

Lecture 32: Male Reproductive Physiology and Aggression.

A. Structure and function of testis.

Testis has two functions: (1) production of sperm, and (2) secretion of androgens.

Structure of testis reflects its dual function: (1) Spermatogenesis occurs within ***Seminiferous tubules***. (2) Androgen secretion is mainly by ***Leydig cells***, which are found in interstitial spaces between seminiferous tubules.

(**Overhead:** Fig. 12.7 Turner & Bagnara, p.369: cross section of Tilapia testis)

1. Spermatogenesis

(**Overhead:** Fig 13.1 Turner & Bagnara, P. 407 - cross section of seminiferous tubule)

The seminiferous tubules have a basement membrane that, together with Sertoli cells, forms a ***blood-testis barrier***. Because blood does not penetrate the seminiferous tubules:

1. The developing spermatozoa receive nutrients indirectly, from Sertoli cells, rather than from capillaries.
2. The interior of the tubules are 'immunologically privileged' - no immune reactions.

This is important because sperm become haploid (by meiosis) beginning at puberty — long after the immune system develops — so haploid sperm are considered non-self by the immune system. A male will produce antibodies that attack his own sperm, if the sperm are exposed to circulation (lymphocytes).

Once sperm leave the seminiferous tubules, they are attacked by the immune system.

Testosterone suppresses the immune system - and T levels are much higher within seminiferous tubules than in circulation (due to androgen binding protein - see below). Likely function is to suppress immune response within testis, because some lymphocytes do 'slip in'

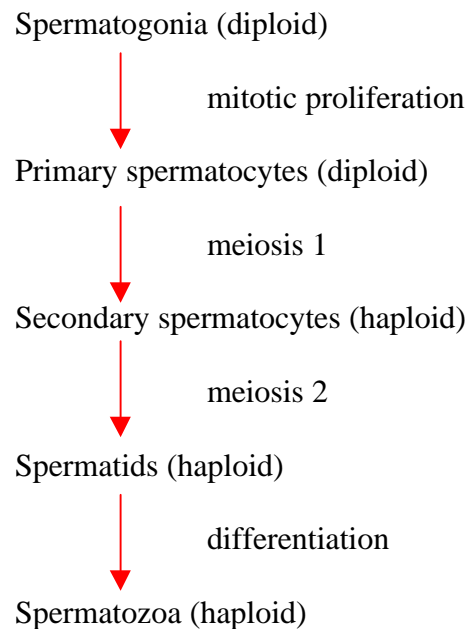
(**Overhead:** see gap marked B)

Proceeding from the basement membrane toward the lumen (central passage) of the tubule, find developing sperm embedded in Sertoli cells, which support their growth and differentiation.

Sertoli cells are capable of converting progesterone (a precursor) to testosterone (and to estrogen) but they play a small role in secretion of steroids, relative to Leydig cells.

Spermatogenic cycle

(**Overhead:** Fig 6.9 van Tienhoven, p. 152, stages 1 & 14)



1. Spermatogenic cycle duration varies among species, but generally takes 1-2 months to go from spermatogonia to spermatozoa.

Consequence is that it is very costly to shut down the testes, unless the onset of the next breeding opportunity is very predictable. Females of most species can ovulate within 2-10 days (~ 2 weeks is the maximum length of follicular phase).

Males of many species undergo ***involution*** (literally = shrinking) of testes in nonbreeding season. Androgen secretion ↓, tubule size ↓, sperm production stops.

Example: Golden mantled ground squirrel, *Spermophilus lateralis*. Females are in hibernation, so no gain from maintaining testicular function. Males arouse from hibernation before females, so that sperm production is back on line once females emerge in spring.

(**Overhead:** Fig 2 Barnes et al 1988, Golden mantled ground squirrel).

Another solution: Red-sided garter snake. Produces sperm to be used in subsequent breeding season *before* entering hibernation, to avoid start-up problem.

