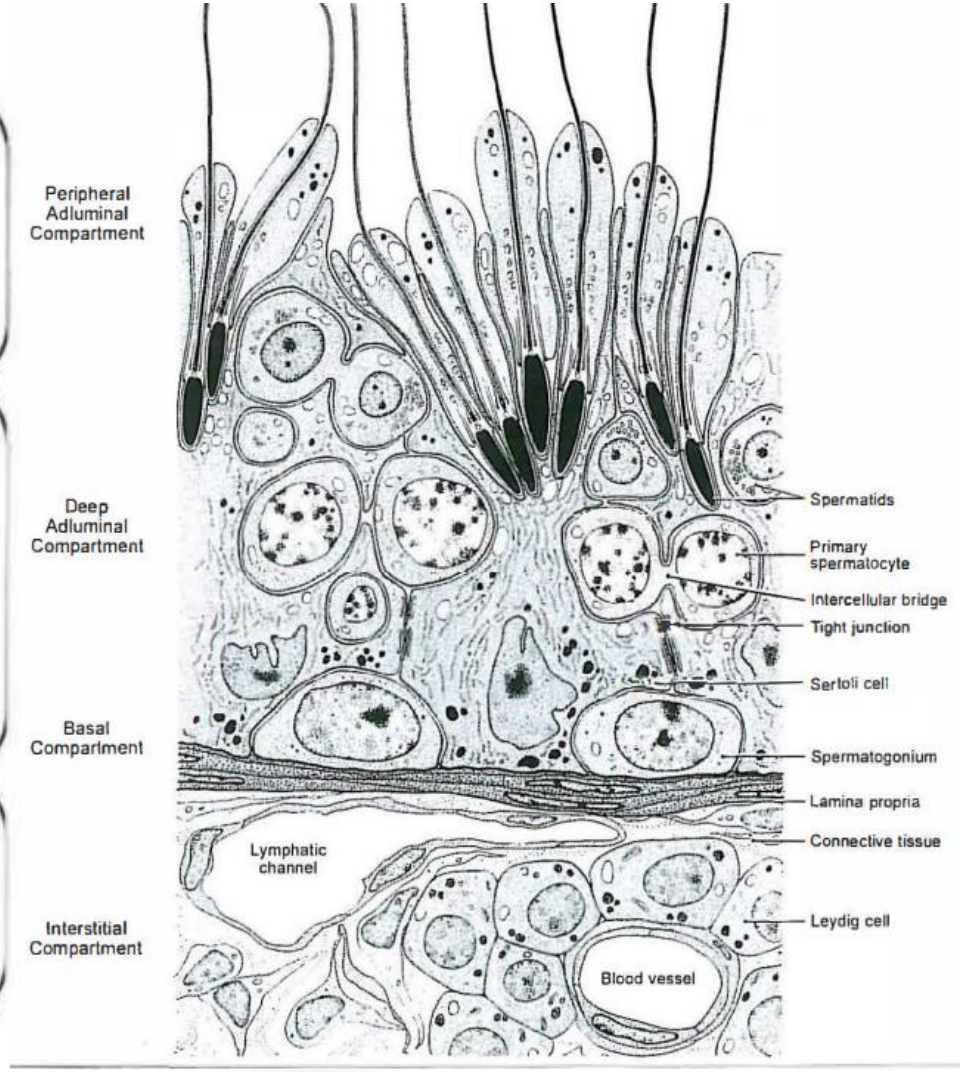
During elongation of the spermatid nucleus, the spermatids are repositioned by the Sertoli cells to become imbedded within long pockets in the cytoplasm of an individual Sertoli cell. When released as a spermatozoon, a major portion of the cytoplasm of each spermatid remains as a residual body (cytoplasmic droplet) within a pocket of the Sertoli cell cytoplasm.

Deep Adluminal Compartment

The primary spermatocytes are moved from the basal compartment through the tight junctions between adjacent Sertoli cells into the adluminal compartment where they eventually divide to form secondary spermatocytes (not shown) and spherical spermatids. The spermatogonia, primary spermatocytes, secondary spermatocytes and spherical spermatids all develop in the space between two or more Sertoli cells and are in contact with them. Note the intracellular bridges between adjacent germ cells in the same cohort or generation.

Basal Compartment

Formation of spermatozoa in the seminiferous epithelium starts near the basement membrane. Here a spermatogonium divides to form other spermatogonia and, ultimately, primary spermatocytes. (From Amann, *J.Dairy Sci.* Vol. 66, No. 12, 1983)



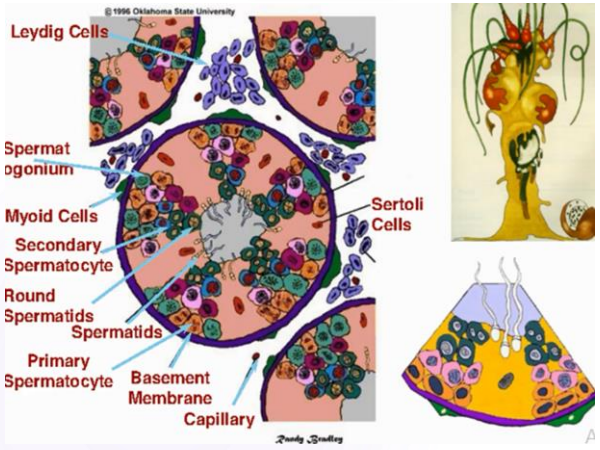
Seminiferous tubule

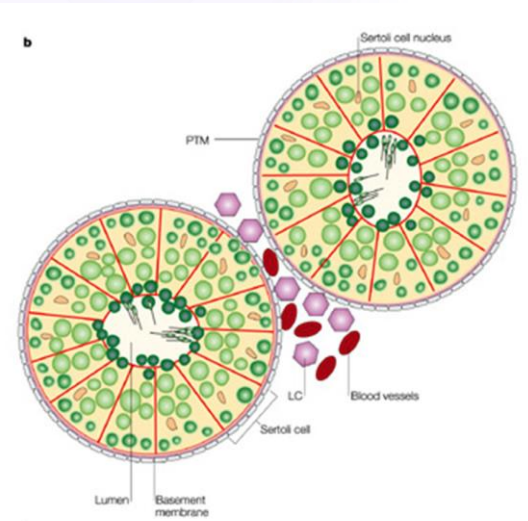
- Because Sertoli cells possess receptors to different hormones (protein and steroid), they have the capability of producing a variety of substances
  - Androgen binding protein (ABP), a testosterone transport protein;
  - Sulfated glycoproteins (SGP) 1 and 2,
    - fertility acquisition (SGP-1)
    - providing a detergent effect that allows cells and fluids to move through the tubular network of the testis (SGP-2);
  - Transferrin, an iron transport protein believed to be required for successful spermatogenesis
  - Inhibin, as in the female, a suppressor of FSH.

Blood-Testis Barrier

III

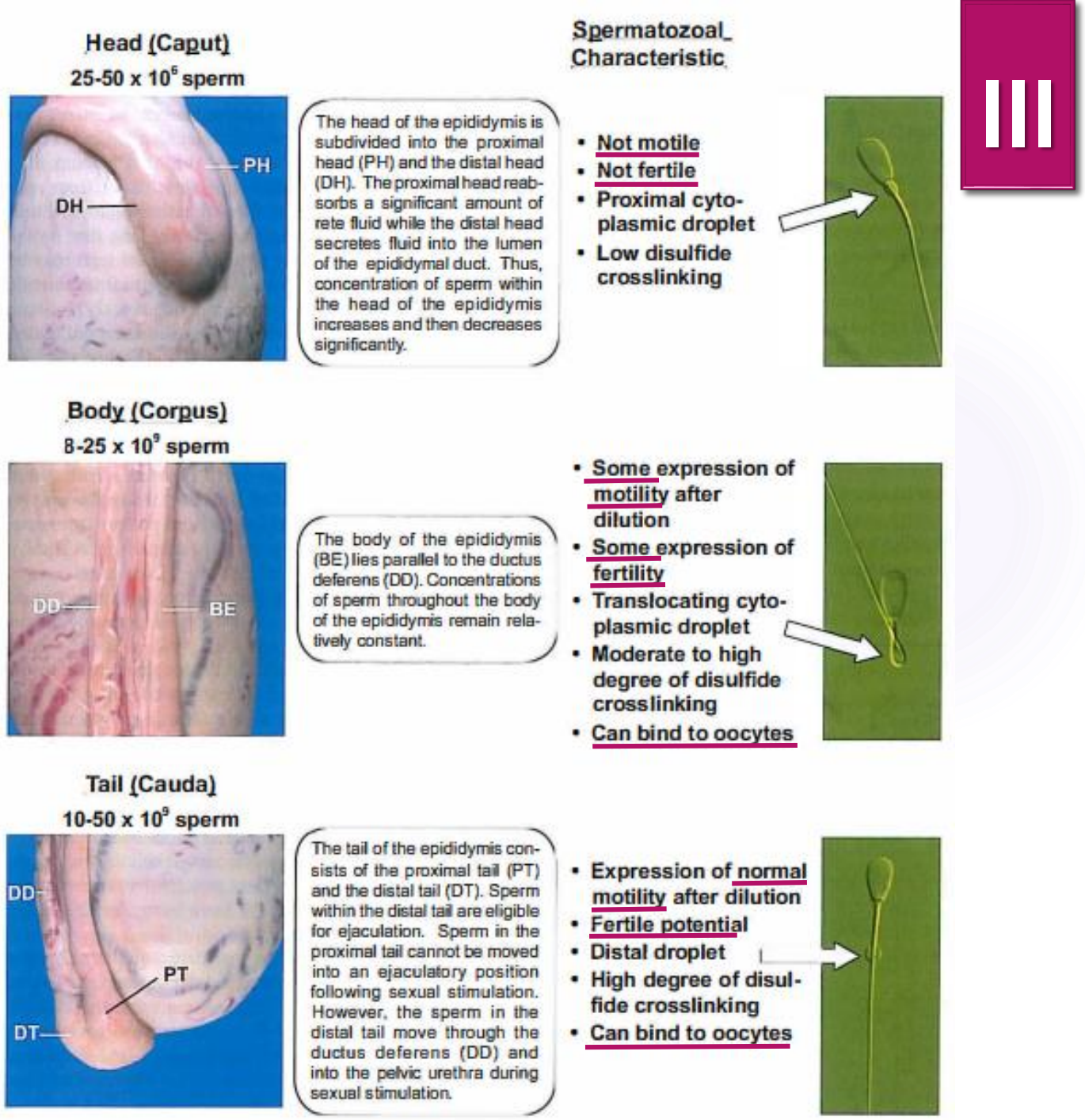
- Adjacent Sertoli cells are tightly attached to each other by tight junctions. The peritubular cells surrounding the seminiferous tubule and the Sertoli cell junctional complexes form the blood-testis barrier (BTB).
  - The primary purpose is to prevent autoimmune reactions from destroying the developing germ cells. The peritubular layer exclude the immune cells (macrophages and lymphocytes) and immunoglobulins (antibodies) from the adluminal compartment. these molecules would recognize the developing germinal elements as foreign because they are undergoing meiosis so they generate immunologic response.
  - In addition to forming the blood-testis barrier, the Sertoli cell junctional complexes provide a type of control for transportation of materials i.e. entering and, at least in part, leaving the adluminal compartment.





Epididymis

- The function of the epididymis is to provide the environment for final maturation of spermatozoa, resulting in acquisition of motility and potential fertility.
- The epididymis also serves as a storage reservoir for spermatozoa. Epididymal function is androgen dependent.



