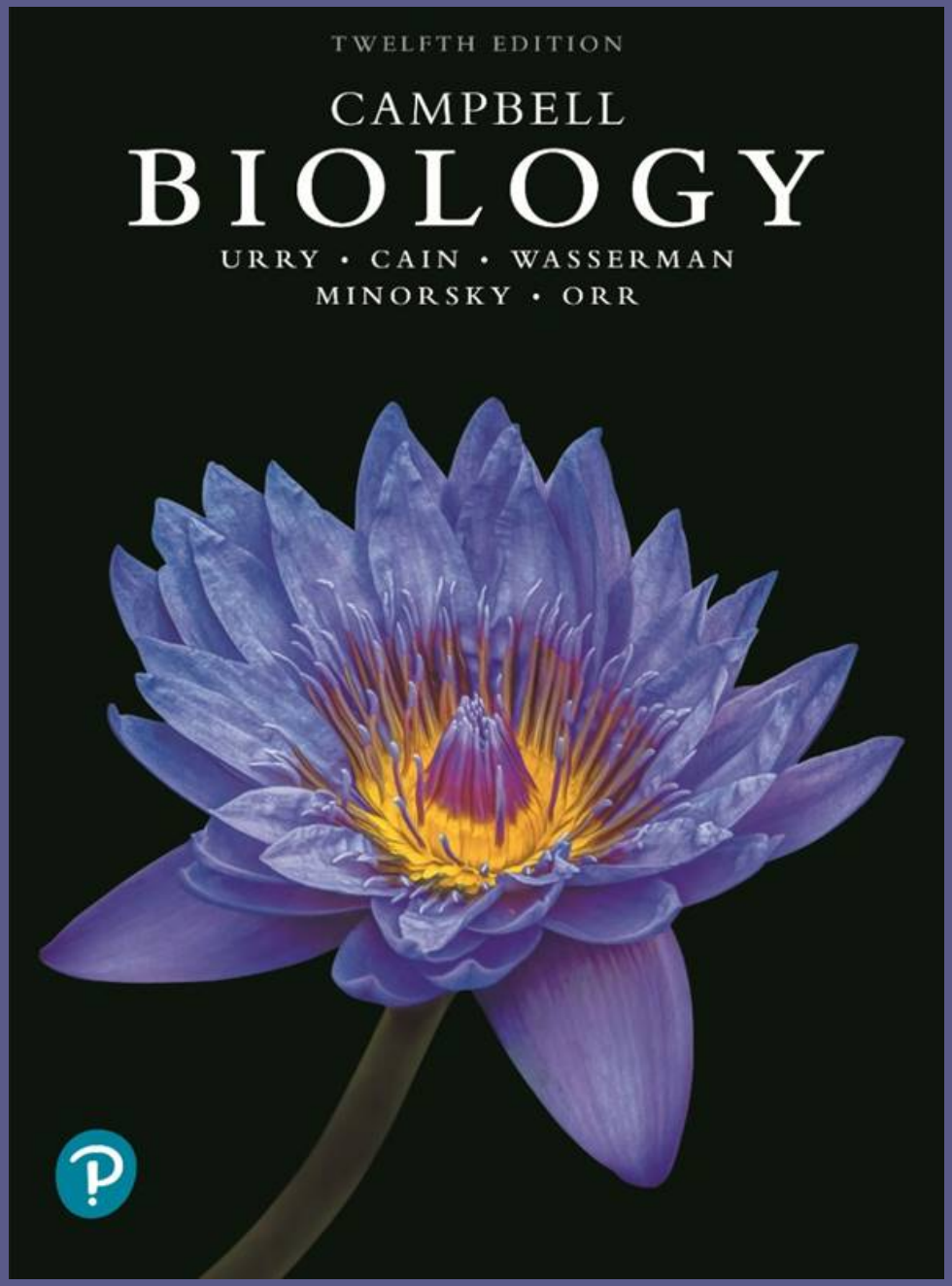


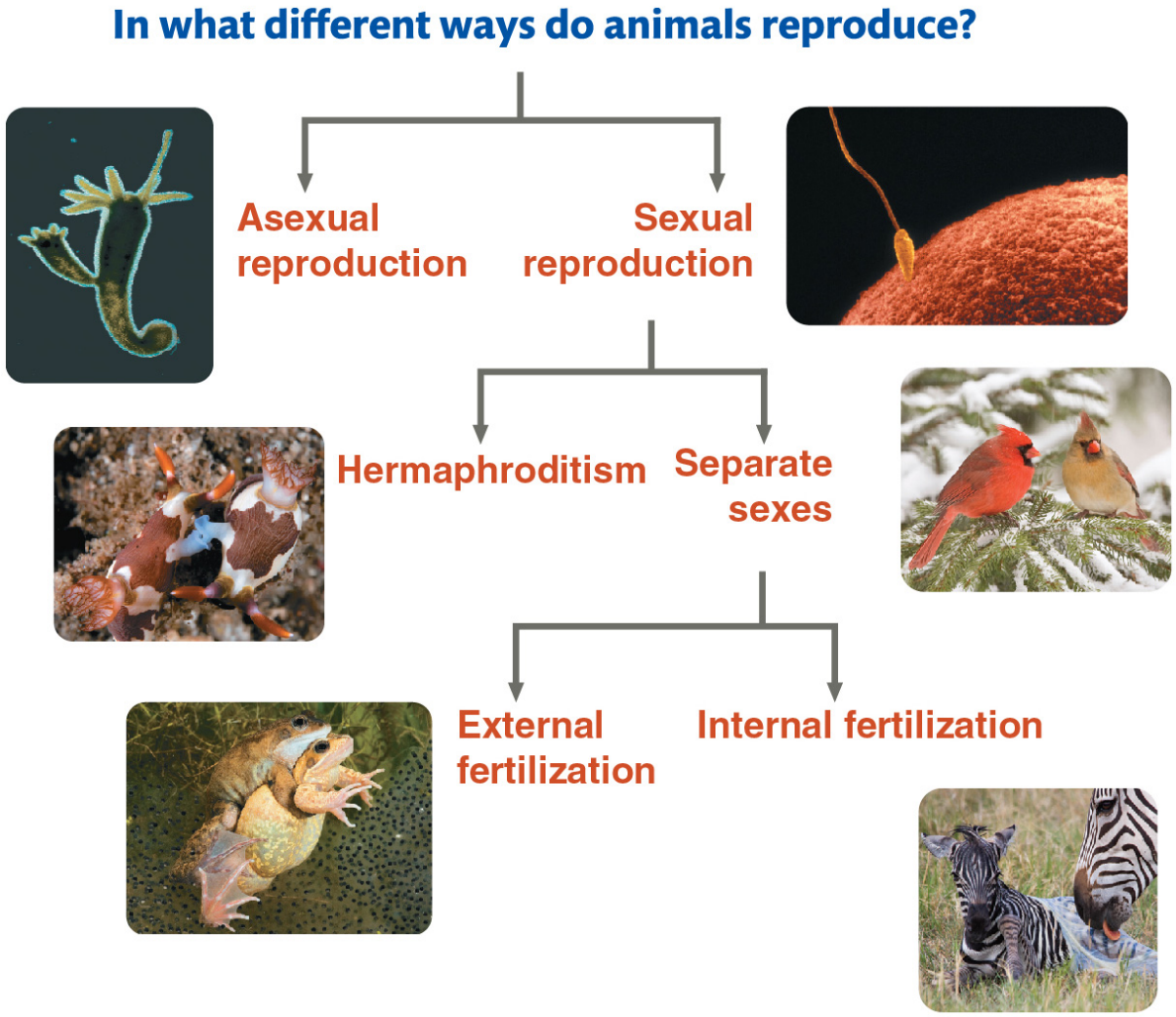
Chapter 46

Animal Reproduction

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

Figure 46.1a

Figure 46.1b


In what different ways do animals reproduce?
Asexual reproduction
Sexual reproduction
Hermaphroditism
Separate sexes
External fertilization
Internal fertilization

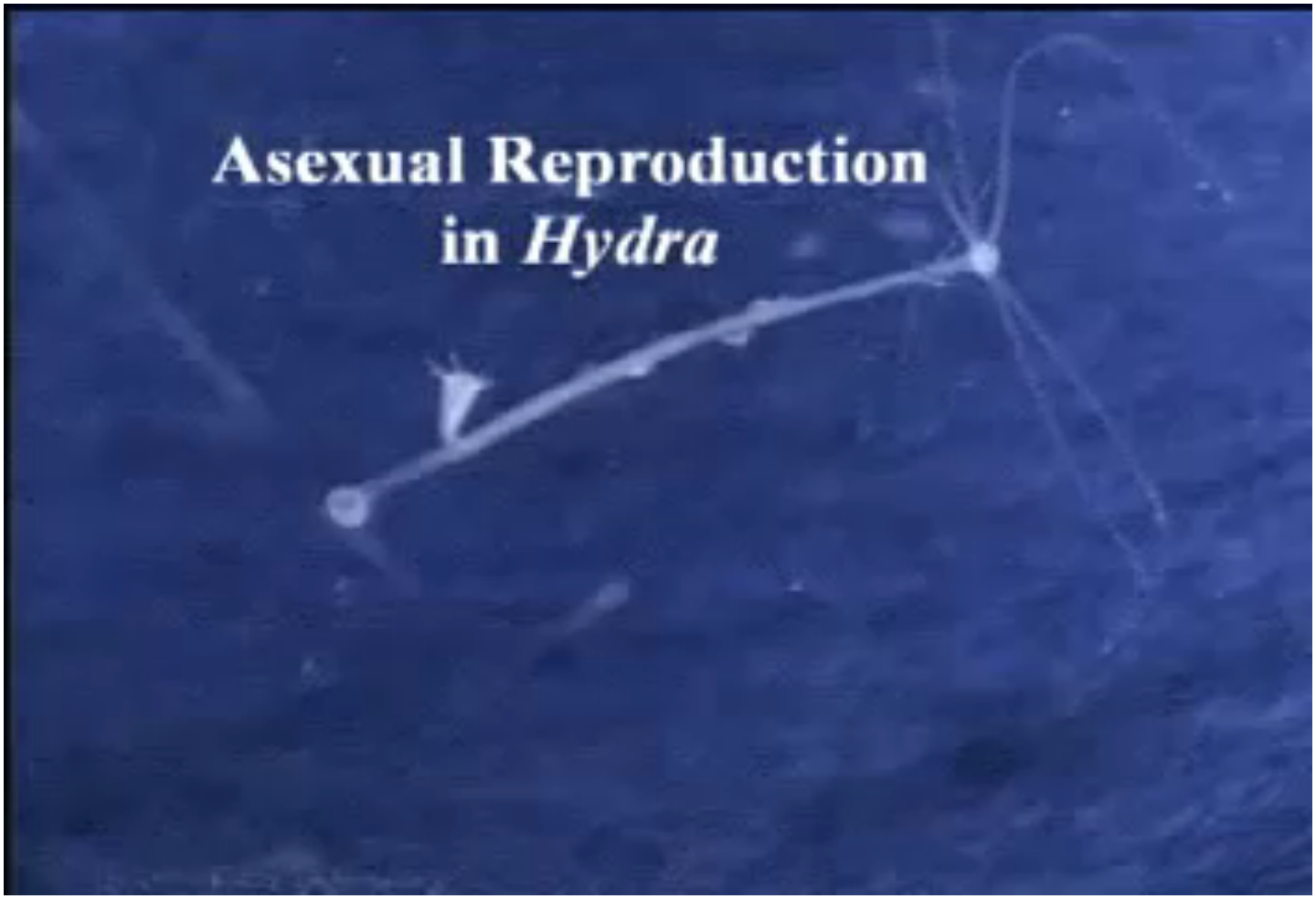
CONCEPT 46.1: Both asexual and sexual reproduction occur in the animal kingdom

- **Sexual reproduction** is the creation of an offspring by fusion of haploid gametes, male **sperm** and female **eggs**, to form a diploid **zygote**
- **Asexual reproduction** is creation of offspring without the fusion of egg and sperm

Mechanisms of Asexual Reproduction

- Budding is a simple form of asexual reproduction found only among invertebrates
- New individuals arise from outgrowths of existing ones
- Many invertebrates reproduce asexually by **fission**, separation of a parent into two or more individuals of about the same size

Video: Hydra Budding



- Fragmentation is breaking of the body into pieces, some or all of which develop into adults
- Fragmentation must be accompanied by regeneration, regrowth of lost body parts
- **Parthenogenesis** is the development of a new individual from an unfertilized egg
- Parthenogenesis is mainly observed in invertebrates, but is observed rarely in some vertebrates

Variation in Patterns of Sexual Reproduction

- For many sexually reproducing animals, finding a partner for reproduction can be challenging
- In **hermaphroditism**, each individual has both male and female reproductive systems
- Any two individuals can mate under this system, and in some species, hermaphrodites can also self-fertilize
- Several organisms can change their sex under certain circumstances