(**Overhead:** Figs 6.8 and 6.9 Crews, p 163- 165, red-sided garter snakes)

For species in which *social status* suppresses reproduction, might expect to find males more resistant to shutting off gonads, b/c they can not turn them on again as easily if an individual becomes dominant.

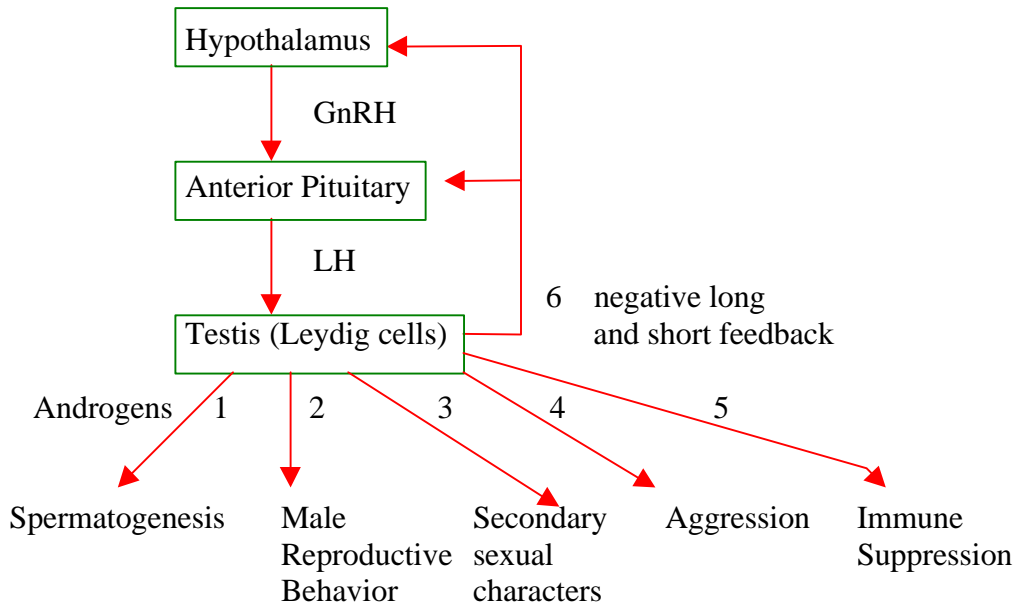
2. During involution, the numbers of all cell types go down. If all spermatogonia (first stage) are lost, then mitotic proliferation cannot occur, and the testis is permanently sterile.
3. Sperm production is temperature sensitive in mammals. Mammals are unique in having testes in scrotum (with a few exceptions, e.g. seals, elephants). Temperature is about 4° cooler than in body. At body temperature, spermatogonia are destroyed. **Cryptorchid** testes (retained in body) occur in many species, and are invariably sterile. In small mammals (e.g. all rodents) testes are drawn into abdominal cavity during winter to reduce surface area (problems of heat loss). A cost of this is reduction in number of spermatogonia, which is offset by mitotic proliferation in spring.

2. Androgen Secretion

Androgens are secreted primarily by the Leydig cells. Leydig cells occupy the interstitial spaces between the seminiferous tubules.

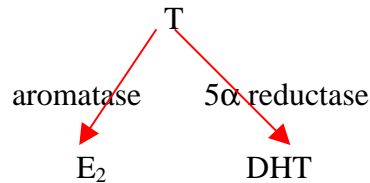
Mammals: Leydig cells form a permanent tissue that is constantly renewed.

Birds: Leydig cells are exhausted en masse at the end of the breeding season, then proliferate again at the start of the next breeding season (probably to reduce weight, just as the right ovary is tiny and nonfunctional in birds to reduce weight).



Testosterone and **androstenedione** are the primary *circulating* androgens secreted by testis.

These are converted to **dihydrotestosterone** or **estradiol** in most target tissues. Although DHT or E₂ are the main *active forms*, T and androstenedione are also active androgens, with weaker effects.