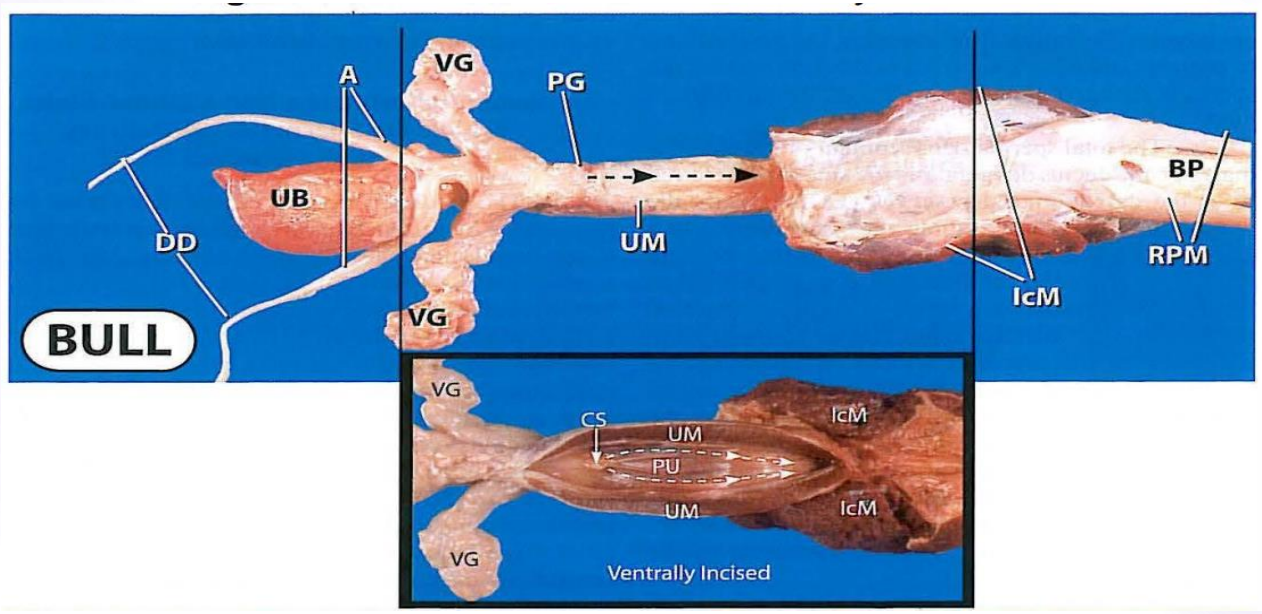
Accessory Sex Glands

III

- The epididymis and accessory sex glands are responsible for production of secretions that contribute to the liquid, noncellular portion of semen known as seminal plasma.
- Seminal plasma is not required for fertility, but is important in natural insemination where a fluid vehicle for delivery of the sperm is needed.
- Spermatozoa that are removed from the tail of the epididymis are equally as fertile as those that are ejaculated.
- In some species (the boar and stallion), the seminal plasma possesses special coagulation properties that plug the female reproductive tract and minimize loss of spermatozoa following copulation and ejaculation.
- The accessory sex glands secrete their products into the lumen of the pelvic urethra.

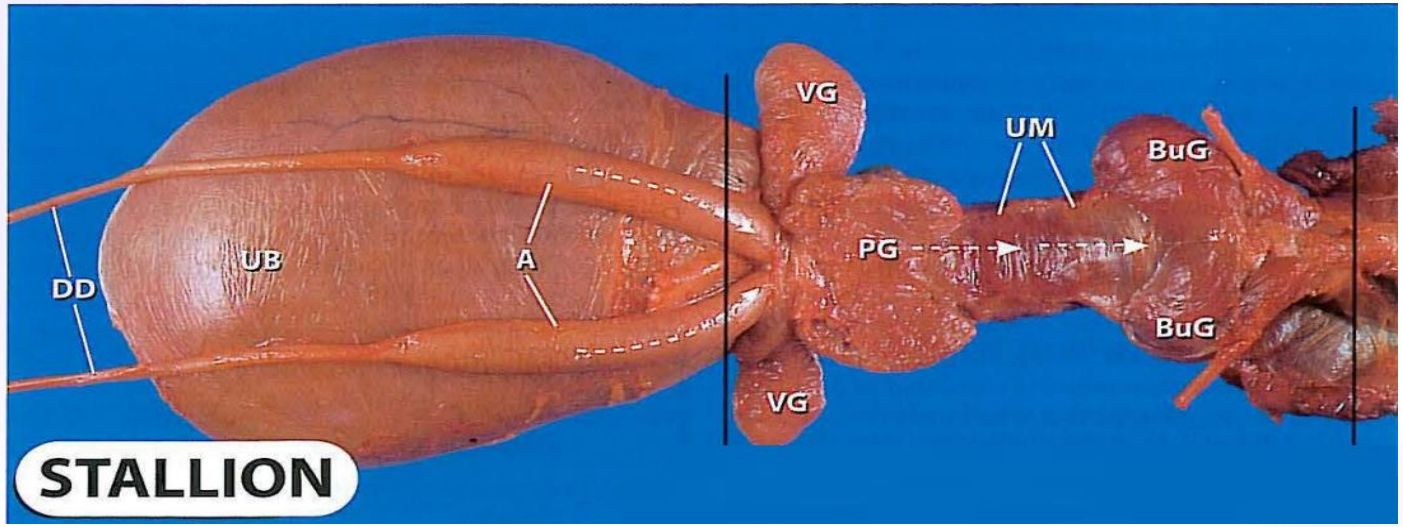
Accessory Sex Glands

- The **ampullae** are enlargements of the ductus deferens that open directly into the pelvic urethra. The enlargement is the result of a dramatic increase in the mucosa within the ampulla.
- The **vesicular glands** (ex. seminal vesicles) are paired glands that are dorsocranial to the pelvic urethra. In bulls and boars the vesicular gland contributes to a large proportion of the ejaculate volume.



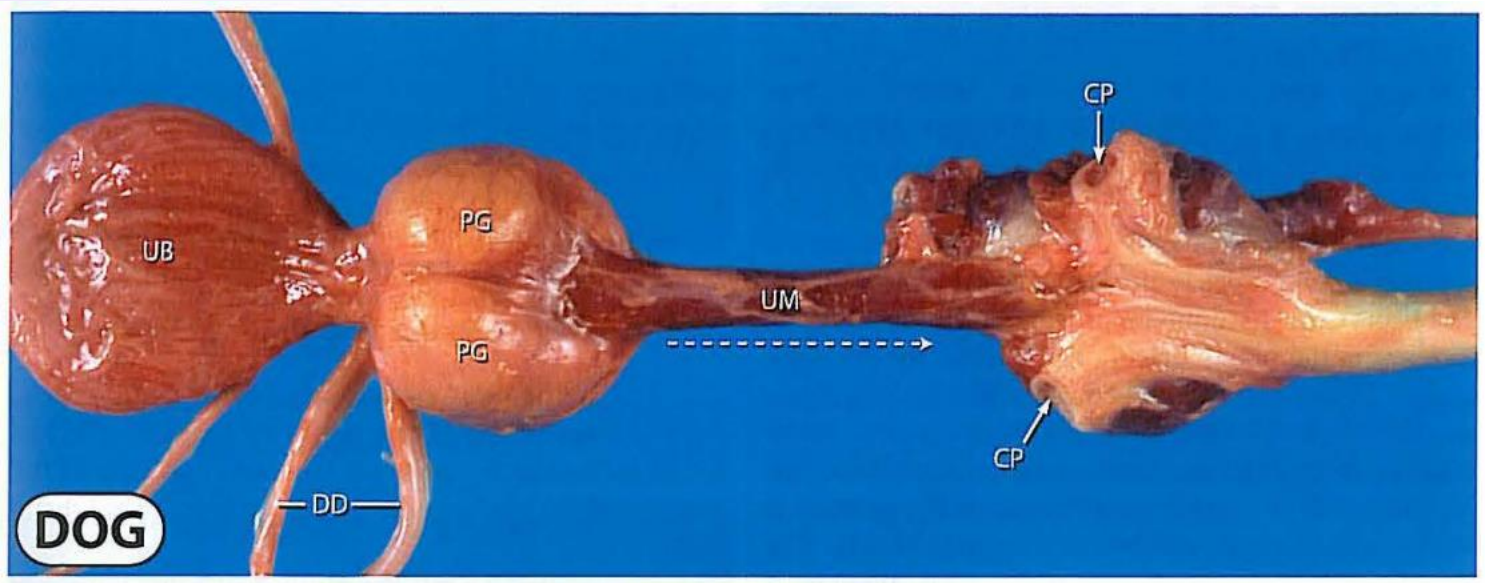
Accessory Sex Glands

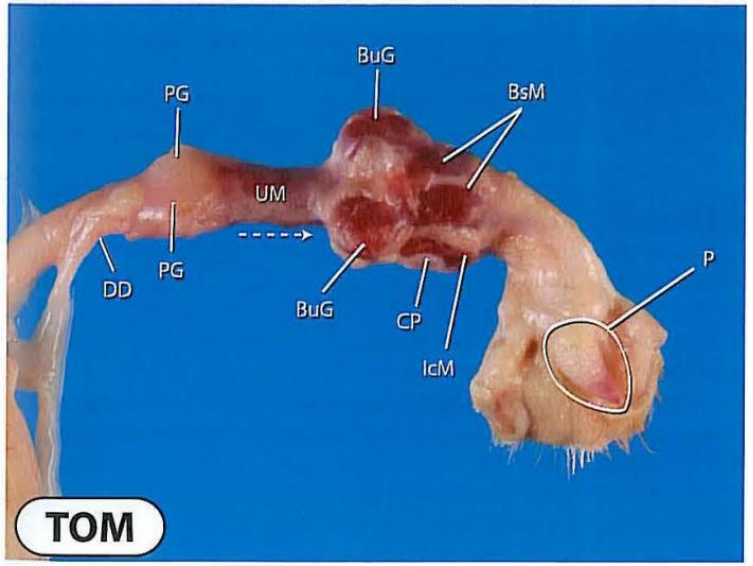
- The **prostate gland** lies in close proximity to the junction between the bladder and pelvic urethra.
- The prostate may have two structural forms:
  - Corpus prostate in which the prostate is outside of the urethralis muscle and is visible as a heart-shaped (boar), or an H-shaped (stallion) structure.
  - Disseminate prostate (Urethral gland) in which glandular tissue is distributed along the dorsal and lateral walls of the pelvic urethra.



Accessory Sex Glands

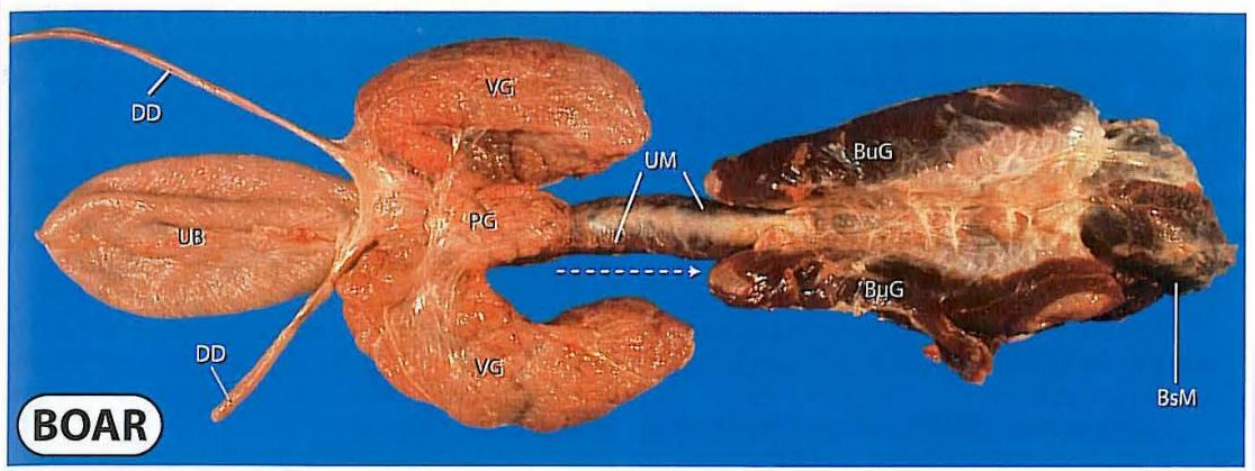
- The **bulbourethral glands** are paired glands located on either side of the pelvic urethra near the ischial arch. These glands are usually small and ovoid shape.
  - These glands produce a viscous secretion that is important because it provides the gel fraction of the ejaculate and causes the seminal plasma to coagulate following ejaculation.





Accessory Sex Glands

- Secretions of the accessory sex glands contain an immense variety of components and ions, most of which have not been assigned a function. In general, most substances found in blood, including hormones and enzymes, can be found in seminal plasma.
  - It should be emphasized that with the exception of fructose as an energy source, the precise role of the other materials is not known.
- The accessory sex glands are dependent on testosterone for full development and maintenance of their structure and function.



Journal Club *(for more reading)*

Abstract

Objective: The aim of the study was to evaluate the secretory dysfunction of the male accessory glands in men with inflammatory versus non-inflammatory chronic pelvic pain syndrome (CPPS).

Methods: One hundred and twelve consecutive patients symptomatic for chronic pelvic pain were included into the study. All underwent a combined granulocyte analysis in expressed prostatic secretions (EPS) and a four-glass-test followed by ejaculate analysis. Patients were subgrouped according to elevated granulocyte counts in prostatic secretions, leukocytes in semen, or any of both. The content/total enzyme activity of the secretory seminal plasma parameters γ-glutamyl-transferase (γ-GT), fructose, and α-glucosidase representing the secretory capacity of the prostate gland, the seminal vesicles, and the epididymes, respectively, were investigated.

Results: The only significant findings were a reduced total enzyme activity of γ-GT in men stratified according to elevated granulocyte counts in prostatic secretions (p=0.022; cutpoint 9.85 U per ejaculate; sensitivity 61.1%, specificity 58.8%, AUC 0.6347) and in men with any inflammatory sign (p=0.033; cutpoint 9.9 U per ejaculate, sensitivity 63%, specificity 58.33%, AUC 0.6404).

Conclusions: Secretory damage of the prostate gland in men with inflammatory CPPS is demonstrable provided that increased granulocytes in prostatic secretions are part of the diagnostic criteria. However, because of the low sensitivity and specificity of γ-GT it cannot be recommended as diagnostic tool to detect inflammatory disease on the basis of reduced secretory capacity.