Figure 46.2

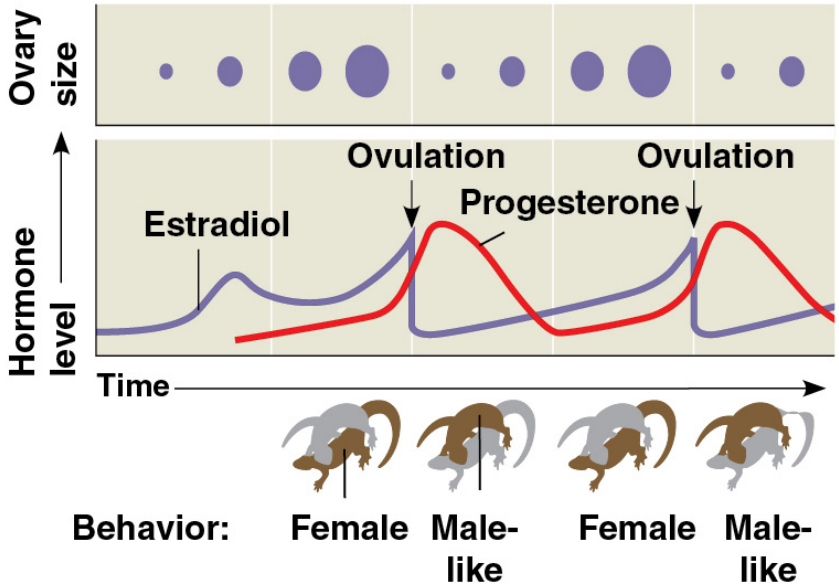
Reproductive Cycles

- Most animals exhibit reproductive cycles related to changing seasons
- Reproductive cycles are controlled by hormones and environmental cues
- **Ovulation** is the release of mature eggs at the midpoint of a female cycle
- Because seasonal temperature is often an important cue in reproduction, climate change can decrease reproductive success

- Some organisms can reproduce sexually or asexually, depending on conditions
- *Daphnia* reproduce asexually when environmental conditions are favorable, and sexually during times of stress
- Whiptail lizards are all female but go through courtship and mating behavior in which one female mimics males
- Over the course of the breeding season the lizards alternate roles several times

Figure 46.3

(a) *A. uniparens* females

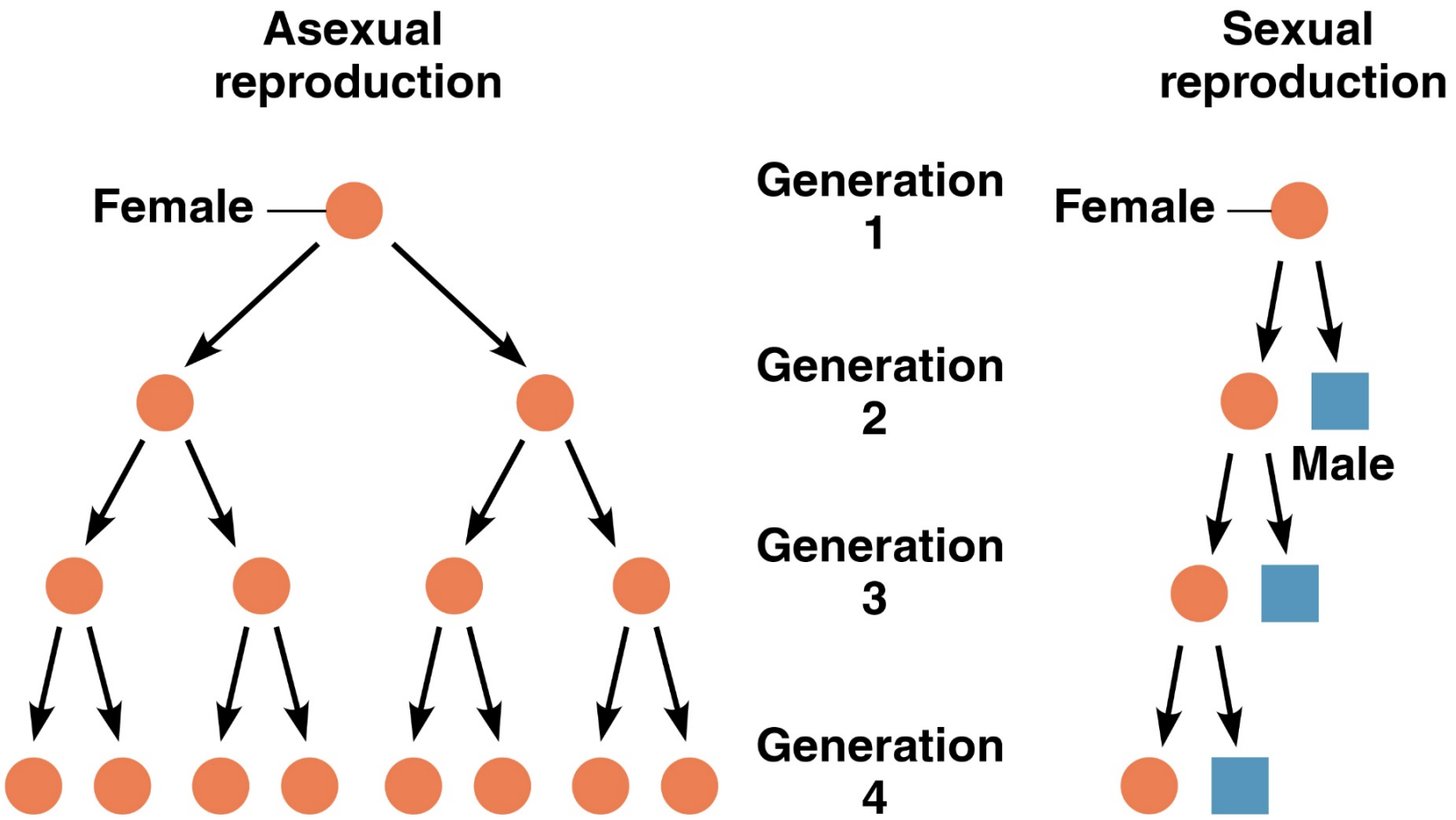


(b) The changes in sexual behavior of *A. uniparens* individuals are correlated with the cycles of ovulation.

Sexual Reproduction: An Evolutionary Enigma

- Sexual females have half as many daughters as asexual females; this is the “twofold cost” of sexual reproduction
- Despite this, almost all eukaryotic species reproduce sexually
- The reasons for this are uncertain

Figure 46.4


Asexual reproduction
Sexual reproduction
Female
Female
Male
Generation 1
Generation 2
Generation 3
Generation 4

- Sexual reproduction may enhance reproductive success of parents when environmental factors change relatively rapidly
- This is due to their production of genetically varied offspring
- Asexual reproduction is expected to be most advantageous in stable, favorable environments

CONCEPT 46.2: Fertilization depends on mechanisms that bring together sperm and eggs of the same species

- **Fertilization**, the union of egg and sperm, can be external or internal
- In external fertilization, eggs shed by the female are fertilized by sperm in the external environment
- A moist habitat is always required for external fertilization to allow sperm to swim to the egg and to prevent the gametes from drying out

Figure 46.5

- Some species with external fertilization exhibit spawning, in which individuals cluster in the same area to release their gametes into the water at the same time
- In some cases, chemical signals trigger spawning; in others, environmental cues are responsible

- Internal fertilization is an adaptation that enables sperm to reach an egg despite a dry external environment
- Internal fertilization requires behavioral interactions and compatible copulatory organs
- Mating animals may make use of pheromones, chemicals released by one organism that influence the physiology and behavior of individuals of the same species

Ensuring the Survival of Offspring

- Internal fertilization is typically associated with production of fewer gametes but the survival of a higher fraction of zygotes
- Internal fertilization is also often associated with mechanisms to provide protection of embryos and parental care of young

- Internally fertilized eggs of birds and other reptiles have shells and internal membranes
- These protect against water loss and physical damage as the embryos develop
- Some animals retain the embryo, which develops inside the female
- In many animals, parental care helps ensure survival of offspring

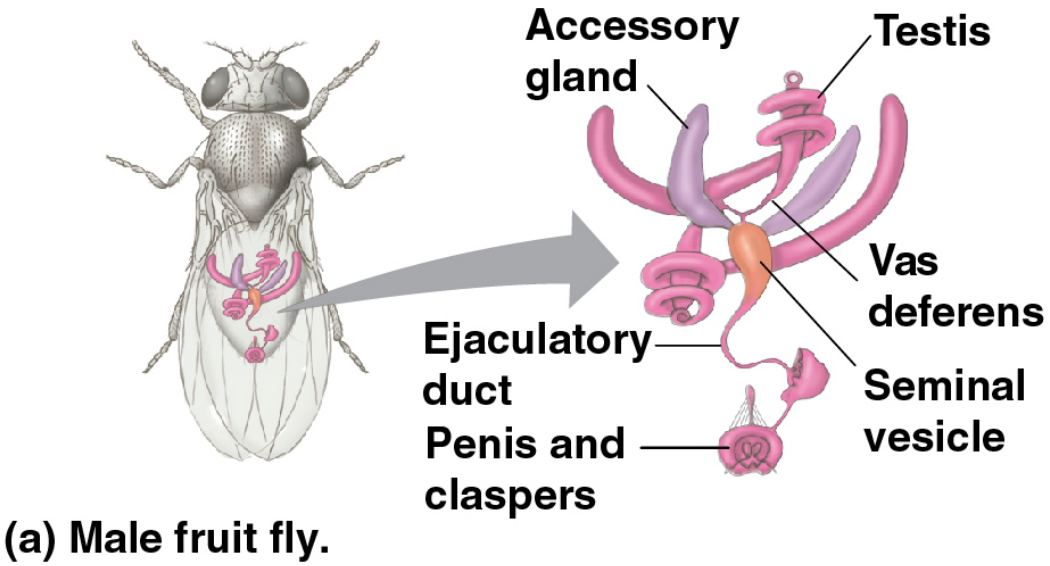
Figure 46.6

Gamete Production and Delivery

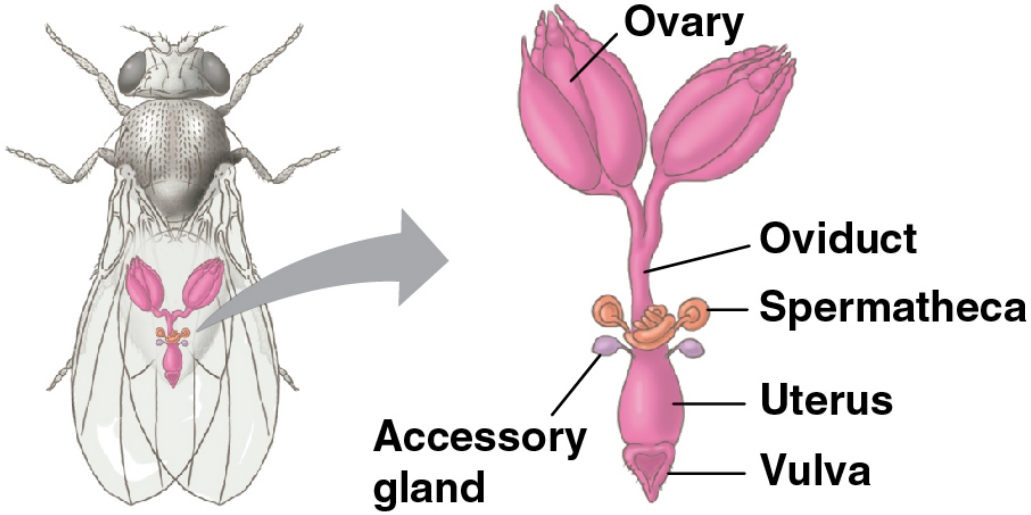
- To reproduce sexually, animals must produce gametes from precursor cells
- In most species, individuals have **gonads**, organs that produce gametes
- Some organisms do not have gonads, but gametes form from undifferentiated tissue
- More elaborate systems include sets of accessory tubes and glands that carry, nourish, and protect gametes and developing embryos

- Most insects have separate sexes with complex reproductive systems
- In many insects, the female has a **spermatheca** in which sperm is stored during copulation
- The female then fertilizes her eggs under conditions likely to promote survival of offspring

Figure 46.7



(a) Male fruit fly.



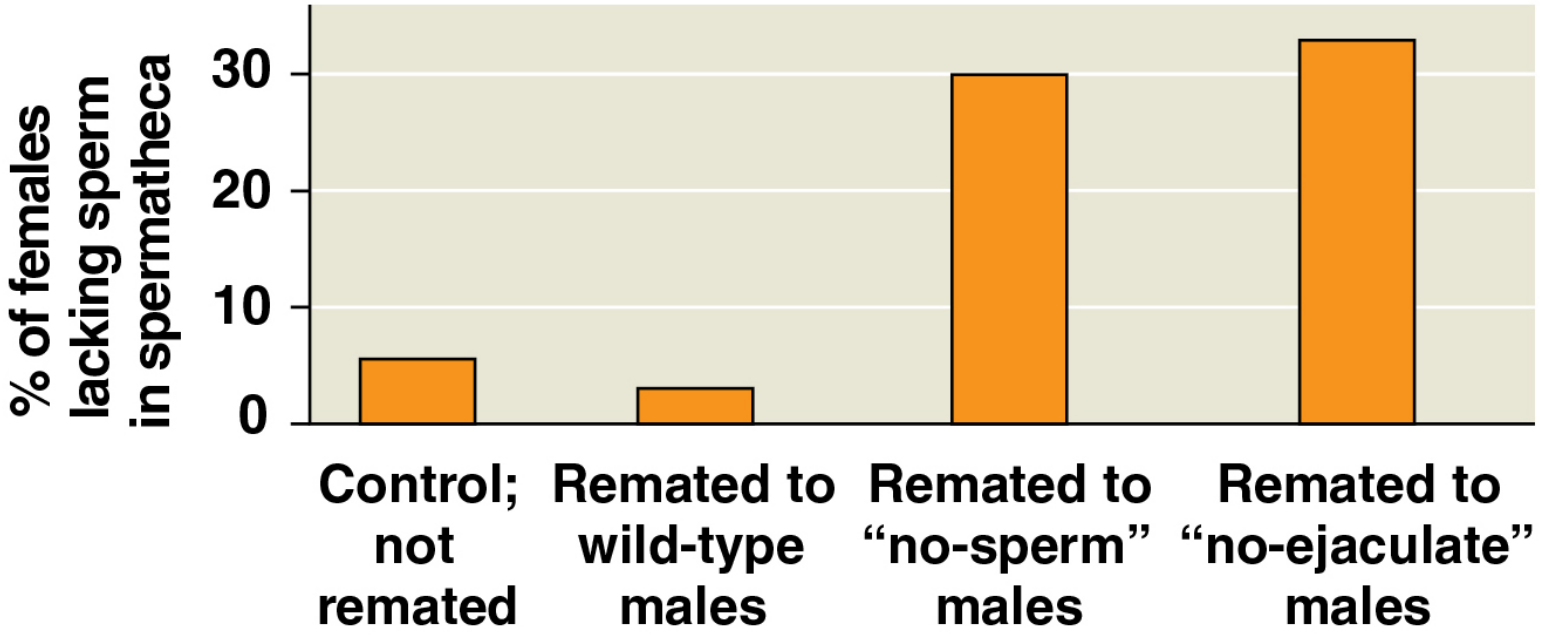
(b) Female fruit fly.