(**Overhead:** Fig. 6.14 van Tienhoven, p.158)

(**Overhead:** Fig 4.1 Baum, p.103- can reinstate some male sexual behaviors in castrated rats with E₂, other behaviors reinstated with DHT. Which hormone is more effective depends on what brain center controls the behavior).

Androgens are typically considered male hormones, and estrogens female. But both sexes have both hormones.

T in females comes from adrenal cortex.

E₂ in males comes from adrenal cortex and testis (Sertoli cells secrete small amounts).

Testosterone: ~5x higher in males than in females for most mammals.

Estradiol: ~10x higher in females than in males for most mammals.

So the difference between the sexes in androgen levels (and estrogen levels) is one of **QUANTITY**, not a matter of presence/absence. Because androgens are involved in aggression, this is an important point.

Males and females differ in the **activating effects** of estrogens and androgens on behavior, due to previous **organizational effects** of androgens and estrogens on the development of the brain.

(**Overhead:** Fig 4.2 Baum. p. 105 - T (or E) both stimulate male sexual behavior in male ferrets, but T (or E) does not stimulate male sexual behavior in females)

(**Overhead:** Fig 2.4 Breedlove, p.56 - recall that T (or E) causes sexual dimorphism in POA, which affects male sex'l behav. Female brain does not have the same *wiring* or *receptors* that are triggered in male brain)

(**Overhead:** Fig 9.2 Glickman & Monaghan, p. 272 - organizational effect of T on aggression in adult life: Castrated at male mice at varying age as juveniles. Then given T as adults to equalize activating stimulus. The grouped with other males and rate of fighting observed. Earlier castration → less fighting)

3. Interactions between Spermatogenesis and Androgen Secretion.

Normal male endocrine function is necessary for spermatogenesis. After hypophysectomy (removal of anterior pituitary), the testes quit producing sperm, shrink, and become spongy.

(**Overhead:** Fig 13-13 Turner & Bagnara, p. 429 - shrinkage, absence of sperm in hypophysectomized rat testis).

LH, FSH and T all play at least indirect roles in spermatogenesis.

(**Overhead:** van Tienhoven Fig 6.12, p. 155 - schematic of gonadotropin and T effects on spermatogenesis).

Main points:

1. LH stimulates Leydig cells to produce T
2. FSH stimulates Sertoli cells to produce androgen binding protein (ABP)
3. ABP causes T to accumulate in tubules at much higher concentration than in circulation.
4. FSH also stimulates Sertoli cells to convert T into more highly active DHT (or E₂)
5. Active androgens needed for some stages of spermatogenesis to proceed
6. FSH itself needed for some stages spermatogenesis to proceed

(**Overhead:** van Tienhoven Fig 6.11, p. 155 - stages of s'genesis and hormonal dependence on T, FSH).

4. Other Effects of Androgens

- A. ***Accessory glands*** - sperm are not viable when they leave the seminiferous tubules. Secretions from accessory glands (prostate, Cowper's gland, glands of Littre, epididymis) are needed to 'potentiate' sperm. These glands are androgen dependent - if the male is castrated, they regress.
- B. ***Secondary sexual characters*** - ornaments involved in two forms of sexual selection.

Sexual selection is a type of natural selection. The distinction is that natural selection favors the spread of genetically determined traits that affect survival and reproduction. Sexual selection focuses on those traits that increase ***reproduction*** of their bearer. Note that a trait can spread via sexual selection even if it reduces survival, as long as the total number of offspring left in a lifetime shows a net increase.

Some evidence that androgens do have a survival cost in wild.

1. Male lifespan is shorter than female in most species, although females face greater energetic costs of reproduction than males - gestation and lactation).

2. Androgens suppress the immune system

(**Overhead:** Dufty 1989, Fig 1 - T levels in males with silastic implant of T)

Experimental approach: Dufty (1989) put silastic implants with T into wild cowbirds, empty implants into control cowbirds

Implants raised T by factor of 1.5x to 10x.