- https://www.europeanurology.com/article/S0302-2838(02)00224-5/pdf

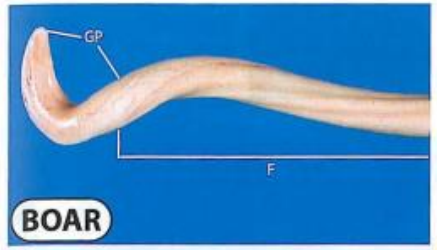
Penis

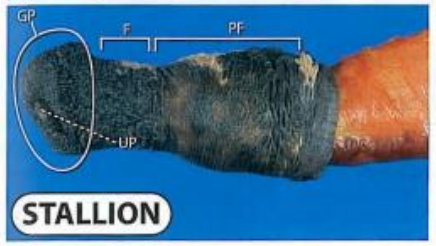
- The penis is the copulatory organ which compose three parts:
  - base (root) of the penis
  - shaft (the main portion of the penis)
  - glans penis (the specialized distal end)
    - The glans penis is heavily populated with sensory nerves and is the homologue of the female clitoris.
- Bulls, boars and rams have a fibroelastic penis with limited erectile tissue encased in a non-expandable, dense connective tissue structure (tuica albuginea).
- In species with a fibroelastic penis, there is a sigmoid flexure, an S-shaped configuration along the shaft of the penis.

Penis

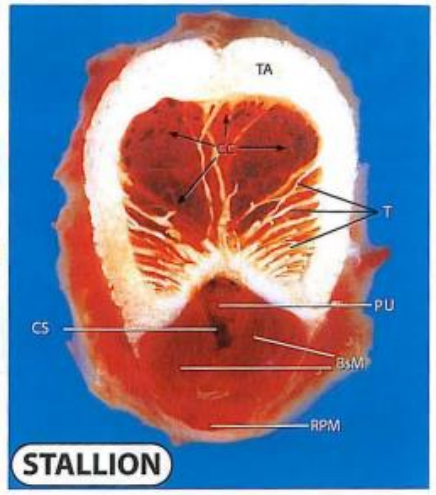
- The shaft of the penis has an area of spongy, erectile tissue known as the corpus cavernosum that makes up the majority of the penile interior.
- In the ventral portion of the penis immediately surrounding the penile urethra is another area of spongy erectile tissue called the corpus spongiosum
- The cavernous tissue in the dog consists of two morphologically distinct regions.
  - These are the bulbus glandis and the pars longa glandis. The bulbus glandis forms a turgid bulb during erection that allows the "copulatory lock" during the final stages of copulation.
  - The dog penis also has an os penis (baculum) that runs through the bulbus glandis and the pars longa glandis.

Penis

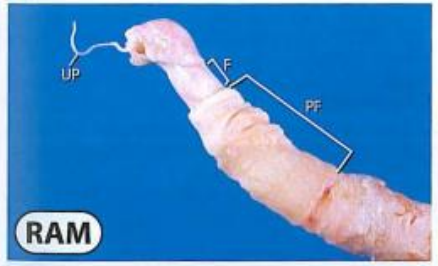


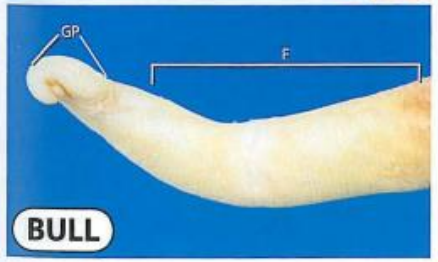


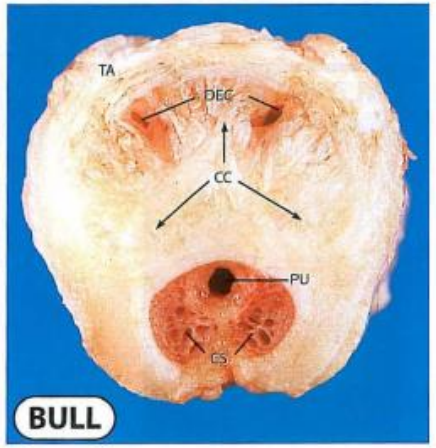
F = Free end of penis
GP = Glans Penis
PF = Preputial Fold
UP = Urethral Process

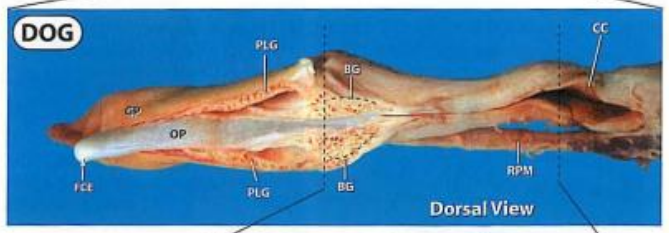


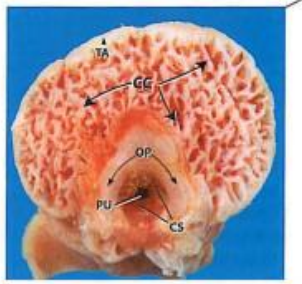
BsM = Bulbospongiosus Muscle
CC = Corpus Cavernosum
CS = Corpus Spongiosum
DEC = Dorsal Erection Canals
RPM = Retractor Penis Muscle
TA = Tunica Albuginea
T = Trabeculae (from tunica albuginea)
PU = Penile Urethra



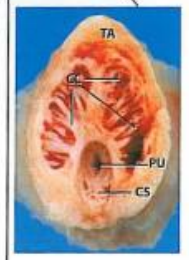


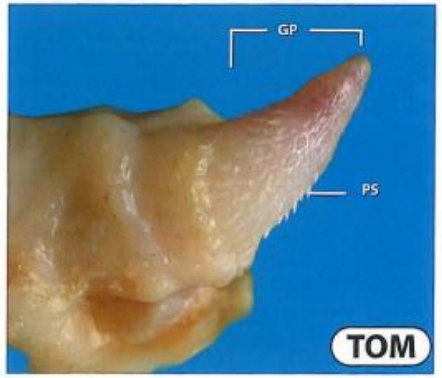


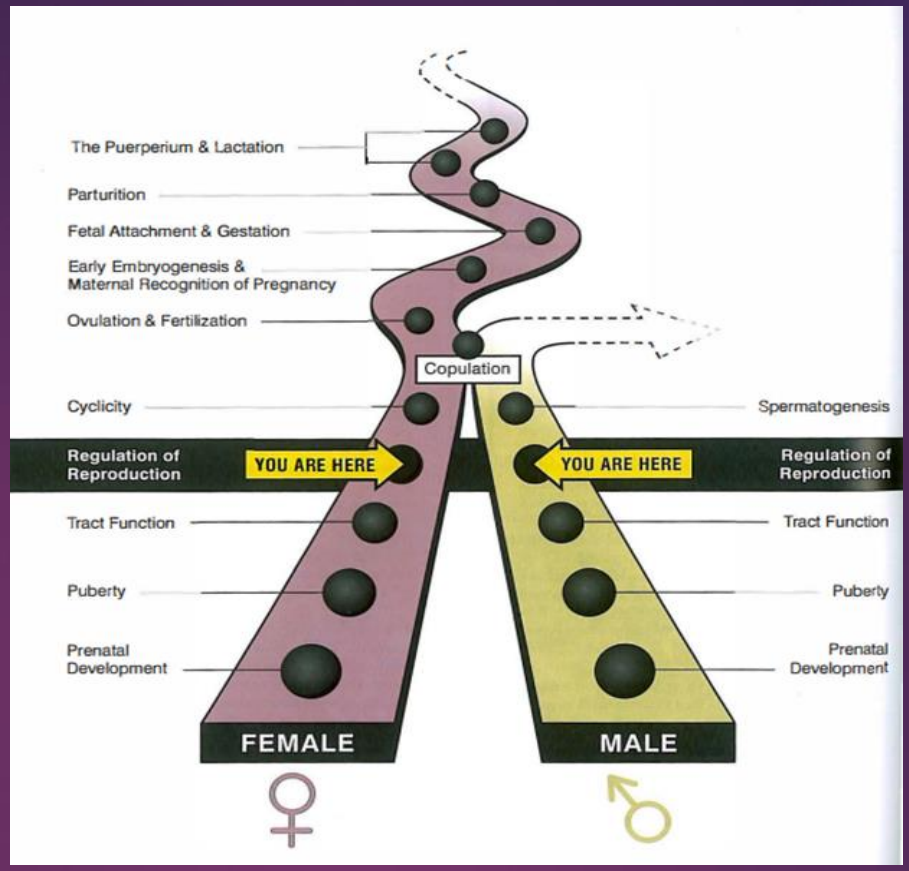




BG = Bulbus Glandis
CC = Corpus Cavernosum
CP = Cartilaginous Process
CS = Corpus Spongiosum
FCE = Fibrocartilaginous end of Os Penis
GP = Glans Penis
OP = Os Penis
PLG = Pars longa glandis
PS = Penile Spines
PU = Penile Urethra
RPM = Retractor Penis Muscle
TA = Tunica Albuginea







Section IV

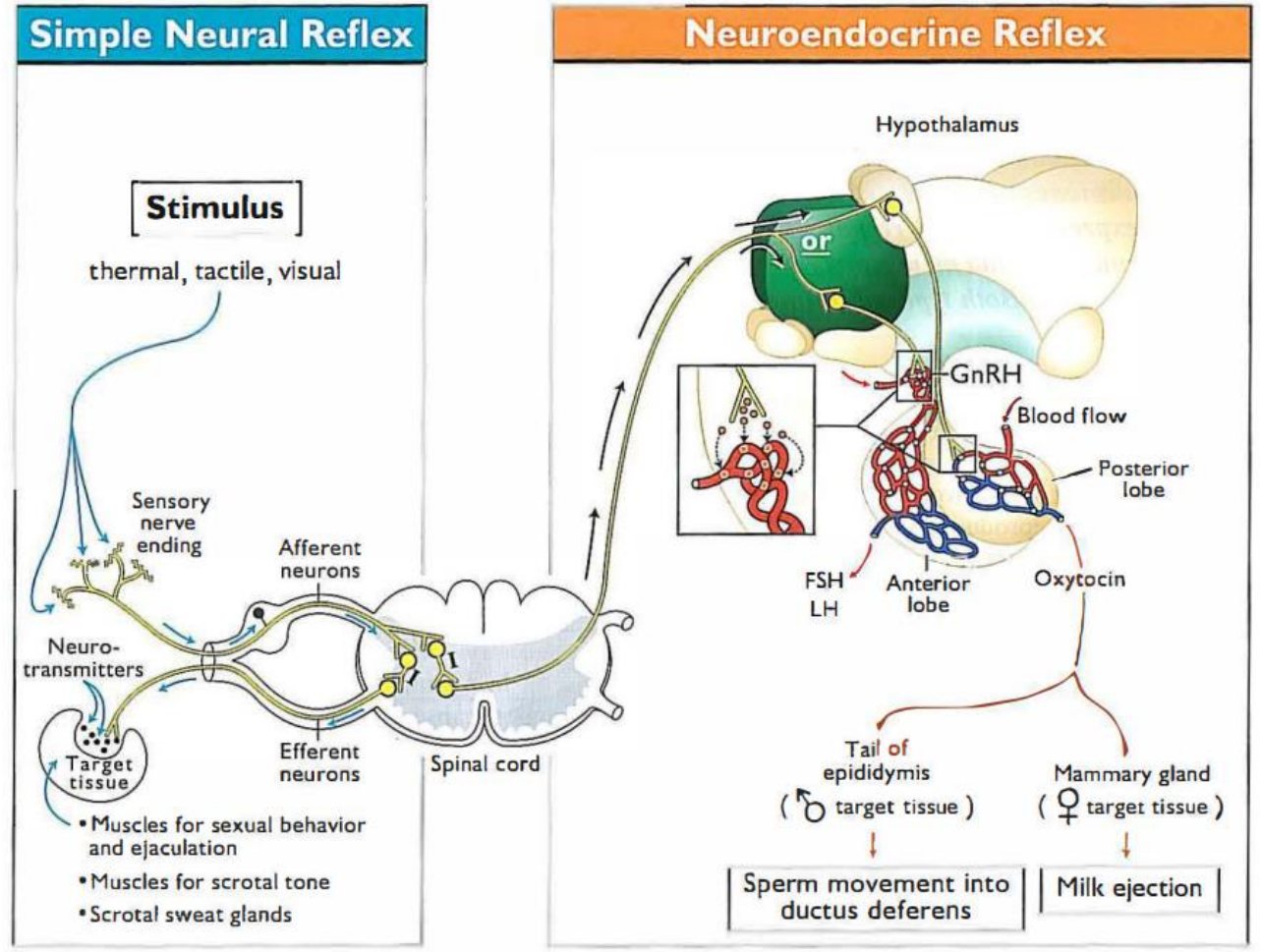
The Regulation of Reproduction

Nerves, Hormones and Target Tissues

Regulation of the reproductive system

IV

- Reproduction is regulated by a remarkable interplay between the nervous system and the endocrine system.