- A **cloaca** is a common opening between the external environment and the digestive, excretory, and reproductive systems
- A cloaca is common in nonmammalian vertebrates; mammals usually have a separate opening to the digestive tract

- Monogamy is relatively rare among animals
- Males and/or females of some species have evolved mechanisms to decrease the chance of their mate mating with another individual
- Females can sometimes influence the relative reproductive success of their mates

Figure 46.8

Results



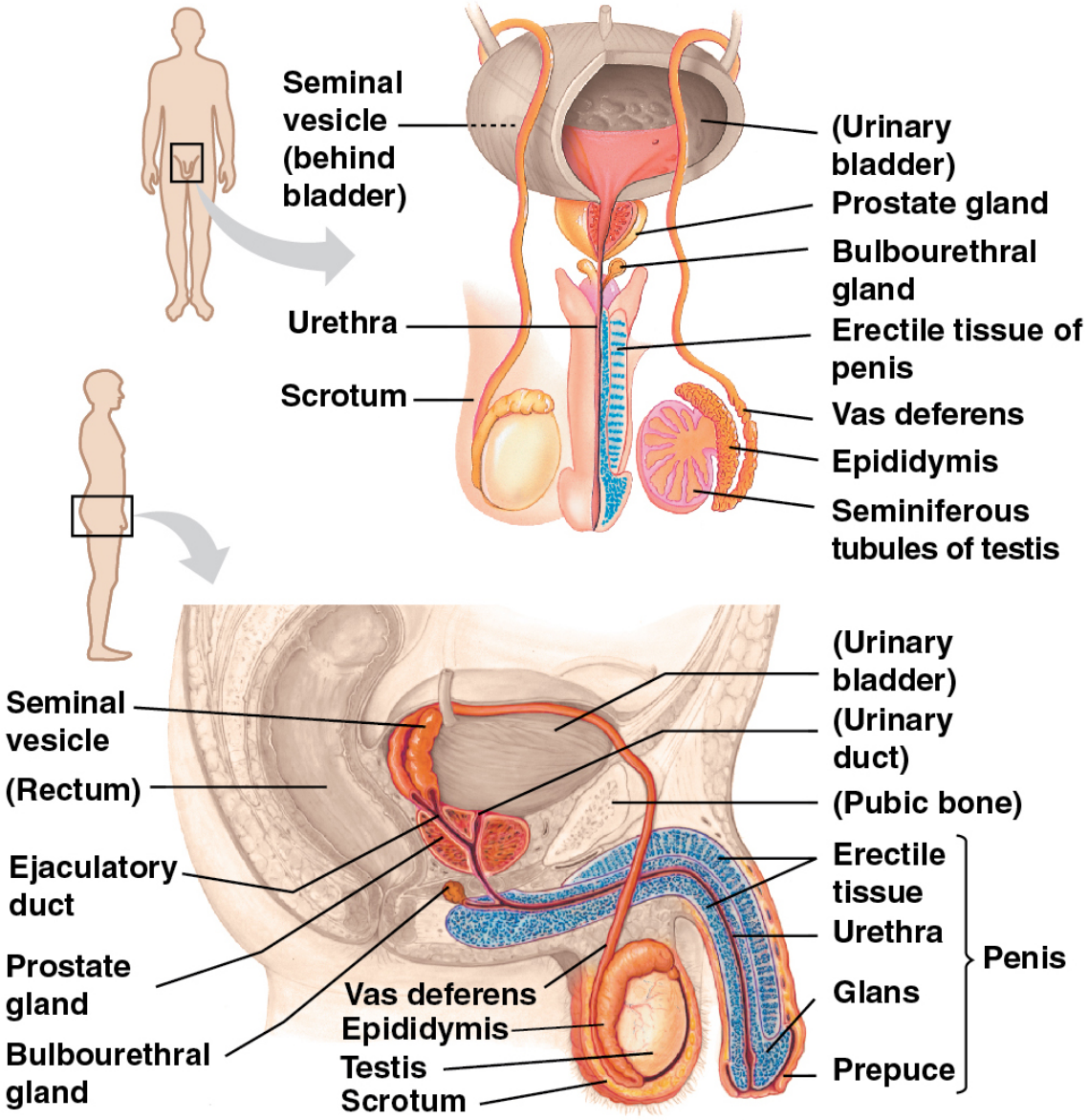
CONCEPT 46.3: Reproductive organs produce and transport gametes

- This section focuses on the human reproductive system

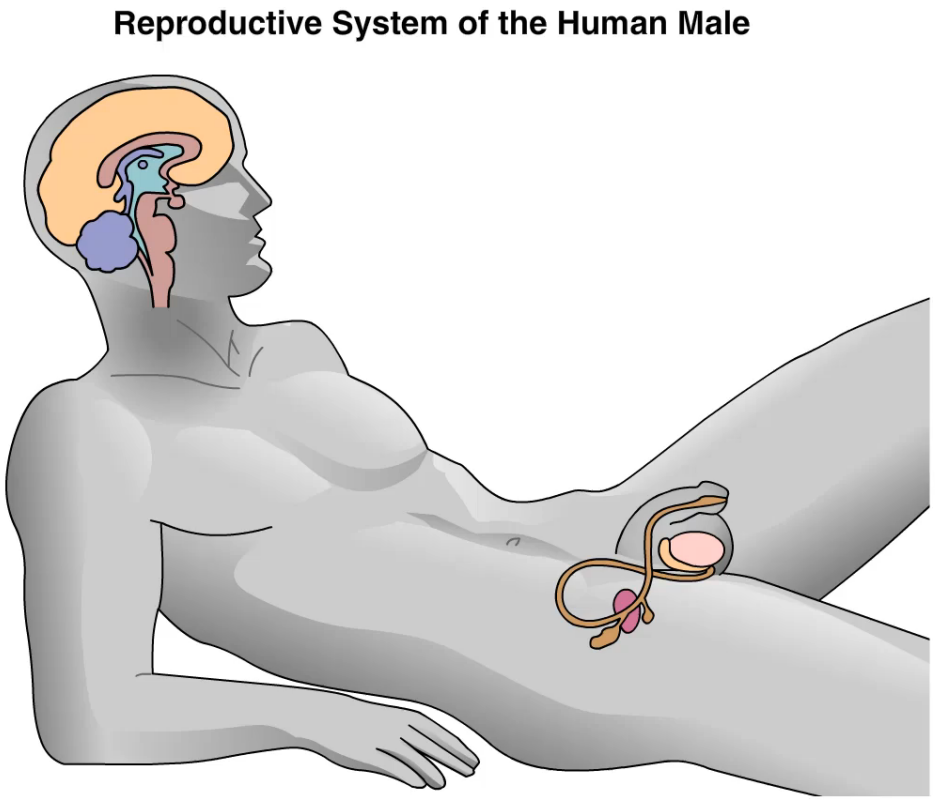
Human Male Reproductive Anatomy

- The male's external reproductive organs are the scrotum and penis
- Internal organs are the gonads that produce sperm and hormones, accessory glands that secrete products needed for sperm movement, and ducts that carry sperm and glandular secretions

Figure 46.9


Seminal vesicle (behind bladder)
Urethra
Scrotum
(Urinary bladder)
Prostate gland
Bulbourethral gland
Erectile tissue of penis
Vas deferens
Epididymis
Seminiferous tubules of testis
Seminal vesicle
(Rectum)
Ejaculatory duct
Prostate gland
Bulbourethral gland
Vas deferens
Epididymis
Testis
Scrotum
(Urinary bladder)
(Urinary duct)
(Pubic bone)
Erectile tissue
Urethra
Glans
Prepuce
Penis

Animation: Male Reproductive Anatomy



Testes

- The male gonads, or **testes**, produce sperm in highly coiled tubes called **seminiferous tubules**
- Production of normal sperm cannot occur at the body temperatures of most mammals
- The testes of many mammals are held outside the abdominal cavity in the **scrotum**, where the temperature is lower than in the abdominal cavity

Ducts

- From the seminiferous tubules of a testis, sperm pass into the coiled duct of the **epididymis**
- In humans, it takes 3 weeks for the sperm to travel the 6-m length of this duct
- During **ejaculation**, sperm are propelled through the muscular **vas deferens** and the ejaculatory duct, and then exit the penis through the **urethra**

Accessory Glands

- **Semen** is composed of sperm plus secretions from three sets of accessory glands
- The two **seminal vesicles** contribute about 60% of the total volume of semen
- The **prostate gland** secretes its products directly into the urethra through several small ducts
- The bulbourethral glands secrete a clear mucus before ejaculation that neutralizes acidic urine remaining in the urethra

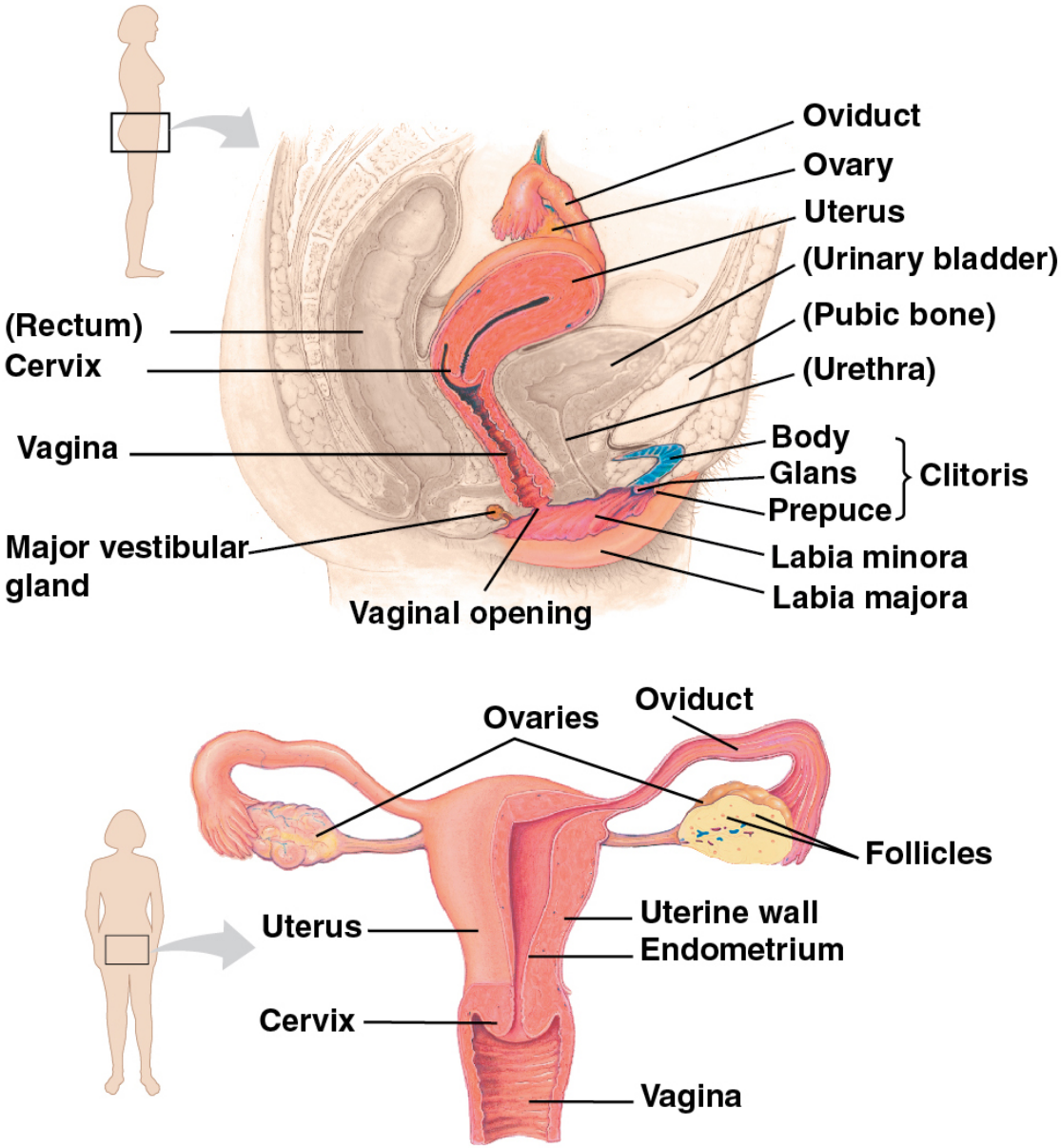
Penis

- The human **penis** is composed of three cylinders of spongy erectile tissue
- During sexual arousal, the erectile tissue fills with blood from the arteries, causing an erection
- The head of the penis, or **glans**, has a thinner skin covering than the shaft and is more sensitive to stimulation
- The glans is surrounded by a fold of skin called the prepuce, or foreskin