Implanted birds were >6x more likely to die during next year.

Two possible mechanisms for ↑ mortality - increased fighting & injury, or decreased immunity and hence increased vulnerability to pathogens.

Sexual selection operates in two ways -

intrasexual competition, usually among males ("male-male competition")

intersexual mate choice, usually choice of males by females ("female choice")

Reproduction is cheaper for males than for females, b/c females produce the larger gamete (anisogamy), and in mammals, females pay costs of gestation and lactation. Relative to these costs, sperm is cheap, energetically.

Result: Female reproduction is limited by energy
 Male reproduction is limited by access to females.

Consequence: Males have many *physical and behavioral adaptations* that are sexually selected by male-male competition, or by female mate choice. These traits are almost always *androgen-dependent*.

Examples:

Swordfish (Xiphophorus helleri) males have modified tail. Longer tail → greater mating success. Also longer tail → slower swimming speed, reduced turning ability → greater vulnerability to predation. Treat female with T, develops tail.

(**Overhead:** Fig 12-12 Turner & Bagnara, P. 385 - *Xiphophorus* photo)

Frogs and toads (many species) have mating callosities on forearm, which help to grasp female in amplexus (fertilization of eggs as they are spawned). Many species are 'explosive breeders' - emerge from hibernation, hop to pond, call for females, mate. 'Mating balls' make it difficult for a given male to hang on.

Body size, callosity size both depend on T and help in male-male competition.

Larger males have lower calls, more attractive to females

(**Overhead:** Figs 7.1, 7.2 and 7.4 Howard, p.100 in Clutton Brock)

Bird plumage is often sexually dimorphic, with males carrying bright ornaments that are involved in courtship displays. Male plumage is T dependent in most species, and

plumage develops in female pattern in absence of T. Exceptions occur (e.g. chickens) in which male plumage is neutral, and E₂ produces female plumage.

Bird Song in the songbirds, only males sing. Recall from lecture one that brain centers involved in song learning and production are sexually dimorphic, and dimorphism depends on androgens. The *syrinx* is muscular organ involved in singing. T promotes growth of syrinx E₂ inhibits growth.

Phalarope - an interesting exception to vertebrate pattern - sex-role reversed. Males care for eggs and chicks, while females are more aggressive and compete for males. And as expected by sexual selection theory, females are the ones with bright badges. Paralleling all the other sex-role reversals, development of female plumage is T dependent.

Antlers, horns and wattles also T dependent

Body mass dimorphism is T dependent. Males are larger in 75% of mammals (interesting that females are bigger in a substantial minority, but this is not well-studied). Larger mass of males is due to ↑ protein anabolic activity and ↓ in amino acid catabolism in muscle and in protein matrix of bone.

Not all muscles are equally affected. Those muscles that are involved in male-male competition or female choice, or mating itself, are more responsive to T effects.

Anabolic steroids in athletics: exogenous androgens (usually synthetic) taken to build muscle mass, or to allow harder training without muscle breakdown. This works, but requires high doses. Negative feedback on hypothalamus and AP causes ↓ FSH and ↓ LH secretion and can lead to sterility with prolonged high doses. Some synthetic steroids have weak feedback.

Sex-changing fish: E.g. the Medaka, *Oryzias latipes*. Genetically, females are XX and males XY. Can change physically (fin size and shape, color) and behaviorally to other sex. Estrone converts an XY male into a phenotypic female. Testosterone converts an XX female into a phenotypic male. Interestingly, this means that a female might produce eggs that carry a Y chromosome, or a male might produce sperm with an X chromosome. Consequently, get YY individuals sometimes. These are viable males that father only sons.

C. *Sexual Behavior*

Two components of male sexual behavior: *motivation* and *performance*.