Sensory nerves, responding to a stimulus, synapse with interneurons (I) in the spinal cord. Efferent neurons travel directly to the target tissue to cause a response.

Sensory nerves synapse with interneurons (I) in the spinal cord. Efferent neurons travel to the hypothalamus where hypothalamic neurons release neurohormones. These neurohormones enter the blood and activate target tissues, such as the anterior lobe of the pituitary, mammary gland or the epididymis.

Hypothalamus and Pituitary

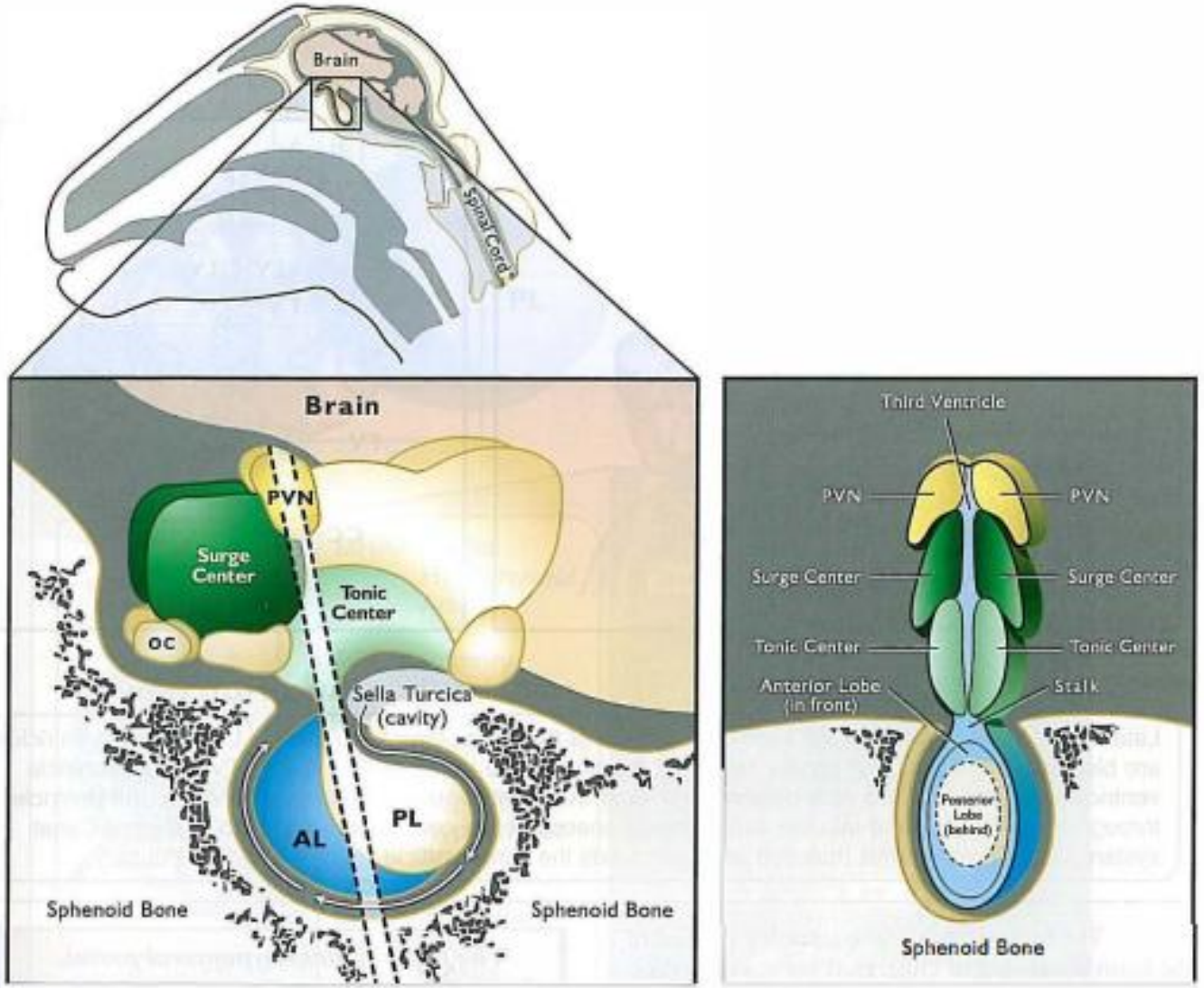
IV

Saggital view

The hypothalamus is a specialized ventral portion of the brain consisting of groups of nerve cell bodies called hypothalamic nuclei that appear as lobules in the figure. The surge center, the tonic center and the paraventricular nucleus (PVN) have direct influence on reproduction. The anterior and posterior lobes of the pituitary are positioned in a depression of the sphenoid bone called the sella turcica.

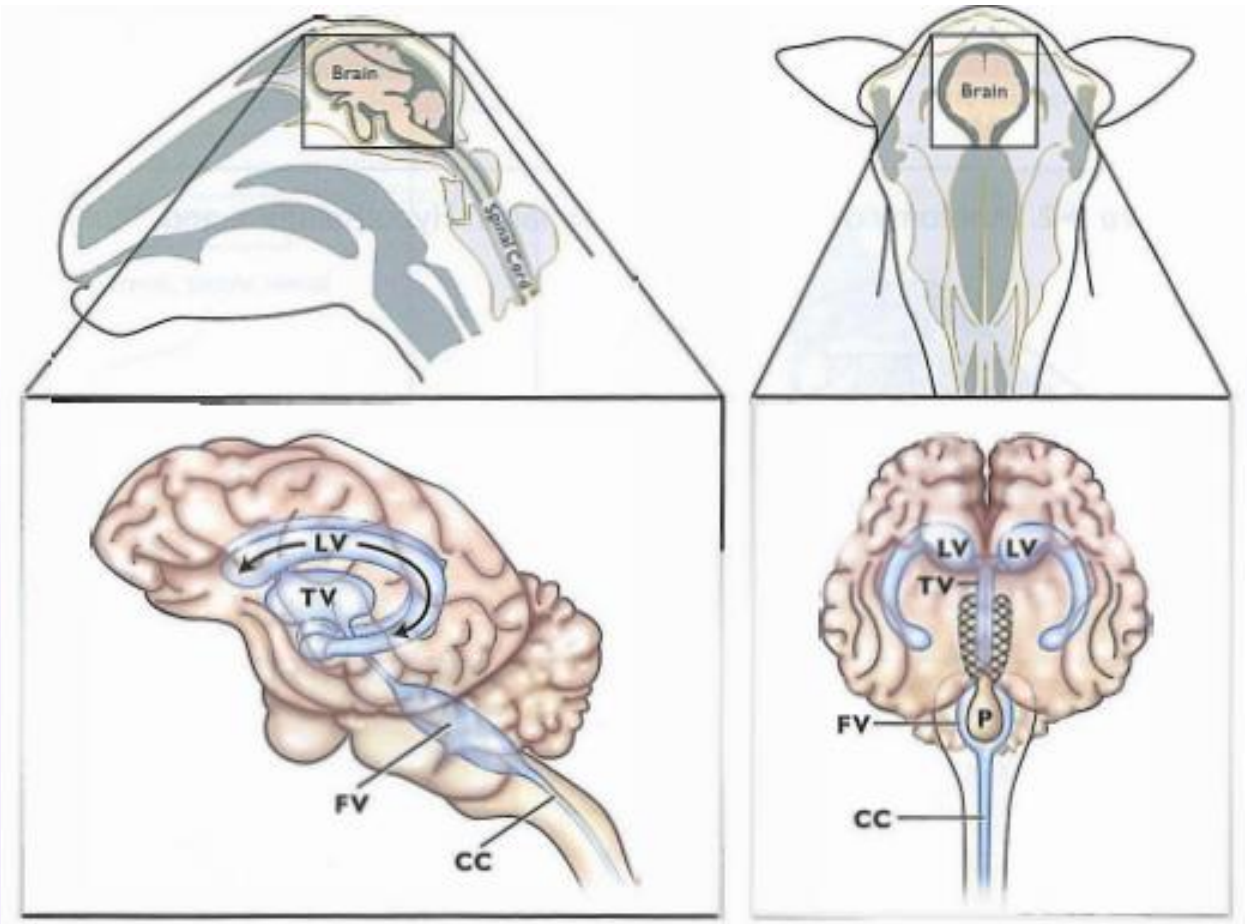
Frontal view

This view illustrates the relationship of the paraventricular nucleus (PVN), the surge center and the tonic center to the third ventricle and pituitary. The vertical line in the left panel represents the plane of section shown in the right panel. Notice that the third ventricle (a brain cavity) separates the lateral portions of the hypothalamus. AL = Anterior Lobe of the Pituitary, PL = Posterior Lobe of the Pituitary, OC = Optic Chiasm.



Ventricular System of the Brain

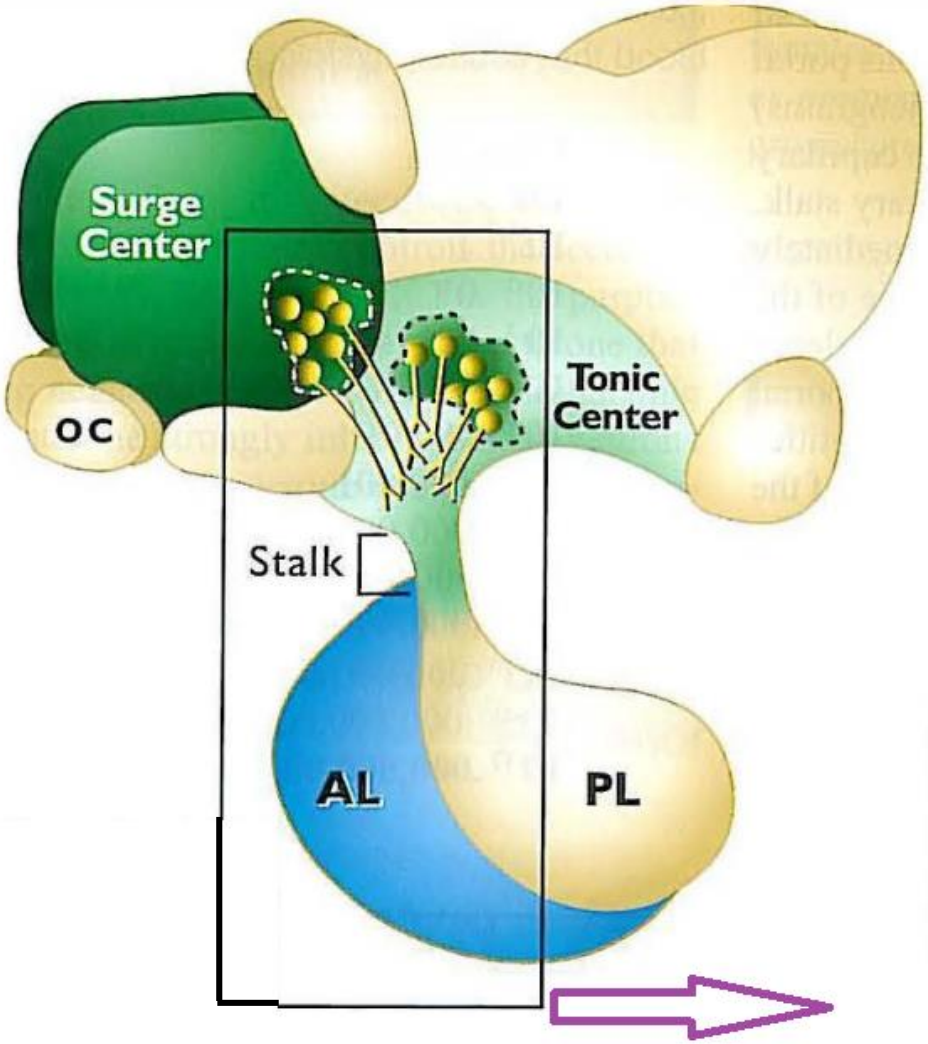
IV



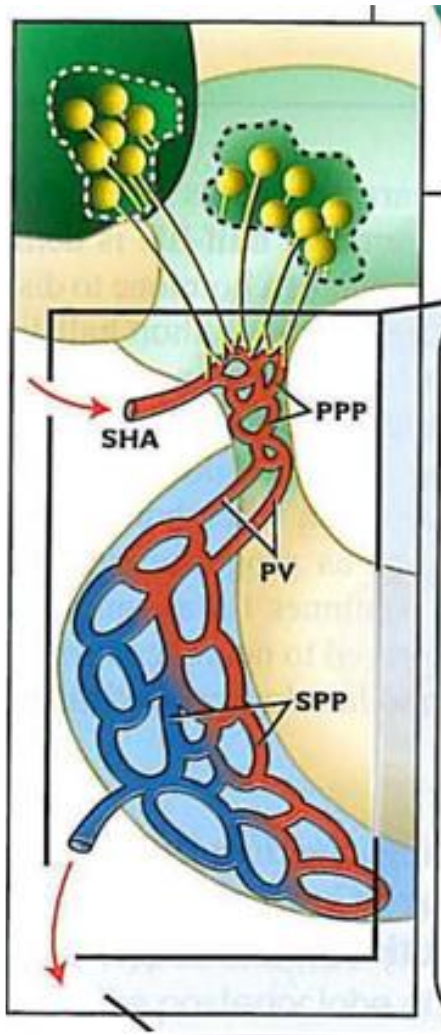
Lateral and anterior views of the ventricular system of the brain. The ventricles are blue-shaded "bags" and appear here as if the brain were transparent. The ventricular system is filled with cerebrospinal fluid that continuously circulates through the ventricles and into the subarachnoid spaces of the central nervous system. The hypothalamus (hatched area) surrounds the third ventricle.