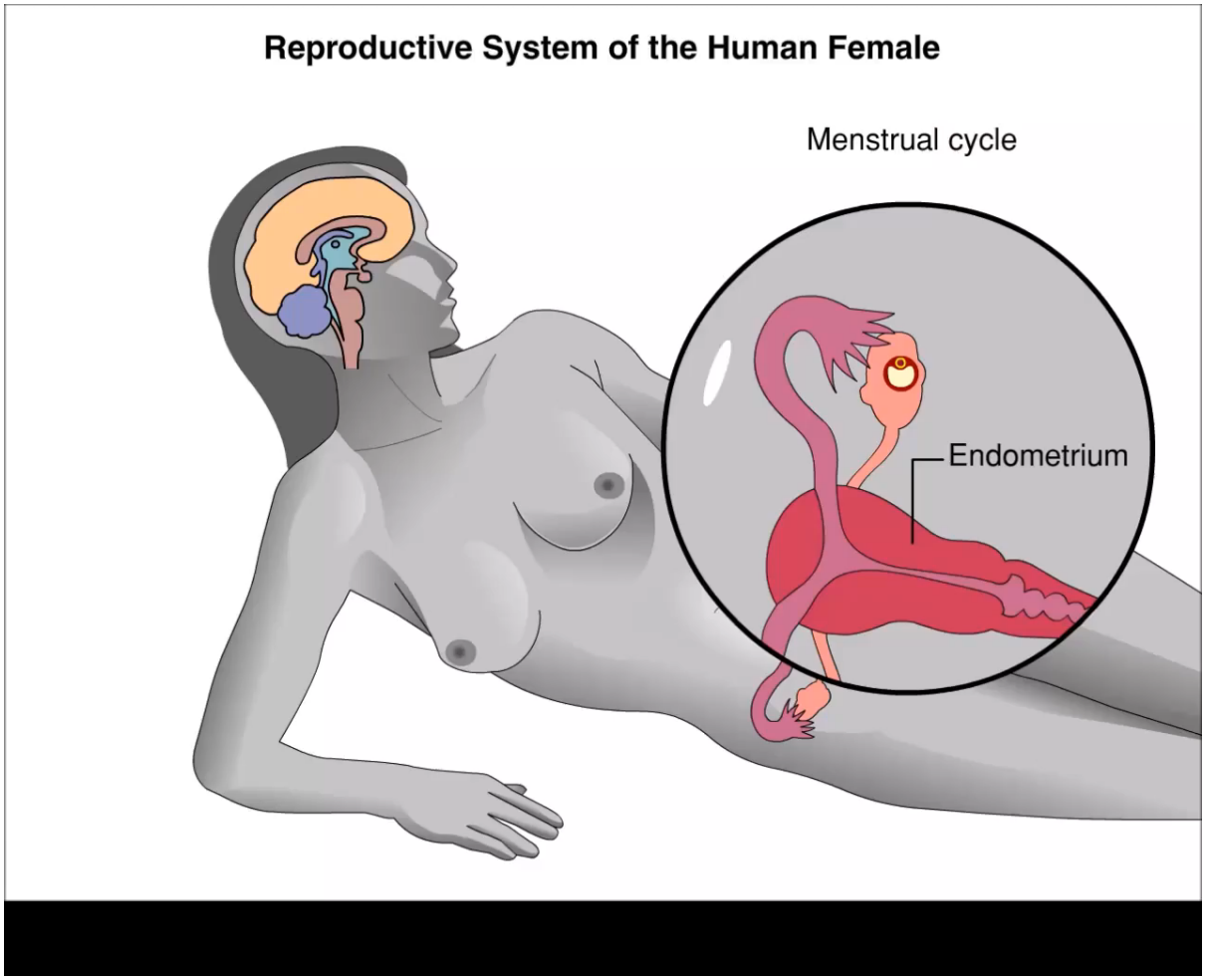
Human Female Reproductive Anatomy

- The female external reproductive structures include the clitoris and two sets of labia
- The internal organs are a pair of gonads and a system of ducts and chambers that carry gametes and house the embryo and fetus

Figure 46.10


Oviduct
Ovary
Uterus
(Urinary bladder)
(Pubic bone)
(Urethra)
(Rectum)
Cervix
Vagina
Body
Glans
Prepuce
Clitoris
Major vestibular gland
Vaginal opening
Labia minora
Labia majora
Ovaries
Oviduct
Follicles
Uterus
Uterine wall
Endometrium
Cervix
Vagina

Animation: Female Reproductive Anatomy



Ovaries

- The female gonads, the **ovaries**, flank the uterus in the abdominal cavity
- Each ovary contains many **follicles**, which consist of a partially developed egg, called an **oocyte**, surrounded by support cells

Oviducts and Uterus

- The egg cell travels from the ovary to the uterus via an **oviduct**, or fallopian tube
- Cilia in the oviduct convey the egg to the **uterus**, also called the womb
- The uterus lining, the **endometrium**, has many blood vessels
- The uterus narrows at the **cervix**, then opens into the vagina

Vagina and Vulva

- The **vagina** is a muscular but elastic chamber that is the repository for sperm during copulation and serves as the birth canal
- The vagina opens to the outside at the **vulva**, which consists of the **labia majora**, **labia minora**, hymen, and **clitoris**

- The clitoris has a head called a glans covered by the prepuce, a small hood of skin
- The vagina, labia minora, and clitoris are rich with blood vessels; the clitoris also has many nerve endings

Mammary Glands

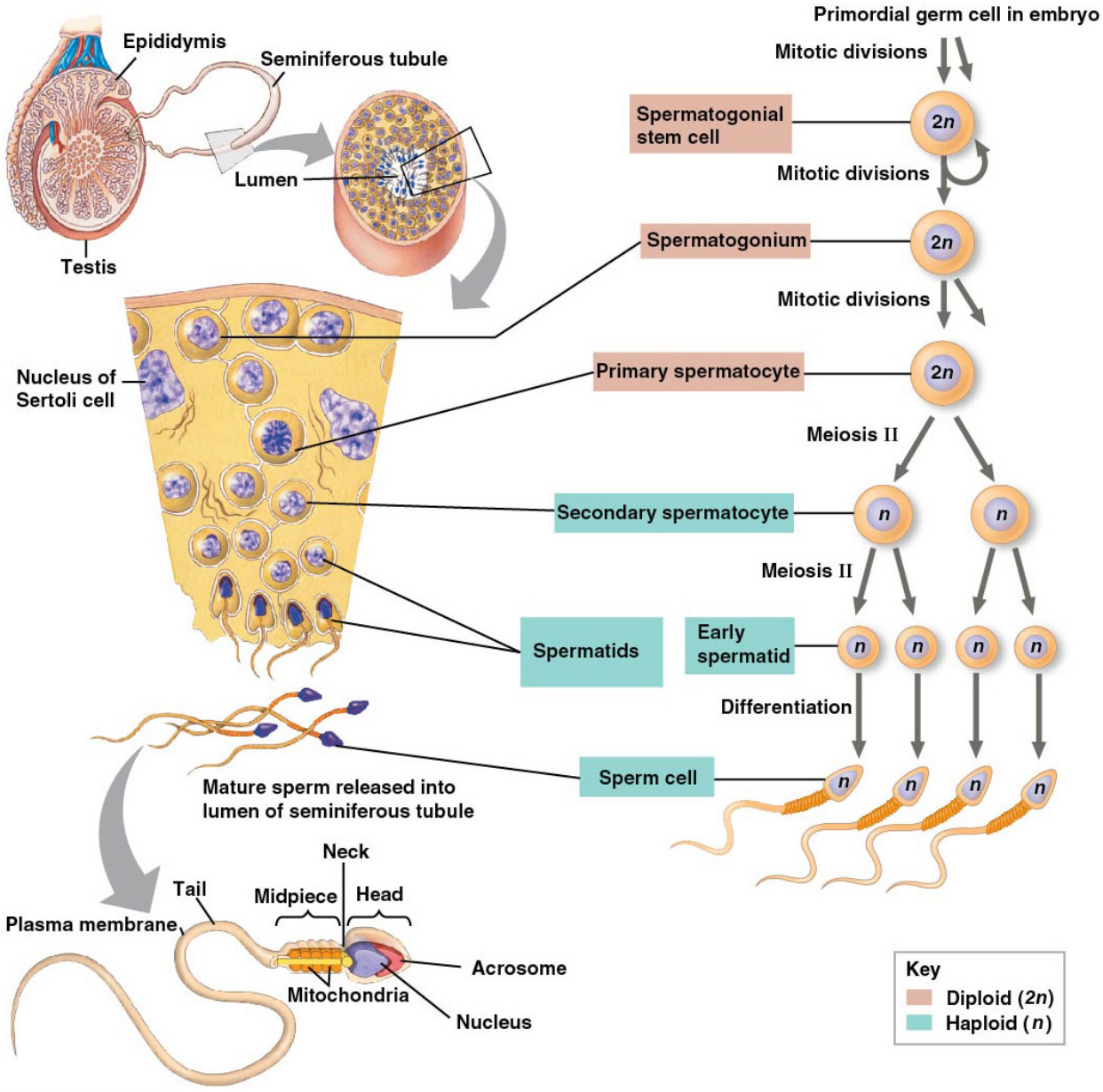
- The **mammary glands** are not part of the reproductive system but are important to mammalian reproduction
- Within the glands, small sacs of epithelial tissue secrete milk

Gametogenesis

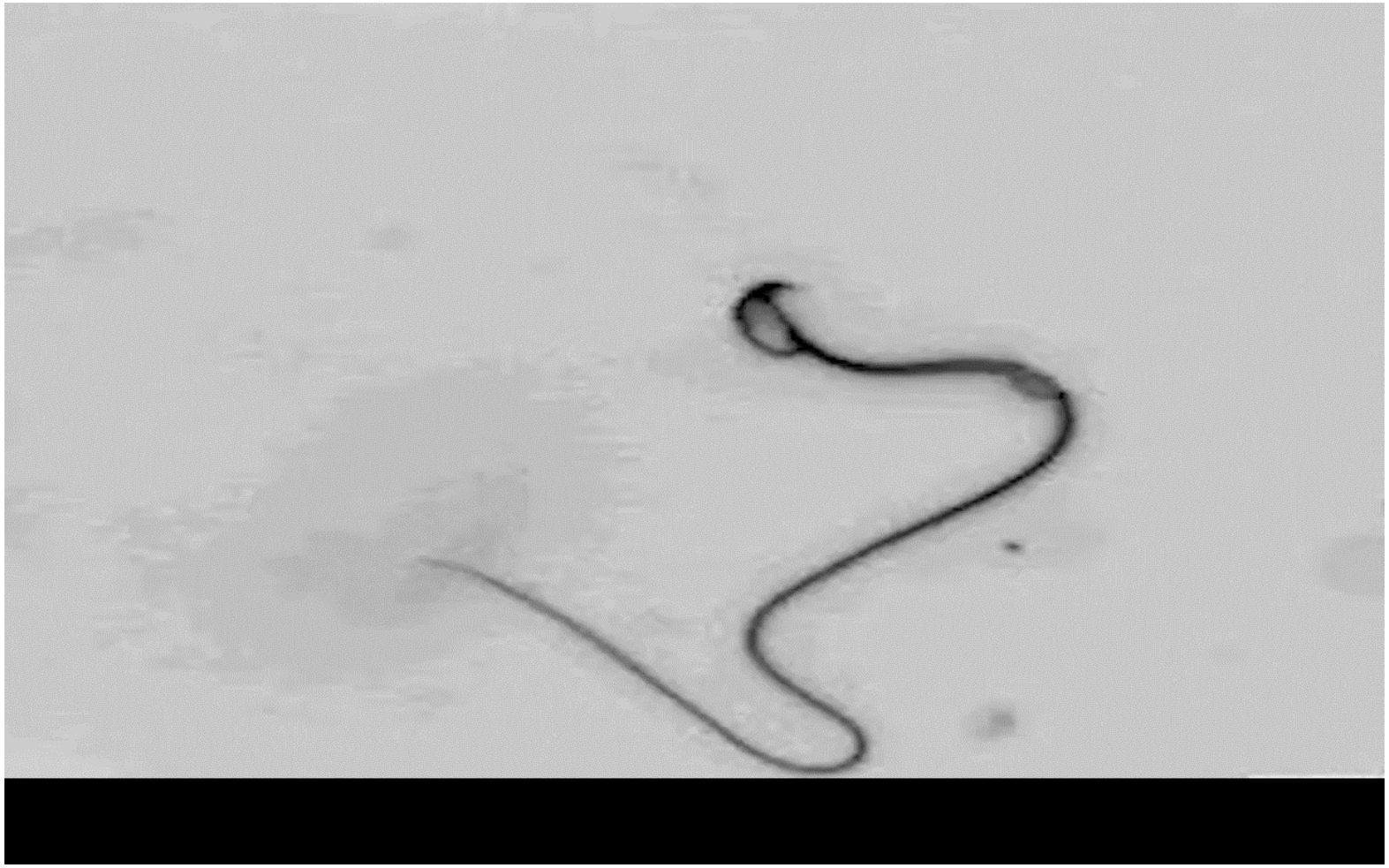
- **Gametogenesis** is the production of gametes
- There is a close relationship between the gonads' structure and their function

- **Spermatogenesis**, the formation of sperm, is continuous and prolific
- Hundreds of millions of sperm are produced per day; each sperm takes about 7 weeks to develop