These two components are under independent control. *Androgens stimulate both components*, by binding to sites in:

Amygdala (mainly olfactory inputs) controls *motivation* to mate
Preoptic area (mainly visual inputs) controls *mating performance*

Experiments with rats by Everitt & Stacey show these effects well.

(Overhead: Baum, Fig. 4.5 p. 110 - experimental chamber)

Male must press lever 10x to gain access to female - rate of lever pressing measure motivation, independent of mating performance.

Once female is in compartment with male, % that copulate is measure of performance.

(Overhead: Fig 4.6, p.111 - results)

1. Castration reduces both motivation and performance, because it reduces T levels.
2. Lesions in amygdala reduce motivation, but once female is in chamber, all of these males mate normally.
3. Lesions in pre-optic area don't affect motivation, but these males don't mate once the female is in chamber (even though they have worked specifically to get access to female).

Note that this issues are not well studied outside of a few rodents - and there may be interspecific differences in control of these behaviors.

In many species, rates of mating behavior *do not correlate* with mating behavior. E.g. most birds, most primates. Nonetheless, androgen levels fluctuate a great deal in these species - so what is this variation doing? Current thought is that variation in T levels are tied to need for aggressive & paternal behavior.

D. Aggression: Wingfield's Challenge Hypothesis

Over about 30 years, John Wingfield and coworkers have studied behavioral endocrinology of many bird species in the wild, leading to the following view of the relationships between testosterone, aggression, reproduction, and mating systems.

(Overhead: Wingfield et al 1990, Fig.1 - schematic of T levels)

1. Remember that Leydig cells of bird testis are renewed each year.
2. At onset of breeding season, T levels rise from a very low nonbreeding baseline to breeding baseline.
3. Breeding baseline is sufficient for all reproductive behaviors, developments of secondary sexual characteristics and spermatogenesis.

(Overhead: Wingfield et al, Fig 2: schematic of point 3)

4. Nonetheless, increased T levels above the breeding baseline are commonly seen - what is this 'extra' T doing? Wingfield argues that ↑T above the breeding baseline up

to the physiological maximum causes \uparrow aggression, especially in periods with 'social instability'. Also argues that $\uparrow T \rightarrow \downarrow$ paternal care of young.

(**Overhead:** Wingfield et al, Fig. 3: aggression and care as functions of T)

(**Overhead:** Wingfield & Hahn 94, Fig 5a: $T \uparrow$ during simulated territorial intrusion)

5. In monogamous species, males provide extensive care for young . If T interferes with paternal care, they must reduce T once young appear. In polygynous species, Males provide little care for young, so T levels are less constrained to be low.
6. In polygynous species, the main factor determining number of offspring for males is access to females, so need aggression to defend mates from intruders, and to fight for access to females in *other* males' territories.
7. These arguments predict different profiles of T concentration over time for males in different mating systems:

(**Overhead:** Wingfield et al Fig. 4 - predicted T profiles for single broods)

(**Overhead:** Wingfield et al Fig. 5 - " " " " for double broods)

Do see patterns very much like those predicted.

(**Overhead:** Figs 3 & 4 Wingfield et al 1997)

8. A basic prediction is that males in polygynous species keep T levels near physiological maximum throughout the breeding season, while males in monogamous species reduce T except when establishing nests or during egg laying (aggression necessary at these times, reduce at other times to facilitate care of nestlings).

Challenges are intrusions by other males during the breeding season, especially territorial establishment or at laying.

Monogamous males' T responds to behavioral challenges (rising from breeding baseline to maximum).

Polygynous males' T does not respond to challenges (its already at maximum, so it can't respond).

(**Overhead:** Wingfield et al, 1990, Fig 7: test of this hypothesis - it does pretty well.)

9. A caveat. This idea has been tested with few mammals. In dwarf mongoose (*Helogale parvula*), data don't support the hypothesis. Males provide lots of care for young, so T should respond to challenges. But T levels show no response to periods of aggression.

(**Overhead:** Creel et al 1990, Figs 1,2,3 and Table 1)