LV = Lateral Ventricles
TV = Third Ventricle
FV = Fourth Ventricle
CC = Central Canal
P = Pituitary

The Hypothalamo-Hypophyseal Portal System IV



Axons from neurons in the surge center and the tonic center extend to the stalk region where their endings terminate upon blood vessels of the hypothalamo-hypophyseal portal system. This portal system consists of: the superior hypophyseal artery; the primary portal plexus, (where the surge center and tonic center neurons terminate); the medial hypophyseal artery that supplies part of the anterior lobe of the pituitary (AL); the portal vessels that transport blood containing releasing hormones; and the secondary portal plexus that delivers blood (and releasing hormones) to the cells of the anterior lobe.



MHA = Medial Hypophyseal Artery

PPP = Primary Portal Plexus

PV = Portal Vessels

SHA = Superior Hypophyseal Artery

SPP = Secondary Portal Plexus

PVN and the PL of the Pituitary

IV

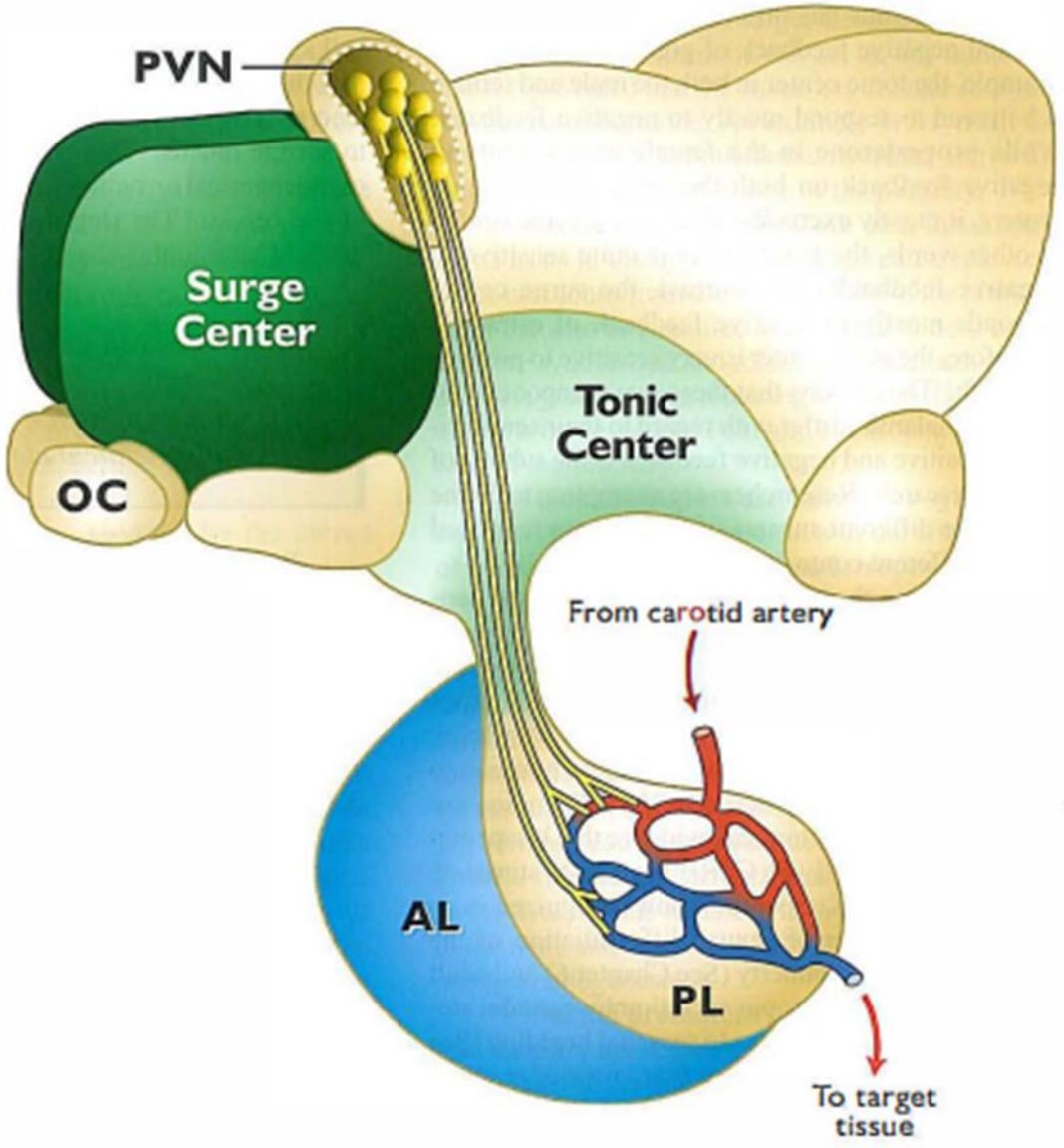
Axons from neurons originating in the hypothalamus (PVN) extend into the posterior lobe of the pituitary where they release their neurohormones into a capillary plexus.

AL = Anterior Lobe of the Pituitary

OC = Optic Chiasm

PL = Posterior Lobe of the Pituitary

PVN = Paraventricular Nucleus



Endocrine control vs. Neural control

IV

- In contrast to neural regulation, the endocrine system relies on hormones to cause responses. A hormone is a substance produced by a gland that acts on a remote tissue (target tissue) to bring about a change in the target tissue. These changes involve alterations in metabolism, synthetic activity and secretory activity.
- Hormones are characterized as having relatively short half-lives which is important because once the hormone is secreted and released into the blood and causes a response, it is degraded so that further responses do not occur.
- Compared to neural control, hormonal control is slower and has durations of minutes, hours or even days.

Positive and Negative Feedbacks

IV

- Almost all reproductive functions are controlled by positive and negative feedback mechanisms.
- These mechanisms control the secretion of GnRH that in-turn controls the secretion of the goanadotropins FSH and LH.
  - Progesterone strongly inhibits GnRH neurons and therefore when progesterone is high, GnRH neurons secrete only basal levels of GnRH. Such basal secretion while allowing for some follicular development will not allow sufficient follicular development for the secretion of high levels of estradiol.

$$\uparrow P_4 \rightarrow \downarrow GnRH \rightarrow \downarrow FSH \ \& \ LH = \text{Incomplete follicular development}$$

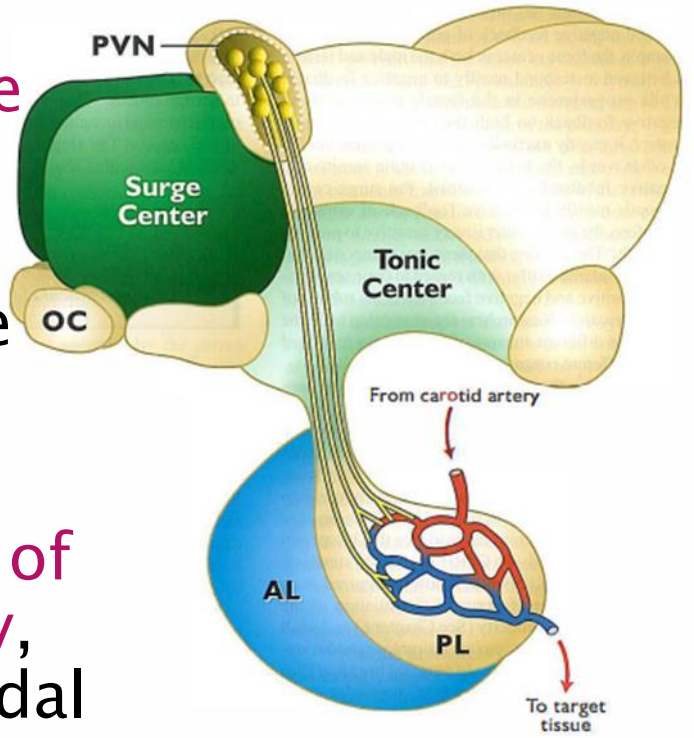
$$\uparrow E_2 \rightarrow \uparrow GnRH\ (surge) \dashrightarrow LH\ surge = \text{Ovulation}$$

  - The female contains a surge center that is responsible for secreting large quantities of GnRH that induce ovulation. The surge center will not release large quantities of GnRH until there is positive feedback by estradiol.

Positive and Negative Feedbacks

IV

- The tonic center in both the male and female is believed to respond mostly to negative feedback. While progesterone in the female exerts a strong negative feedback on both the surge and the tonic centers, it mostly exerts its effect on the tonic center.
- In contrast, the surge center responds mostly to positive feedback of estradiol.
- A new class of neuropeptides called kisspeptins has emerged as the possible "gatekeepers" for GnRH release which are secreted by hypothalamic neurons in the periventricular, preoptic and arcuate nuclei.
- Kisspeptin is now recognized as an important regulator of sexual differentiation of the brain, the timing of puberty, and adult regulation of gonadotropin secretion by gonadal steroids, especially as it relates to seasonal breeding.



Reproductive Hormones

IV

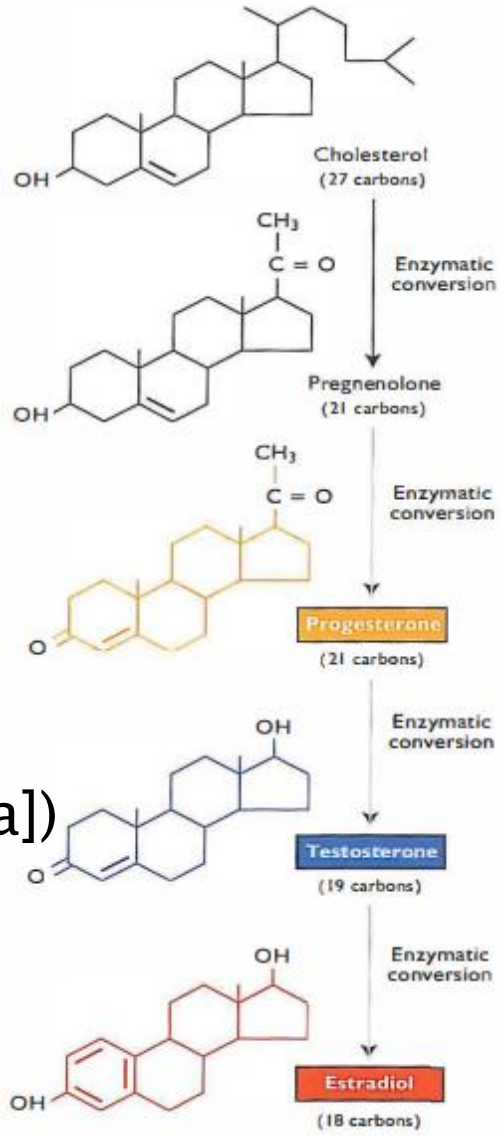
Reproductive hormones can be classified according to their:

- Source of origin
  - Hypothalamic hormones (GnRH),
  - Pituitary hormones (FSH,LH, PL, OT),
  - Gonadal hormones (estrogens, progesterone, inhibin, testosterone, oxytocin, relaxin),
  - Uterine hormones ($PGF_{2\alpha}$),
  - Placental hormones (hCG, eCG),
  - Mammary gland bioactive factor (lactocrine signaling)
    - Lactocrine transmission of relaxin and its effects on development of the neonatal female reproductive tract