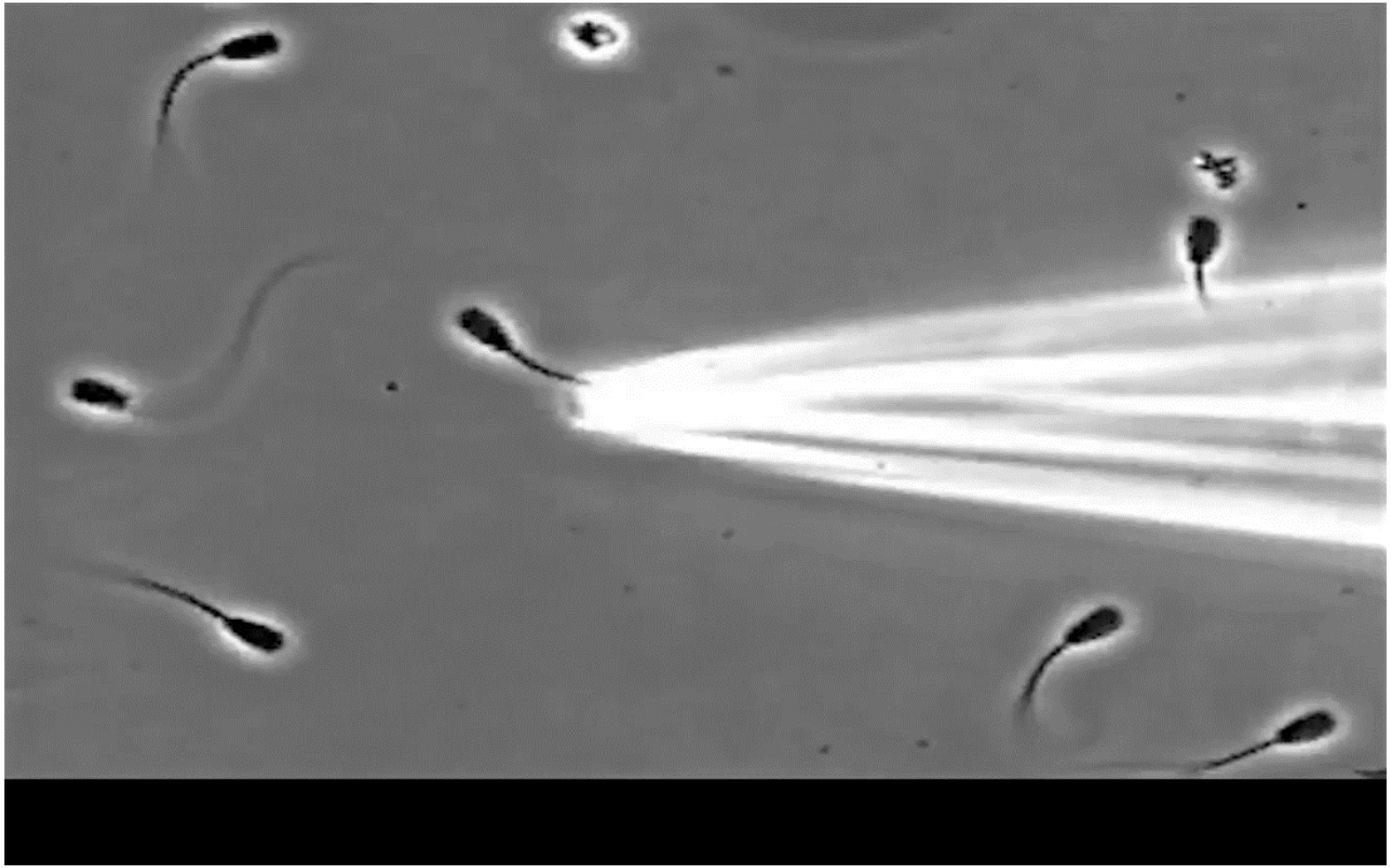
Figure 46.11_1



Video: Motion of Isolated Flagellum

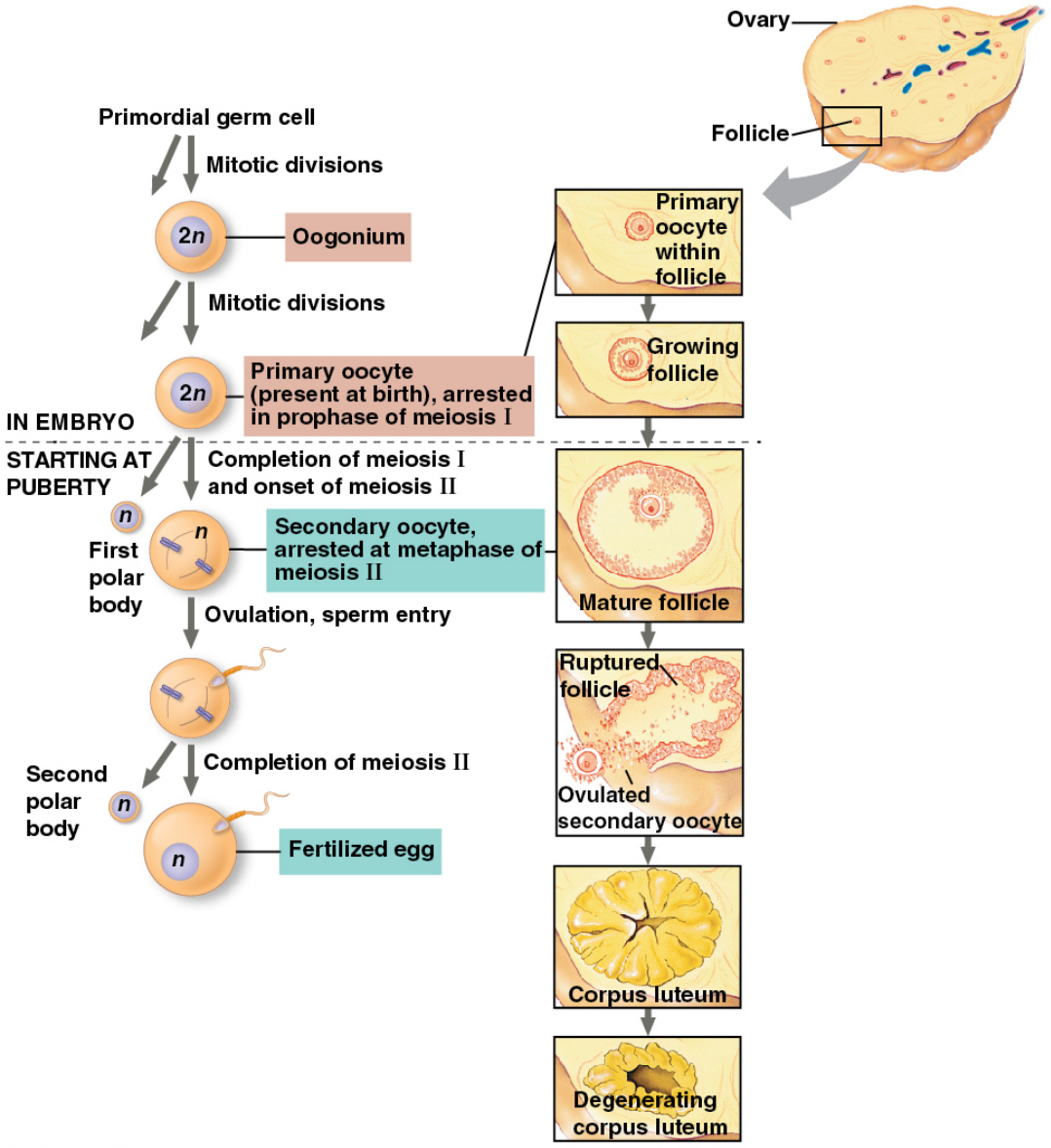


Video: Flagellum Movement in Swimming Sperm



- **Oogenesis**, the development of a mature egg, is a prolonged process
- Immature eggs form in the female embryo but do not complete their development until years or decades later

Figure 46.11_2



- Spermatogenesis differs from oogenesis in three ways:
  - All four products of meiosis develop into sperm, while only one of the four becomes an egg
  - Spermatogenesis occurs throughout adolescence and adulthood
  - Sperm are produced continuously without the prolonged interruptions in oogenesis

CONCEPT 46.4: The interplay of tropic and sex hormones regulates reproduction in mammals

- Mammalian reproduction is coordinated by hormones from the hypothalamus, anterior pituitary, and gonads
- Gonadotropin-releasing hormone (GnRH) is secreted by the hypothalamus and directs the release of **FSH (follicle-stimulating hormone)** and **LH (luteinizing hormone)** from the anterior pituitary

- FSH and LH stimulate sex hormone production by the gonads
- The main sex hormones are steroid hormones
- **Testosterone** is the main androgen
- Estrogens mainly consist of **estradiol** and **progesterone**
- Sex hormones function in gamete production, sexual behavior, and the development of primary and secondary sex characteristics

Figure 46.12

Biological Sex, Gender Identity, and Sexual Orientation in Human Sexuality

- “Biological sex” typically reflects the genitals present at birth and the child’s chromosomes
- Gender identity is distinct and refers to a person’s internal sense of being male, female, some combination, or neither
- The term cisgender describes a person having a gender identity in line with their assigned sex
- The term transgender describes a person who experiences a mismatch between their gender identity and their assigned sex

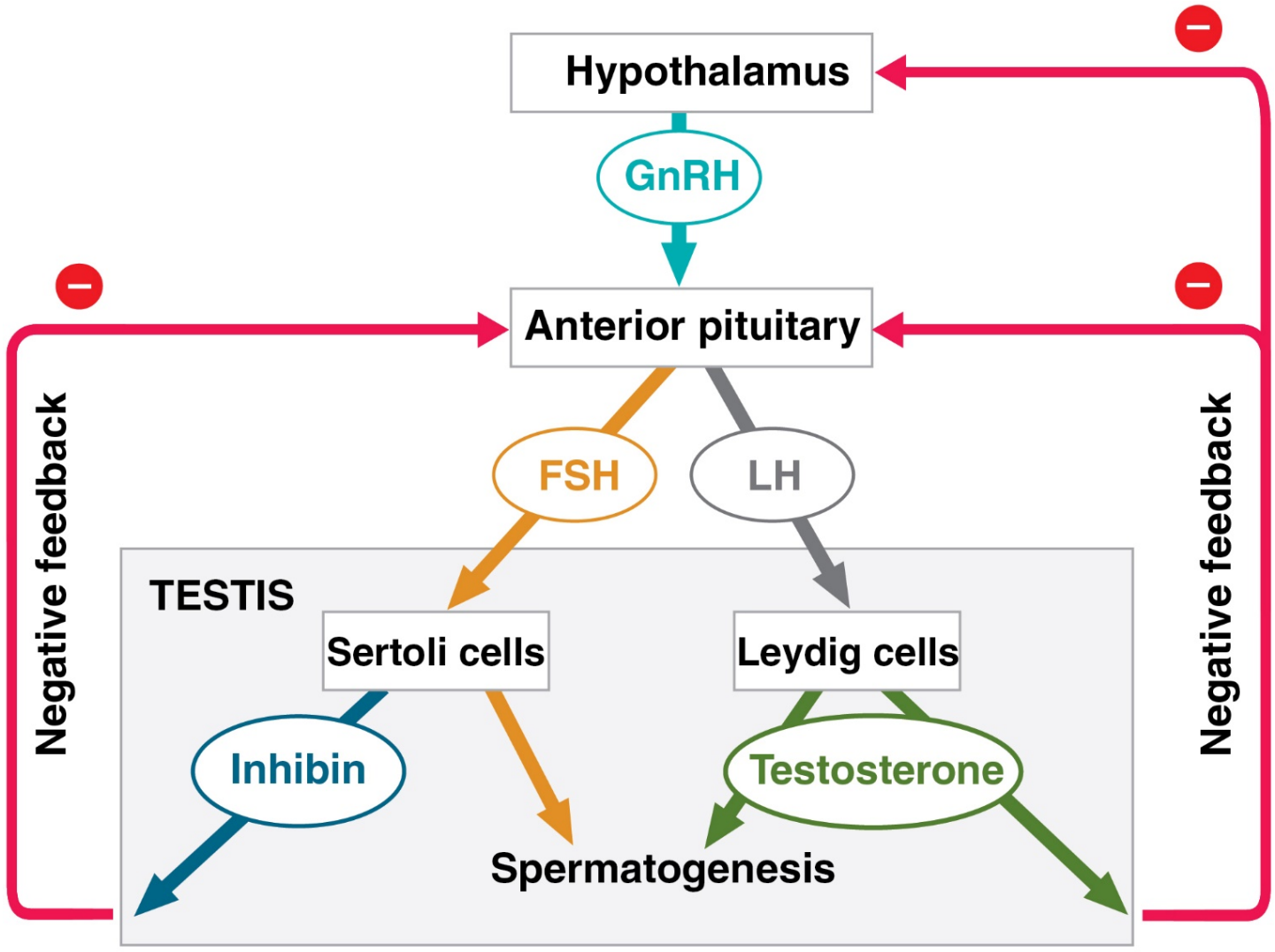
- Sexual orientation identifies the gender of people to whom an individual is attracted romantically, emotionally, and sexually
- Sexual orientation may be heterosexual, homosexual, bisexual, or asexual
- Human sexuality varies considerably

Hormonal Control of the Male Reproductive System

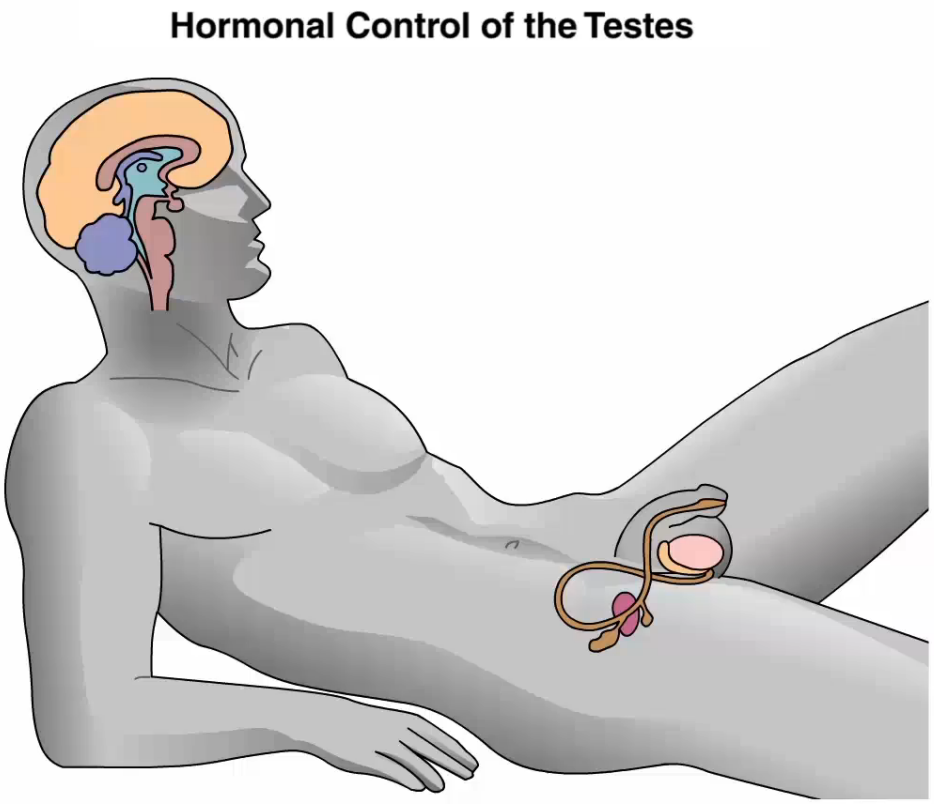
- FSH stimulates Sertoli cells to nourish developing sperm
- LH causes Leydig cells to produce testosterone and other androgens, which in turn promote spermatogenesis

- Testosterone regulates the production of GnRH, FSH, and LH through negative-feedback mechanisms
- Sertoli cells secrete the hormone inhibin, which reduces FSH secretion from the anterior pituitary

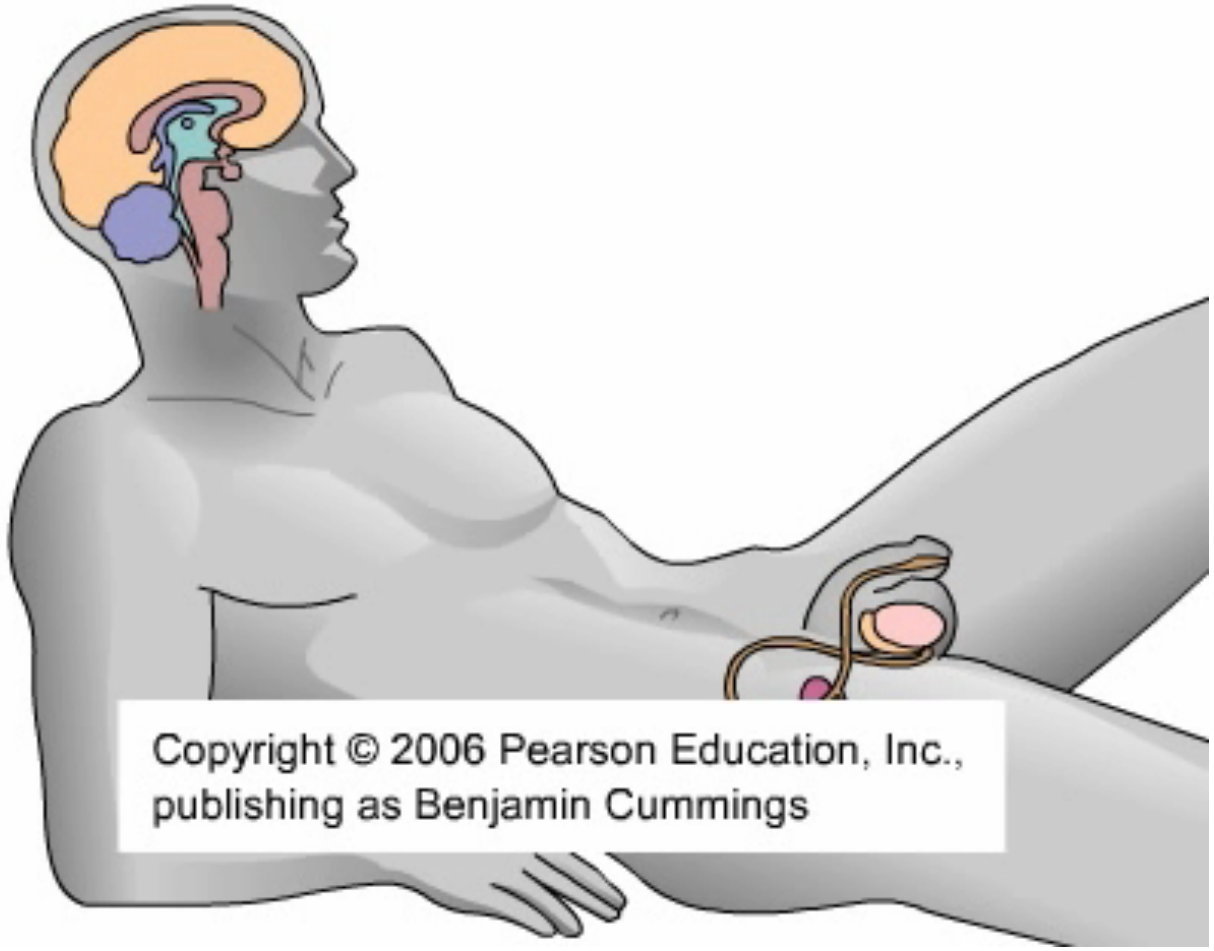
Figure 46.13


Hypothalamus
GnRH
Anterior pituitary
FSH
LH
TESTIS
Sertoli cells
Leydig cells
Inhibin
Testosterone
Spermatogenesis
Negative feedback
Negative feedback

Animation: Hormonal Control of the Testes



Animation: Male Hormones



Hormonal Control of Female Reproductive Cycles

- Hormones closely link the two cycles of female reproduction
- Changes in the ovaries define the **ovarian cycle**
- Changes in the uterus define the **menstrual cycle** (also called the **uterine cycle**)

- In each menstrual cycle, the endometrium thickens with blood vessels in preparation for embryo implantation
- If an embryo does not implant in the endometrium, the endometrium is shed in a process called **menstruation**

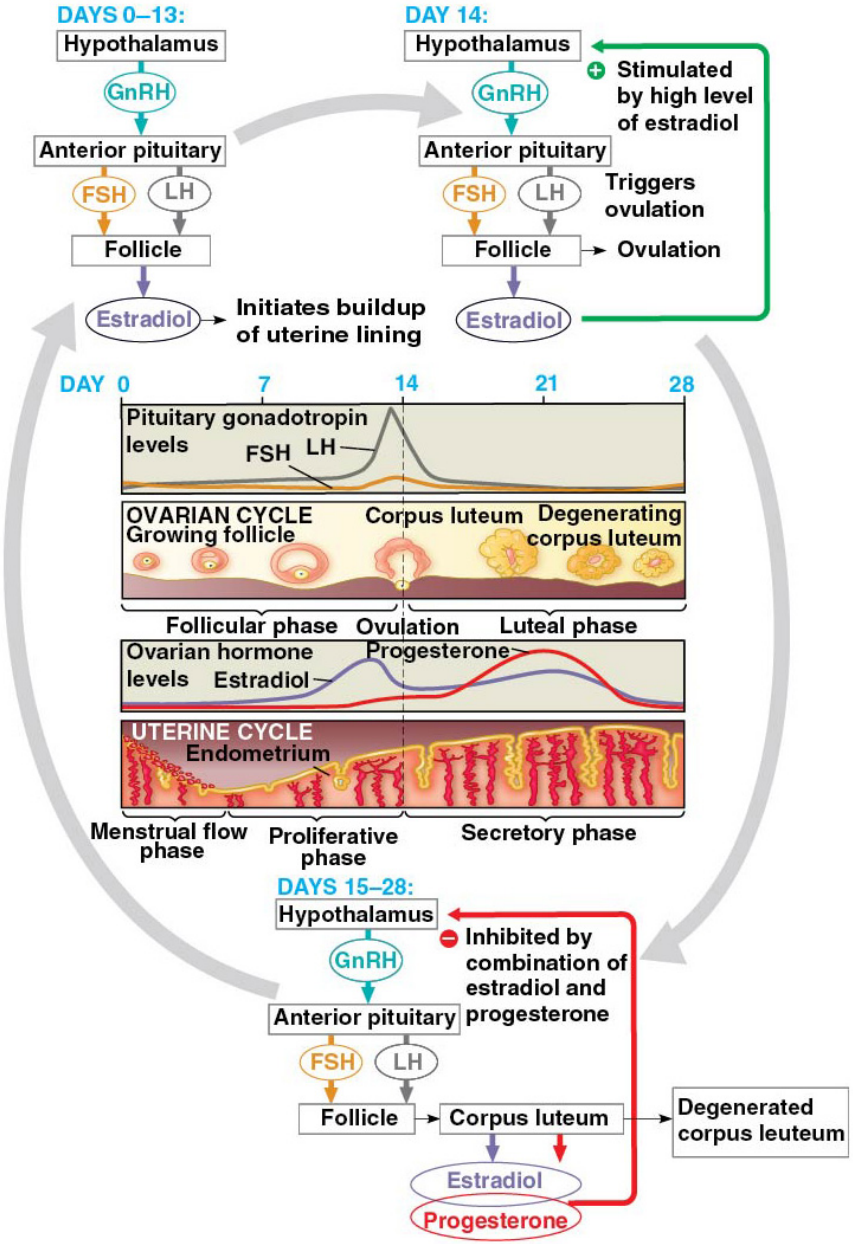
The Ovarian Cycle

- The ovarian cycle begins when the hypothalamus releases GnRH
- The GnRH stimulates the anterior pituitary to secrete small amounts of FSH and LH
- FSH stimulates follicle growth, aided by LH
- The follicles start to make estradiol

- When estradiol secretion by the follicle begins to rise steeply, FSH and LH levels increase markedly
- The maturing follicle enlarges to form a bulge at the surface of the ovary
- The follicular phase ends at ovulation, and the secondary oocyte is released
- The luteal phase follows ovulation

- LH stimulates the remaining follicular tissue to form the corpus luteum
- The corpus luteum secretes progesterone and estradiol
- These exert negative feedback on the hypothalamus and pituitary to greatly reduce LH and FSH secretion, preventing maturation of another egg

Figure 46.14

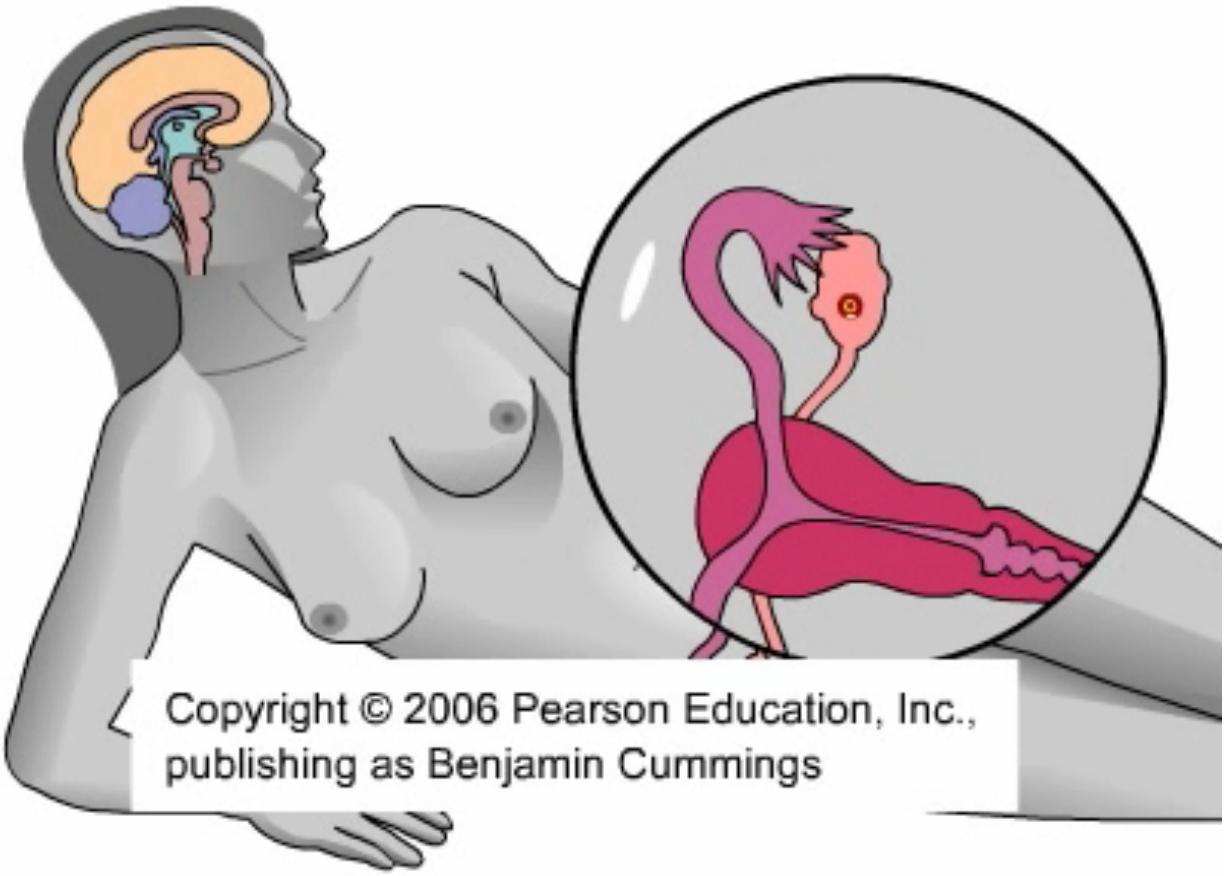

DAYS 0–13:
Hypothalamus
GnRH
Anterior pituitary
FSH
LH
Follicle
Estradiol
Initiates buildup of uterine lining
DAY 14:
Hypothalamus
GnRH
Anterior pituitary
FSH
LH
Follicle
Ovulation
Estradiol
Stimulated by high level of estradiol
Triggers ovulation
DAY 0 7 14 21 28
Pituitary gonadotropin levels
FSH
LH
OVARIAN CYCLE
Growing follicle
Corpus luteum
Degenerating corpus luteum
Follicular phase
Ovulation
Luteal phase
Ovarian hormone levels
Estradiol
Progesterone
UTERINE CYCLE
Endometrium
Menstrual flow phase
Proliferative phase
Secretory phase
DAYS 15–28:
Hypothalamus
GnRH
Anterior pituitary
FSH
LH
Follicle
Corpus luteum
Degenerated corpus leuteum
Estradiol
Progesterone
Inhibited by combination of estradiol and progesterone