Reproductive Hormones

IV

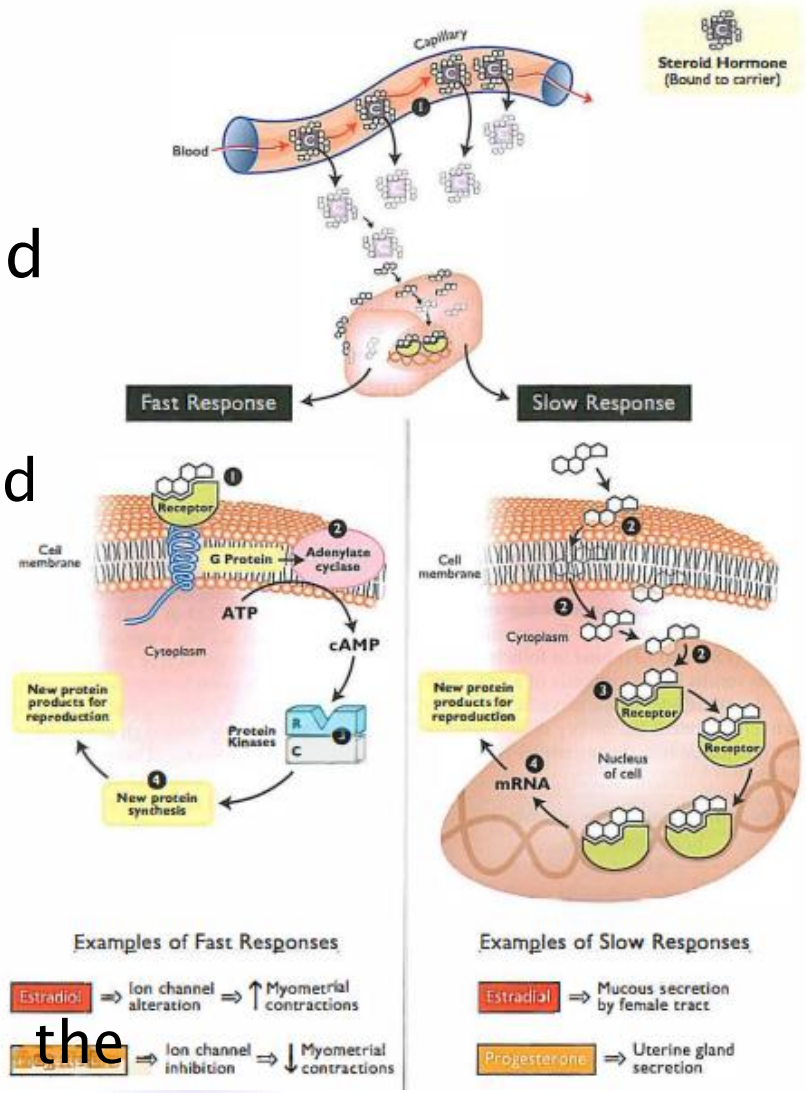
- Mode of action
  - Neurohormones (OT)
  - Releasing hormones (GnRH)
  - Gonadotropins (FSH, LH)
  - Sexual promoters (estrogens, progesterone, testosterone, hCG, eCG, placental lactogen)
  - General metabolic hormones (thyroxin, adrenal corticoids, GH)
  - Luteolytic hormones ($PGF_{2\alpha}$)
- Biochemical structure
  - Peptides (GnRH, PL, Relaxin [from CL of pregnancy and placenta])
  - Glycoproteins with α and β subuints (inhibin, activin, follistatin)
  - Steroids (progesterone, testosterone, estradiol)
  - Prostaglandins ($PGF_{2\alpha}$, PGE_2)



Mechanisms of Steroid Hormone Action

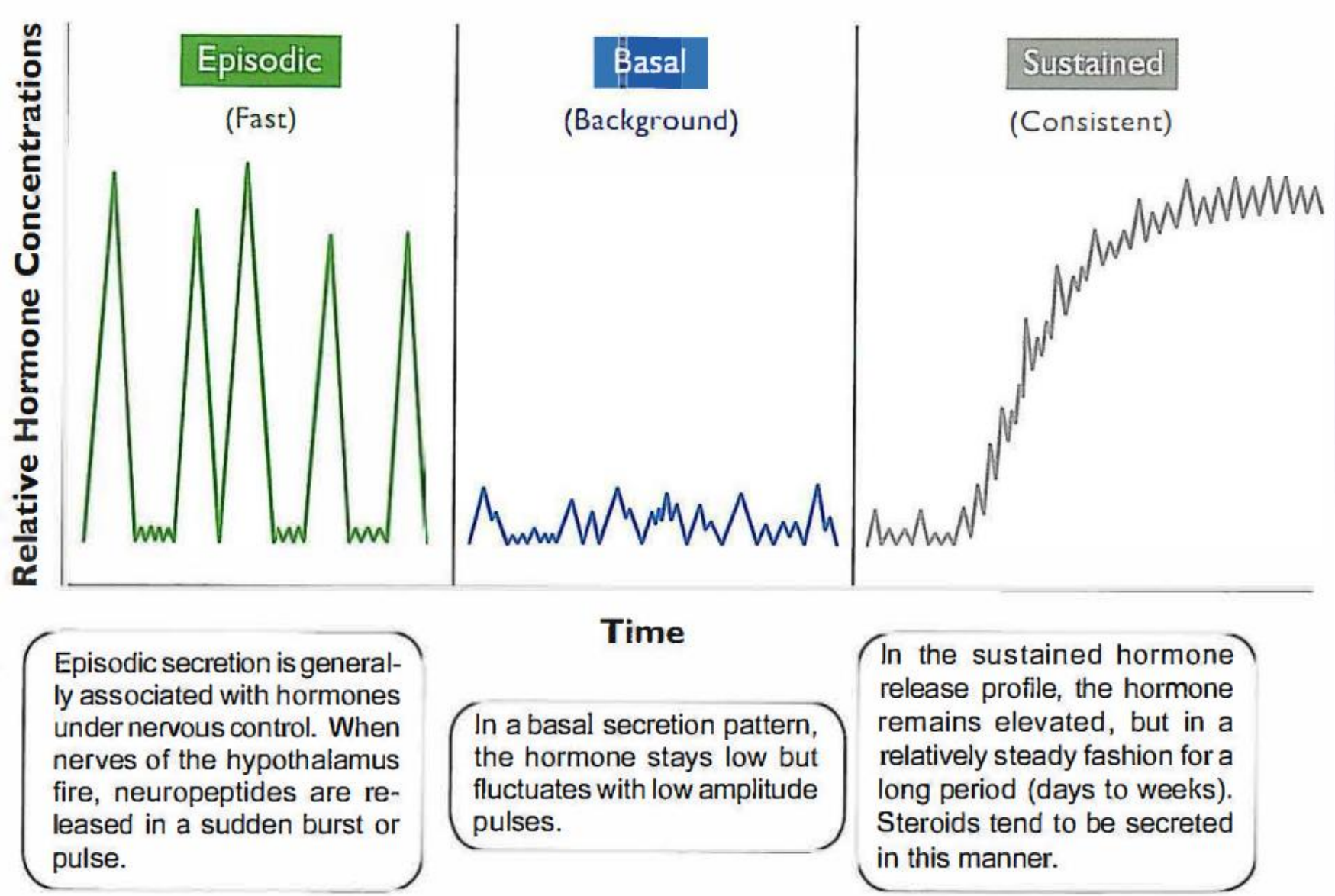
IV

- Step 1 - Steroid Transport
  - bind to a variety of plasma proteins which carry the steroids in the blood and interstitial fluid
- Step 2 - Movement Through the Cell Membrane and Cytoplasm
  - diffuses through the plasma membrane and when enters the cell, it diffuses through the cytoplasm and into the nucleus
- Step 3 – Binding to Nuclear Receptor
  - The steroid-receptor complex (transcription factor) initiates DNA-directed messenger RNA synthesis (transcription)
- Step 4 - mRNA and Protein Synthesis
  - specific proteins are synthesized that will enhance the reproductive process



Hormonal Secretion Patterns

IV



Episodic secretion is generally associated with hormones under nervous control. When nerves of the hypothalamus fire, neuropeptides are released in a sudden burst or pulse.

In a basal secretion pattern, the hormone stays low but fluctuates with low amplitude pulses.

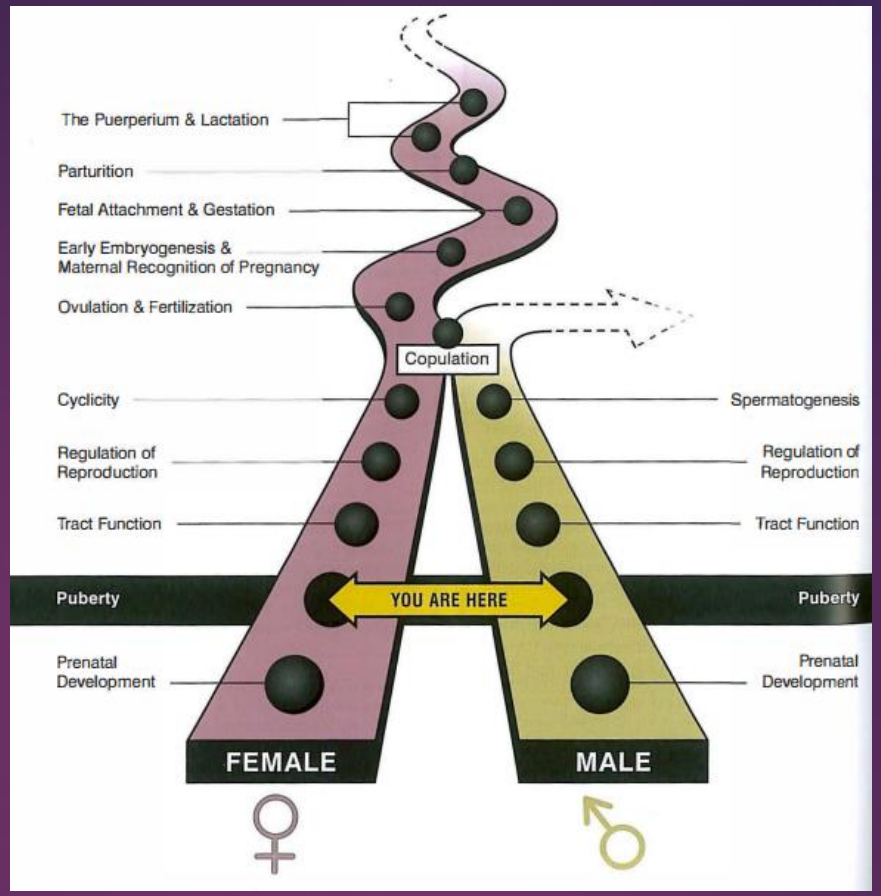
In the sustained hormone release profile, the hormone remains elevated, but in a relatively steady fashion for a long period (days to weeks). Steroids tend to be secreted in this manner.

(Colors shown below are used in graphics throughout the book)

Name of Hormone (Abbrev.)	Biochemical Classification	Source	Male Target Tissue	Female Target Tissue	Male Primary Action	Female Primary Action
Gonadotropin Releasing Hormone (GnRH)	Neuropeptide (decapeptide)	Hypothalamic surge and tonic centers	Anterior lobe-pituit (gonadotroph cells)	Anterior lobe-pituitary (gonadotroph cells)	Release of FSH and LH from anterior lobe-pituitary	Release of FSH and LH from anterior lobe-pituitary
Luteinizing Hormone (LH)	Glycoprotein	Anterior lobe (pituitary) (gonadotroph cells)	Testis (interstitial cells of Leydig)	Ovary (cells of theca interna and luteal cells)	Stimulates testosterone production	Stimulates ovulation, formation of corpora lutea and progesterone secretion
Follicle Stimulating Hormone (FSH)	Glycoprotein	Anterior lobe-pituitary (gonadotroph cells)	Testis (Sertoli cells	Ovary (granulosal cells)	Sertoli cell function	Follicular development and estradiol synthesis
Prolactin (PRL)	Protein	Anterior lobe-pituitary (lactotroph cells)	Testis and brain	Mammary cells, corpus luteum in some species (rat and mouse)	Can induce maternal behavior in females and males	Lactation, maternal behavior and corpora lutea function (some species)
Oxytocin (OT)	Neuropeptide (octapeptide)	Synthesized in the hypothalamus, stored in the posterior lobe-pituitary; synthesized by corpus luteum.	Smooth muscle of epididymal tail, ductus deferens and ampulla	Myometrium and endometrium of uterus, myoepithelial cells of mammary gland	$PGF_{2\alpha}$ synthesis and pre-ejaculatory movement of spermatozoa	Uterine motility, promotes uterine $PGF_{2\alpha}$ synthesis, milk ejection
Estradiol (E_2)	Steroid	Granulosal cells of follicle, placenta, Sertoli cells of testis	Brain Inhibits long bone growth	Hypothalamus, entire reproductive tract and mammary gland	Sexual behavior	Sexual behavior, GnRH, elevated secretory activity of the entire tract, enhanced uterine motility
Progesterone (P_4)	Steroid	Corpus luteum and placenta		Uterine endometrium, mammary gland, myometrium, hypothalamus		Endometrial secretion, inhibits GnRH release, inhibits reproductive behavior, promotes maintenance of pregnancy
Testosterone (T)	Steroid	Interstitial cells of Leydig, cells of theca interna in female	Accessory sex glan tunica dartos of scrotum, seminifero epithelium, skeletal muscle	Brain, skeletal muscle, granulosal cells	Anabolic growth, promotes spermatogenesis, promotes secretion of accessory sex glands	Substrate for E_2 synthesis, abnormal masculinization (hair patterns, voice, behavior, etc.)
Inhibin	Glycoprotein	Granulosal cells (female) Sertoli cells (male)	Gonadotrophs of anterior lobe-pituita	Gonadotrophs of anterior lobe-pituitary	Inhibits FSH secretion	Inhibits FSH secretion
Prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$)	Prostaglandin (C-20 fatty acid)	Uterine endometrium, vesicular glands	Epididymis	Corpus luteum, uterine myometrium, ovulatory follicles	Affects metabolic activity of spermatozoa, causes epididymal contractions	Luteolysis, promotes uterine tone and contraction, ovulation
Relaxin (RLN or RLX)	Protein Polypeptide	Corpus lutem, placenta prostate	Sperm and male trac	Pelvic ligaments, cervix, mammary gland, nipples		Softening of pelvic ligaments, cervix, connective tissue remodeling in tract
Human chorionic gonadotropin (hCG)	Glycoprotein	Trophoblast of blastocyst (chorion)		Ovary	Sperm motility, tract growth	Facilitate production of progesterone by ovary
Equine chorionic gonadotropin (eCG)	Glycoprotein	Chorionic girdle cells		Ovary		Causes formation of accessory corpora lutea
Placental lactogen	Protein	Placenta		Mammary gland of dam		Mammary stimulation of dam