The Uterine (Menstrual) Cycle

- Before ovulation, ovarian steroid hormones stimulate the uterus to prepare for support of an embryo
- Estradiol secreted by follicles signals the endometrium to thicken
- The follicular phase of the ovarian cycle is thus coordinated with the proliferative phase (days 6–14) of the uterine cycle

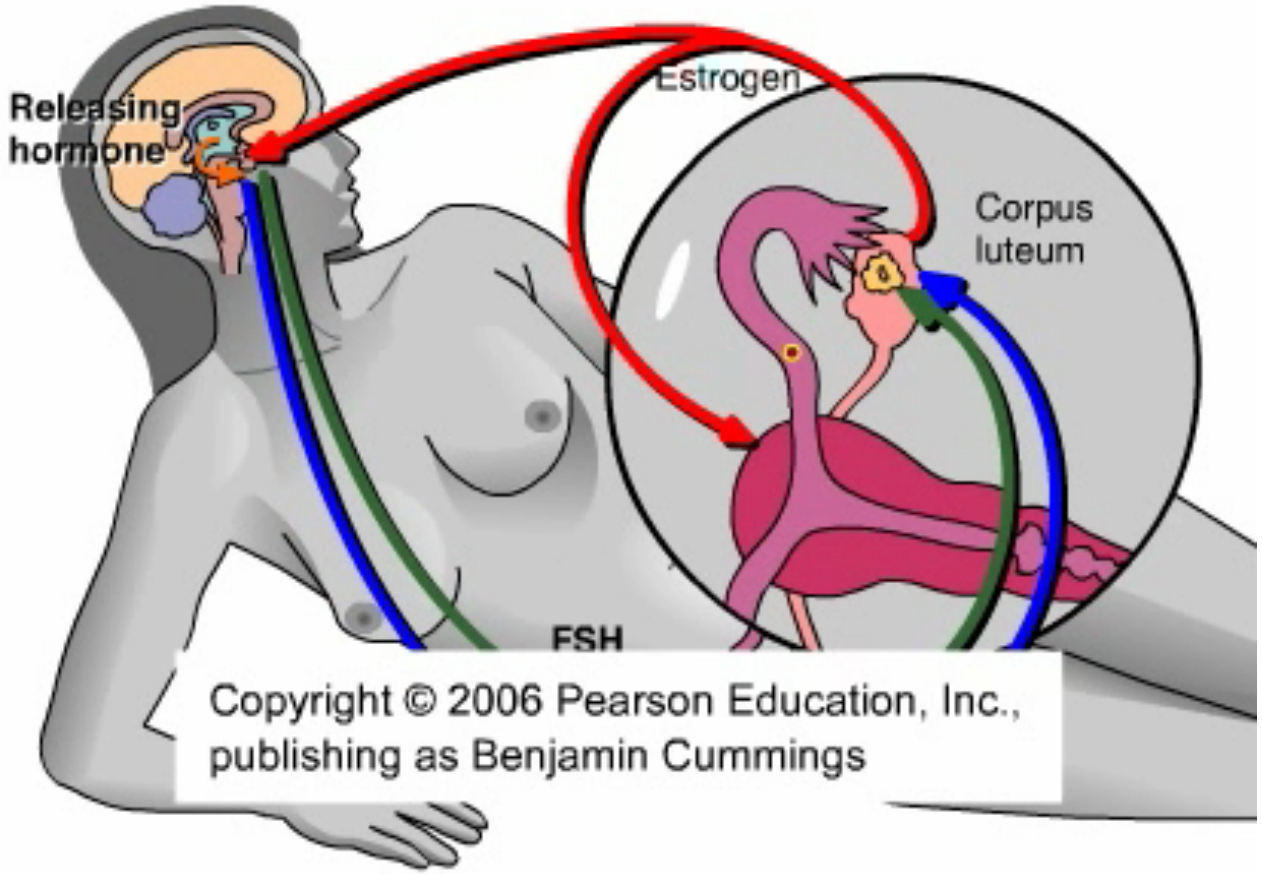
- After ovulation, the estradiol and progesterone secreted by the corpus luteum stimulate maintenance and development of the uterine lining
- Endometrial glands secrete a nutrient fluid that can sustain an embryo prior to implantation
- Thus, the luteal phase of the ovarian cycle is coordinated with the secretory phase (days 15–28) of the uterine cycle

Video: Ovulation



- Once the corpus luteum has disintegrated, the rapid drop in ovarian hormones causes a shedding of the endometrial tissue
- The result is menstruation, days 1–5 of the menstrual cycle
- During this phase, a new set of ovarian follicles begins to grow

Video: Post Ovulation



- About 7% of women suffer from a condition called **endometriosis**
- **In this condition,** cells of the uterine lining migrate to an abnormal, or **ectopic**, location
- This ectopic tissue swells and breaks down each ovarian cycle, just as the uterine lining does
- This results in pelvic pain and bleeding into the abdomen

Menopause

- After about 500 cycles, women undergo **menopause**, the cessation of ovulation and menstruation
- Menopause is very unusual among animals
- Menopause might have evolved to allow a mother to provide better care for her children and grandchildren

Menstrual Versus Estrous Cycles

- Menstrual cycles are characteristic only of humans and some other primates
  - The endometrium is shed from the uterus in a bleeding called menstruation
  - Sexual receptivity is not limited to a time frame

- **Estrous cycles** are characteristic of most mammals
  - The endometrium is reabsorbed by the uterus
  - Sexual receptivity is limited to a “heat” period called estrus
  - The length and frequency of estrous cycles vary from species to species

Human Sexual Response

- Two types of physiological sexual reactions predominate in both sexes:
  - Vasocongestion, the filling of tissue with blood
  - Myotonia, increased muscle tension
- The sexual response cycle has four phases: excitement, plateau, orgasm, and resolution
- Excitement prepares the penis and vagina for coitus (sexual intercourse)

- Direct stimulation of genitalia maintains the plateau phase and prepares the vagina for receipt of sperm
- Orgasm is characterized by rhythmic contractions of reproductive structures
  - In males, semen is first released into the urethra and then ejaculated from the urethra
  - In females, the uterus and outer vagina contract

- During the resolution phase, organs return to their normal state and muscles relax
- Following orgasm, the male typically enters a refractory period during which erection and orgasm cannot be achieved
- Females do not have a refractory period

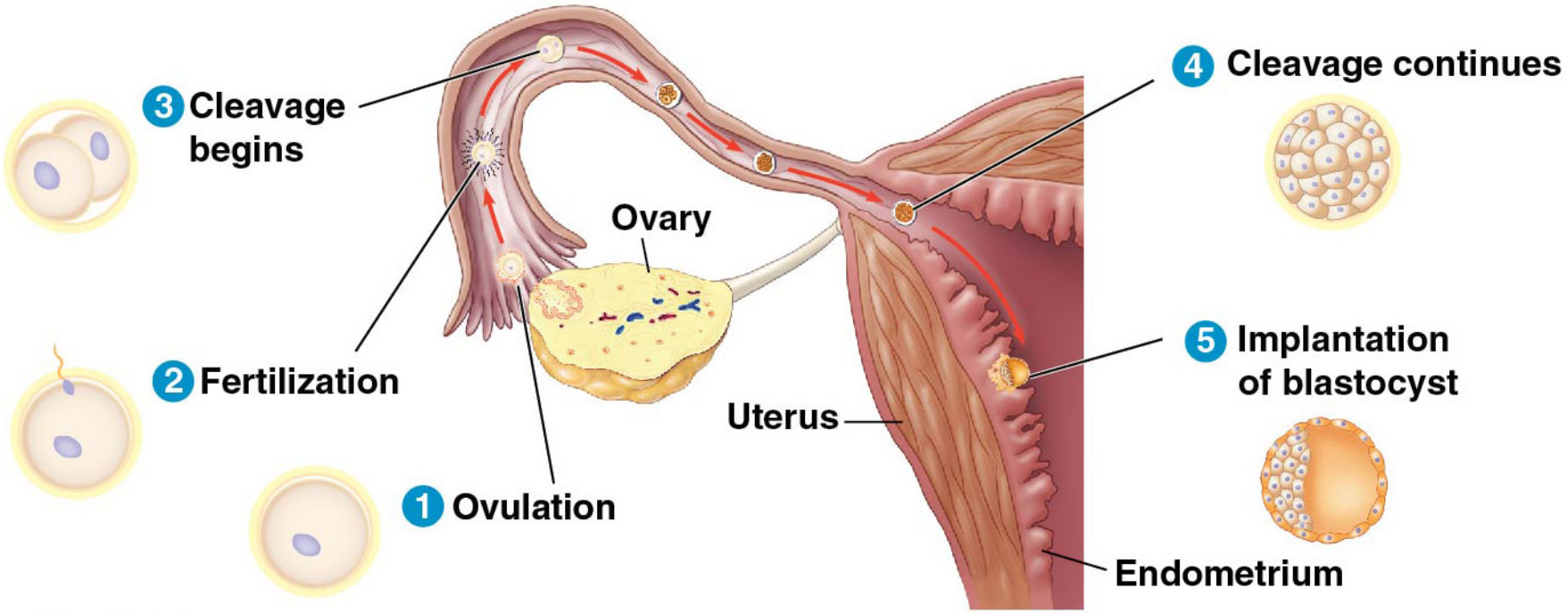
CONCEPT 46.5: In placental mammals, an embryo develops fully within the mother's uterus

- An egg develops into an embryo in a series of predictable events

Conception, Embryonic Development, and Birth

- **Conception**, fertilization of an egg by a sperm, occurs in the oviduct
- The resulting zygote begins to divide by mitosis in a process called cleavage
- Division of cells gives rise to a **blastocyst**, a ball of cells with a central cavity

Figure 46.15


3 Cleavage begins
4 Cleavage continues
Ovary
2 Fertilization
5 Implantation of blastocyst
Uterus
1 Ovulation
Endometrium

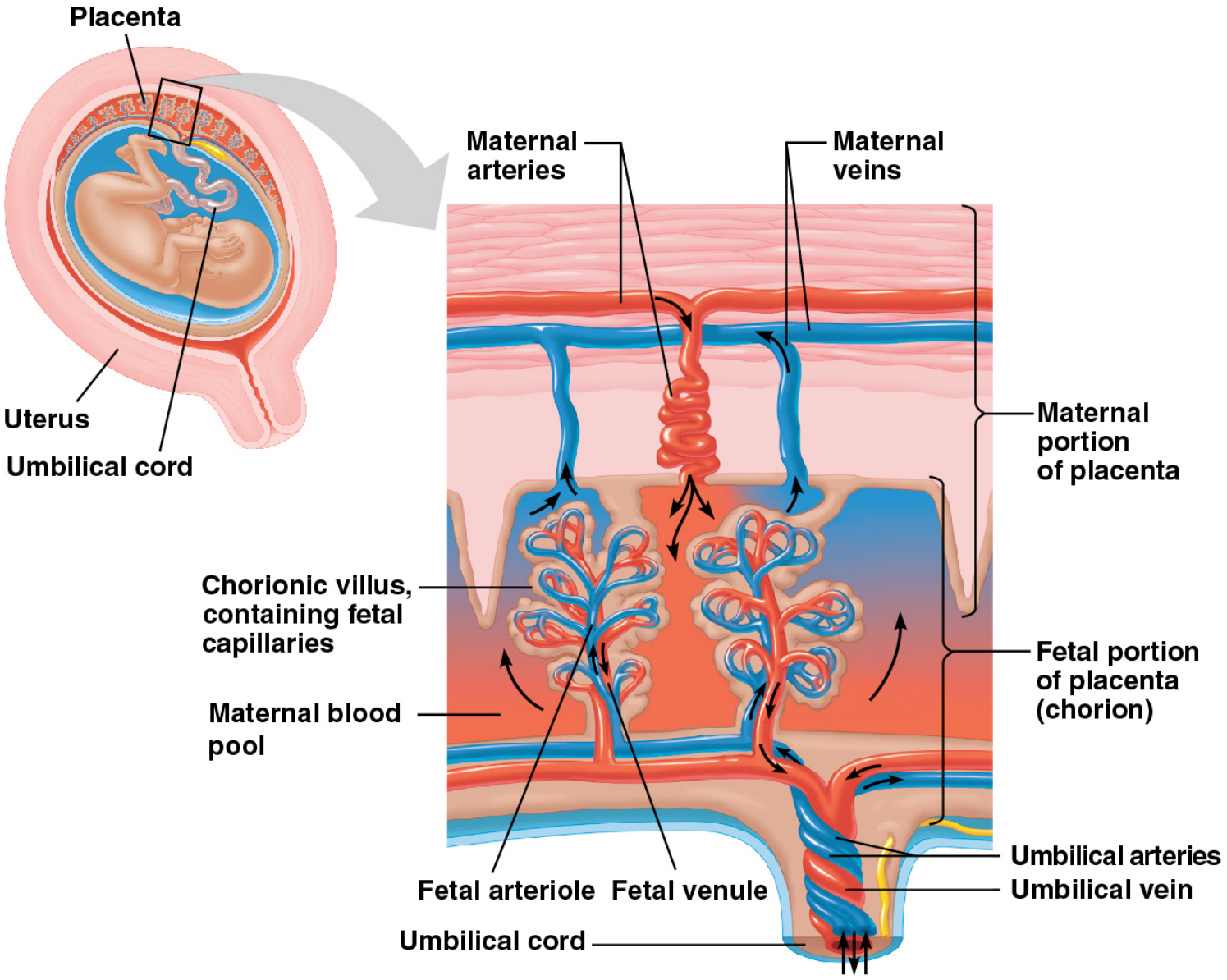
- After blastocyst formation, the embryo implants into the endometrium
- **Pregnancy**, or **gestation**, is the condition of carrying one or more embryos in the uterus
- Duration of pregnancy in other species correlates with body size and maturity of the young at birth
- The roughly nine months of human gestation are divided into three trimesters of equal length