Section V

Puberty



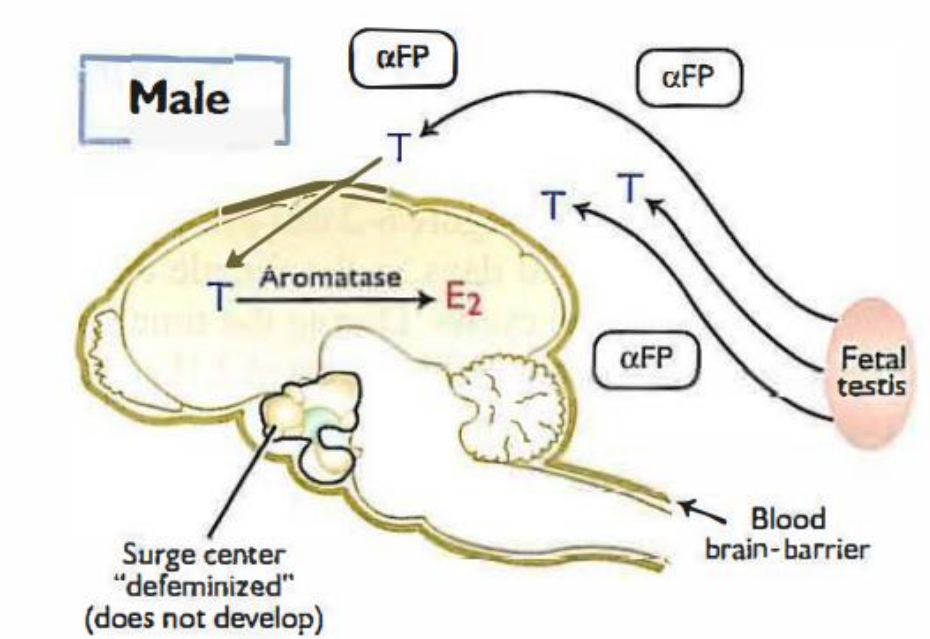
Puberty

V

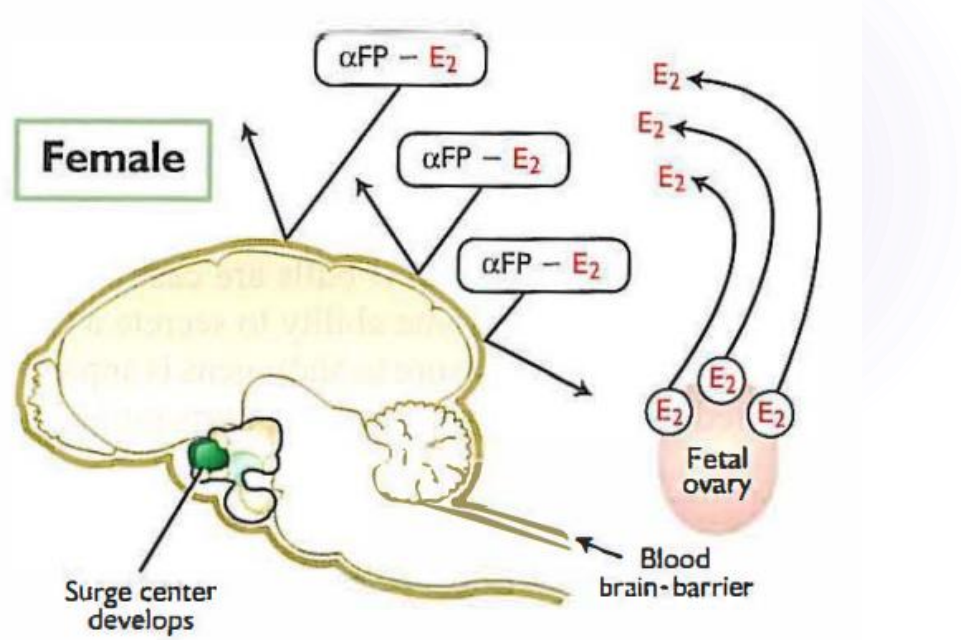
- **Puberty** is the acquisition of reproductive competence.
- It is a process that occurs over time, not an event.
- The onset of puberty depends on the ability of specific hypothalamic neurons to produce GnRH in sufficient quantities to promote and support gametogenesis.
- In the female, hypothalamic GnRH neurons must develop the ability to respond to estradiol positive feedback before they can cause sufficient quantities of GnRH to induce ovulation.
- Development of hypothalamic GnRH neurons is influenced by genetic and environmental factors and their interactions.

Male hypothalamus vs. Female hypothalamus V

- During prenatal development in the male, testosterone from the fetal testis "defeminizes" the brain thus minimizing surge center function.



In the male, Testosterone freely enters the brain because α-FP does not bind it. Testosterone is aromatized into estradiol and the male brain is "defeminized". Therefore, a GnRH surge center **does not** develop.



In the female, α-FP prevents E_2 from entering the brain. The hypothalamus is thus "feminized" and the surge center develops.

LH Secretory Patterns in Males vs. Females

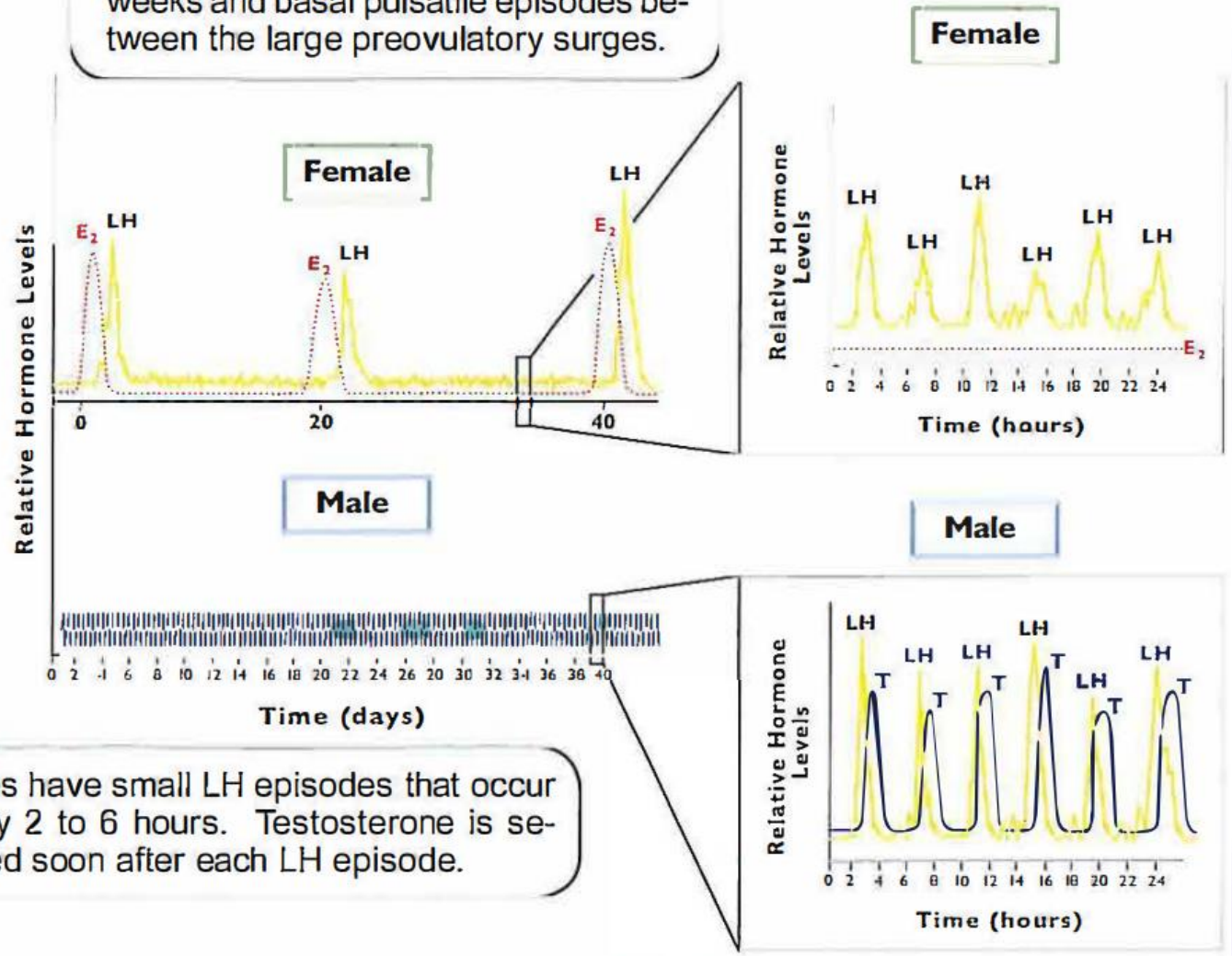
V

- LH does not surge in the male, but maintains a pulsatile pattern of secretion.
  - These pulses occur every 2 to 6 hours in the postpubertal male. This steady GnRH pulsatile rhythm results in steady pulses of LH and, in turn, steady pulsatile secretion of testosterone.
- In contrast, estradiol and LH surge about every 20 days in the female depending on the length of the cycle.
  - During the time between the surges, low amplitude, repeated LH pulses are present.

LH Secretory Patterns in Males vs. Females

V

Females have high amplitude preovulatory episodes of LH once every several weeks and basal pulsatile episodes between the large preovulatory surges.



Males have small LH episodes that occur every 2 to 6 hours. Testosterone is secreted soon after each LH episode.

The Onset of Puberty

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- Generally, puberty can be defined in both the male and female as the ability to accomplish reproduction successfully.
- The fundamental requirement for puberty is the secretion of GnRH at the appropriate frequency and quantities to stimulate gonadotropin release by the pituitary
- Gonadotropins promote gametogenesis, steroidogenesis and the development of reproductive tissues.
- The most important "drivers" of pubertal onset are the ability of presynaptic neurons to provide information to the GnRH neurons.
  - Function of these presynaptic neurons may be influenced by: 1) plane of nutrition, 2) exposure to certain environmental or social cues and 3) the genetics of the individual.

The Onset of Puberty - Criteria

V

- Several criteria can be used to define puberty in domestic animals.
- **In female**:
  - Age at first estrus (heat): The age at which the female becomes sexually receptive.
  - Age at first ovulation: This can be accomplished using palpation or ultrasonography of the ovary per rectum in animals. Also, laparoscopy and endoscopy can be used to determine when ovulation has occurred.
  - Age at which a female can support pregnancy without deleterious effects.
- **In male**:
  - Age when behavioral traits are expressed
  - Age at first ejaculation
  - Age when spermatozoa first appear in the ejaculate
  - Age when the ejaculate contains a threshold number of spermatozoa

Species	Male	Female
Alpaca[2]	2-3 yrs	1 yr
Bovine	11 mo (7-18)	11 mo (9-24)
Camel[2]	3-5 yrs	3 yrs
Canine[1]	9 mo (5-12)	12 mo (6-24)
Equine	14 mo (10-24)	18 mo (12-19)
Feline	9 mo (8-10)	8 mo (4-12)
Llama[2]	2-3 yrs	6-12 mo
Ovine	7 mo (6-9)	7 mo (4-14)
Porcine	7 mo (5-8)	6 mo (5-7)

The Onset of Puberty - Mechanisms

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- The major factor limiting onset of puberty is the failure of the hypothalamus to secrete sufficient quantities of GnRH to cause gonadotropin release.
- In the male, the onset of puberty is brought about because of decreased hypothalamic sensitivity to negative feedback by testosterone/estradiol.
- In the prepubertal female, the surge center is quite sensitive to the positive feedback of estradiol. But, the surge center cannot release "ovulatory quantities" of GnRH because the ovary cannot secrete high levels of estradiol
- At low concentrations of estradiol, the tonic center has a high sensitivity to negative feedback and therefore does not secrete high levels of GnRH and gonadotropins remain low.
- During the pubertal transition, however, the negative feedback sensitivity by the tonic center to estradiol decreases and consequently higher and higher amounts of GnRH are secreted causing an increase in pulse frequency of LH.

The Onset of Puberty - Mechanisms

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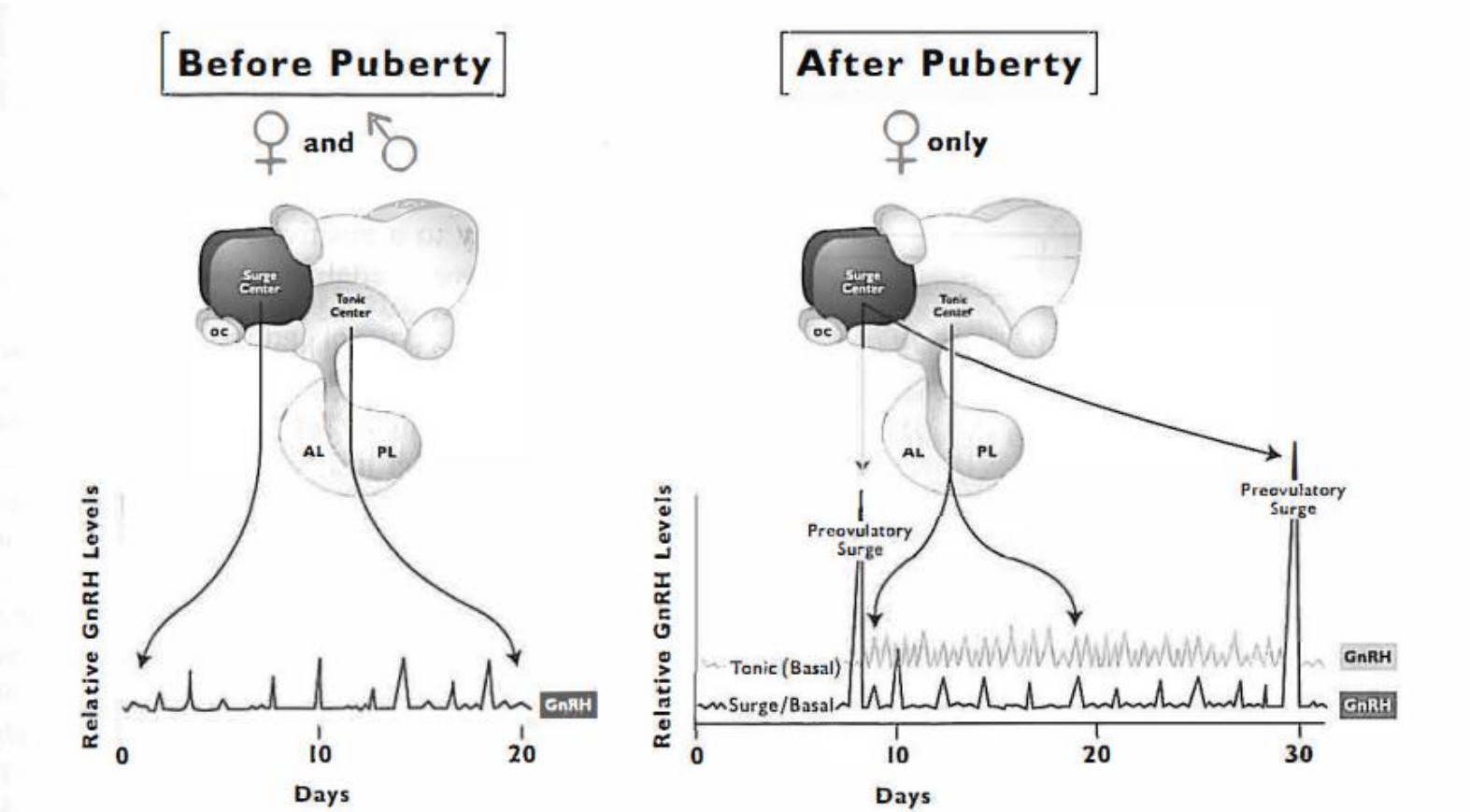

Before puberty in both the female and male, GnRH neurons in the tonic center and the surge center of the hypothalamus release low amplitude and low frequency pulses of GnRH.

After puberty in the female, the tonic center controls basal levels of GnRH, but they are higher than in the prepubertal female because the pulse frequency increases. The surge center controls the preovulatory surge of GnRH. The male does not develop a surge center.

The Onset of Puberty - Mechanisms

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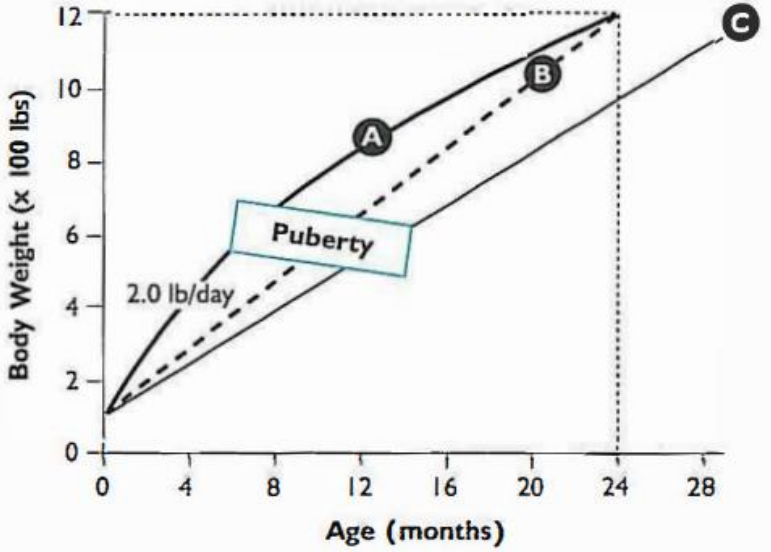
- There is evidence to indicate that initiation of high frequency GnRH pulses is under the influence of glucose and free fatty acid concentrations in the blood.
- The impact of nutrition on the age of pubertal onset in dairy heifers has been shown in different studies.
- Leptin is a hormonal peptide, discovered in 1994, that is secreted by adipocytes (fat cells) and its receptors have also been discovered in the anterior lobe of the pituitary and hypothalamus
- Leptin may be an important signal that "notifies" key hypothalamic neurons that influence GnRH secretion that nutritional status is adequate because a threshold degree of "fatness" has been achieved

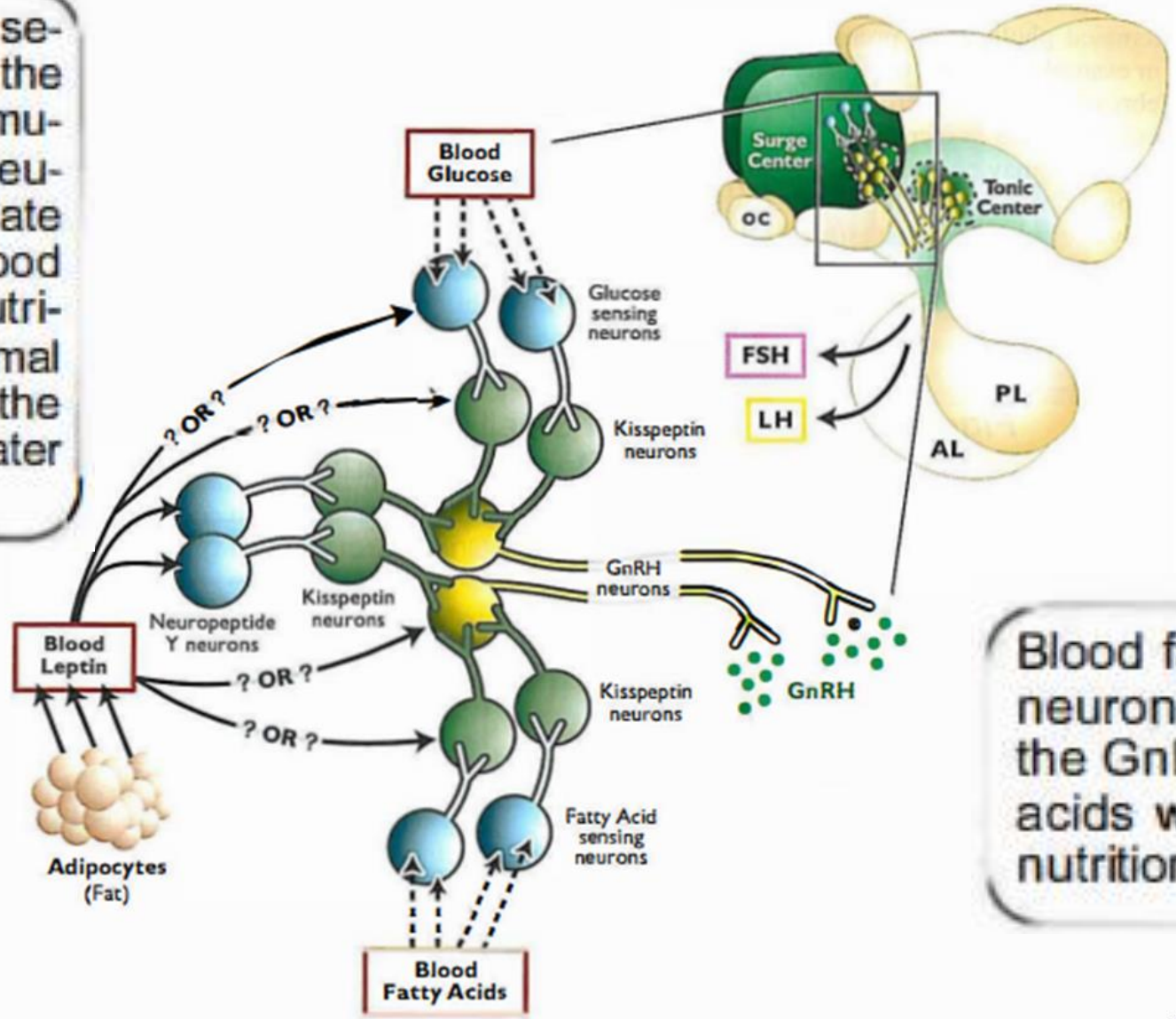


A = High plane of nutrition (2.0 lb/day average daily gain)
B = Moderate plane of nutrition (1.5lb/day average daily gain)
C = Low plane of nutrition (1.2 lb/day average daily gain)

Age at first parturition should be 24 months and the primiparous heifer should weigh 1,200 lb.

Possible Influence of Metabolic Signals on Puberty V

Adipocytes (fat cells) secrete leptin that enters the blood. Leptin may stimulate neuropeptide Y neurons or directly stimulate GnRH neurons. Blood leptin reflects the nutritional status of the animal because the greater the amount of fat the greater the amount of leptin.



Blood glucose concentrations, another indicator of metabolic status, might stimulate glucose sensing neurons that in turn stimulate GnRH neurons.

Blood fatty acids may stimulate neurons that in turn stimulate the GnRH neurons. Blood fatty acids would be an indicator of nutritional status of the animal.

Journal Club (for more reading)

Review > Mol Cell Endocrinol. 2010 Aug 5;324(1-2):70-81. doi: 10.1016/j.mce.2009.12.017. Epub 2009 Dec 22.

Metabolic signals in human puberty: effects of over and undernutrition

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PMID: 20026379 DOI: 10.1016/j.mce.2009.12.017

Abstract

Puberty in mammals is associated with important physical and psychological changes due to the increase in sex steroids and growth hormone (GH). Indeed, an increase in growth velocity and the attainment of sexual maturity for future reproductive function are the hallmark changes during this stage of life. Both growth and reproduction consume high levels of energy, requiring suitable energy stores to face these physiological functions. During the last two decades our knowledge concerning how peptides produced in the digestive tract (in charge of energy intake) and in adipose tissue (in charge of energy storage) provide information regarding metabolic status to the central nervous system (CNS) has increased dramatically. Moreover, these peptides have been shown to play an important role in modulating the gonadotropic axis with their absence or an imbalance in their secretion being able to disturb pubertal onset or progression. In this article we will review the current knowledge concerning the role played by leptin, the key adipokine in energy homeostasis, and ghrelin, the only orexigenic and growth-promoting peptide produced by the digestive tract, on sexual development. The normal evolutionary pattern of these peripherally produced metabolic signals throughout human puberty will be summarized. The effect of two opposite situations of chronic malnutrition: obesity and anorexia, on these signals and how they influence the course of puberty will also be discussed. Finally, we will briefly mention other peptides derived from the digestive tract (such as PYY) that may be involved in the regulatory link between energy homeostasis and sexual development.

Other Factors affecting Puberty

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- **Season of birth** can influence the age of puberty
  - In natural photoperiods, spring-born (February-March) lambs receiving adequate nutrition attain puberty during the subsequent fall (September-October). The age at puberty is about 5 to 6 months after birth. In contrast, fall-born lambs do not reach puberty until about 10 to 12 months.
  - Heifers born in autumn tend to reach puberty earlier than those born in spring. Exposure during the second six months of their life to long photoperiods and spring/summer-like temperatures hastens the onset of puberty.
  - In the bitch there is little seasonality associated with the onset of puberty.
  - In the queen increased photoperiod prompts the onset of puberty.

Other Factors affecting Puberty

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- **Social cues** significantly impact the onset of puberty in many mammalian species.
  - Such mediation is caused by olfactory recognition of pheromonal substances present in the urine.
  - Enhancement of the onset of puberty by the presence of the male has been demonstrated in the ewe, sow and cow.