First Trimester

- The implanted embryo secretes hormones that signal its presence and regulate the mother's reproductive system
- One such hormone, human chorionic gonadotropin (hCG), maintains secretion of progesterone and estrogens during early pregnancy

- During its first 2 to 4 weeks, the embryo obtains nutrients directly from the endometrium
- The outer layer of the blastocyst, called the **trophoblast**, mingles with the endometrium and eventually forms the **placenta**
- Blood from the embryo travels to the placenta through arteries of the umbilical cord and returns via the umbilical vein

Figure 46.16


Placenta
Uterus
Umbilical cord
Maternal arteries
Maternal veins
Maternal portion of placenta
Chorionic villus, containing fetal capillaries
Maternal blood pool
Fetal portion of placenta (chorion)
Umbilical arteries
Umbilical vein
Fetal arteriole
Fetal venule
Umbilical cord

- Splitting of the embryo during the first month of development results in genetically identical (monozygotic) twins
- Release and fertilization of two eggs result in fraternal and genetically distinct (dizygotic) twins

- The first trimester is the main period of **organogenesis**, development of the body organs
- All the major structures are present by 8 weeks, and the embryo is called a **fetus**

Figure 46.17

(a) 5 weeks.

(b) 14 weeks.

- Changes occur in the mother due to a high progesterone level:
  - Mucus plug in the cervix to protect against infection
  - Growth of the placenta and uterus
  - Cessation of ovulation and the menstrual cycle
  - Breast enlargement
  - Nausea is also very common

Video: Ultrasound of Human Fetus 1

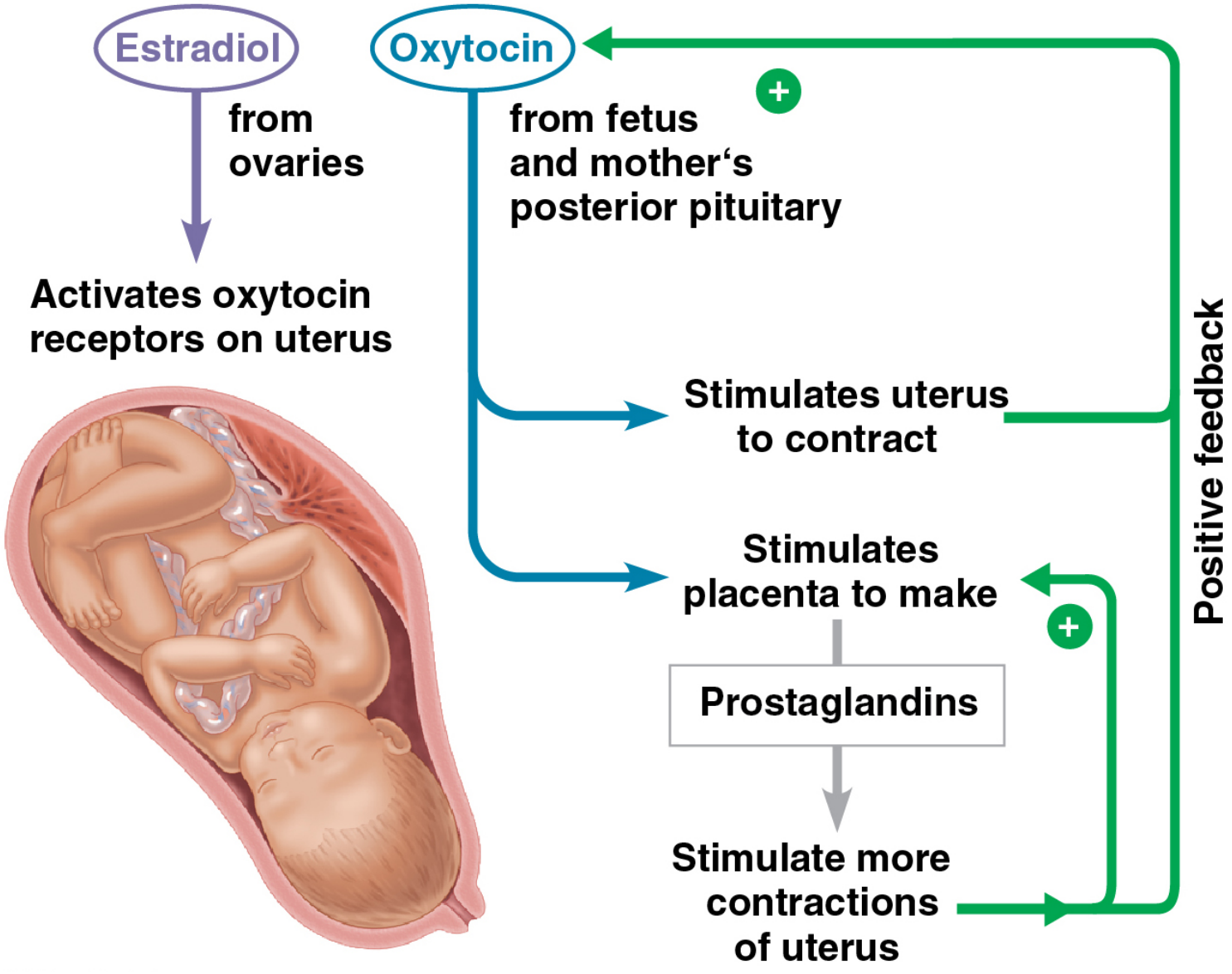
Video: Ultrasound of Human Fetus 2

Second and Third Trimesters

- During the second trimester
  - The fetus grows and is very active
  - The mother may feel fetal movements
  - Hormone levels stabilize
  - The placenta takes over the production of progesterone, the hormone that maintains the pregnancy

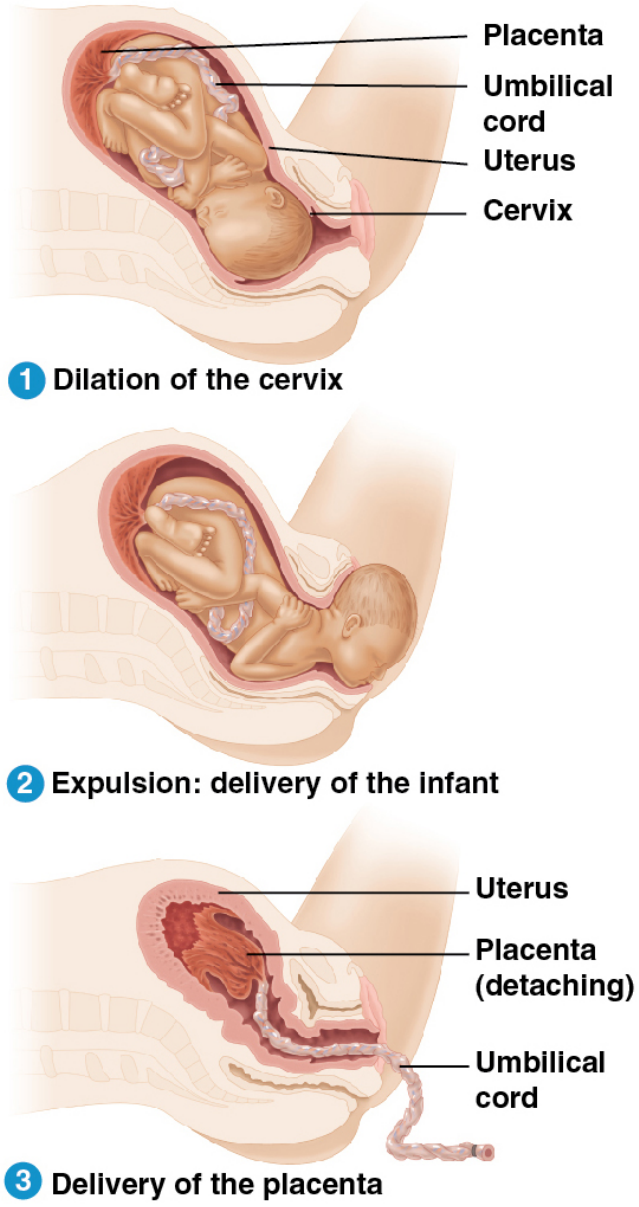
- During the third trimester, the fetus grows and fills the space within the embryonic membranes
- Childbirth begins with labor, a series of strong, rhythmic uterine contractions that push the fetus and placenta out of the body
- Labor is regulated by prostaglandins and hormones such as estradiol and oxytocin

Figure 46.18


Estradiol
from ovaries
Activates oxytocin receptors on uterus
Oxytocin
from fetus and mother's posterior pituitary
+
Stimulates uterus to contract
Stimulates placenta to make
+
Prostaglandins
Stimulate more contractions of uterus
Positive feedback

- Labor typically has three stages:
  - Thinning and opening of the cervix, or dilation
  - Expulsion, or delivery, of the baby
  - Delivery of the placenta
- Postnatal care in mammals includes lactation, the production of mother's milk

Figure 46.19


Placenta
Umbilical cord
Uterus
Cervix
1 Dilation of the cervix
2 Expulsion: delivery of the infant
Uterus
Placenta (detaching)
Umbilical cord
3 Delivery of the placenta

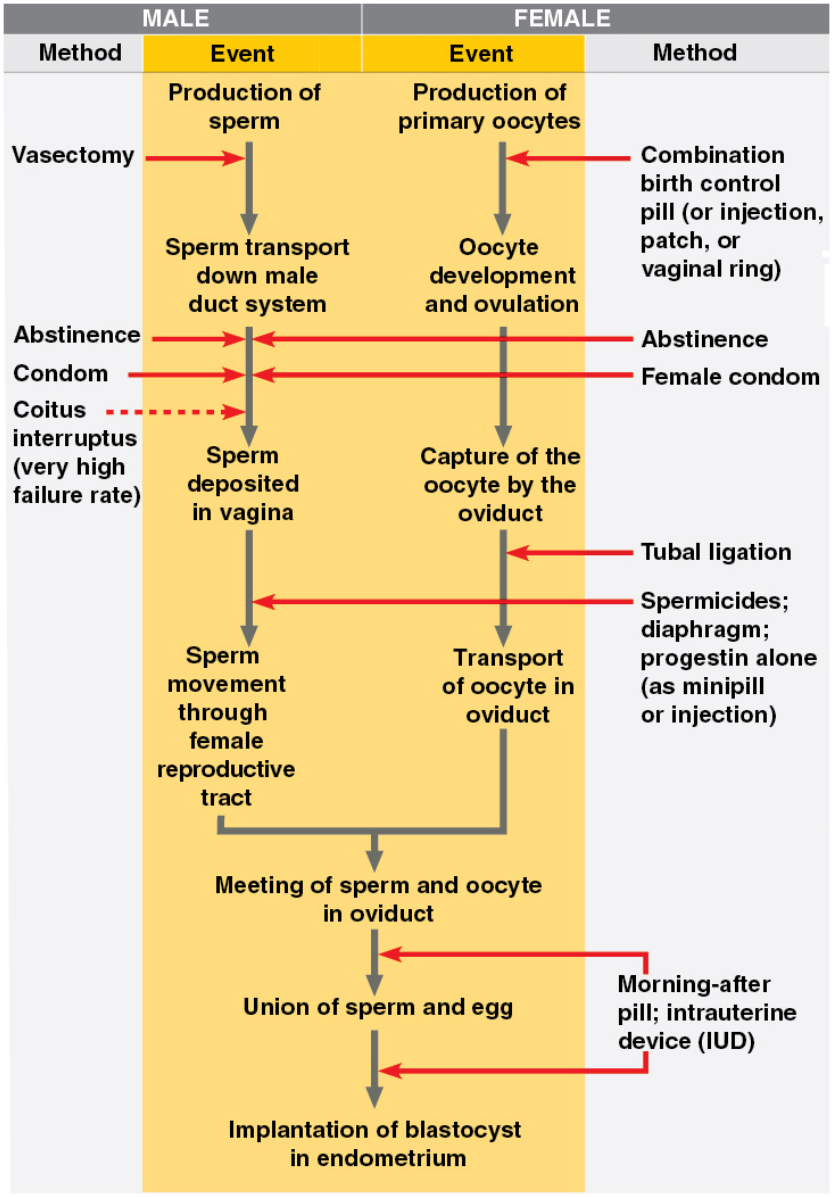
Maternal Immune Tolerance of the Embryo and Fetus

- A woman's acceptance of her 'foreign" offspring is not fully understood
- It may be due to suppression of the immune response in her uterus
- Symptoms of rheumatoid arthritis, an autoimmune disease of the joints, become less severe during pregnancy

Contraception and Abortion

- **Contraception**, the deliberate prevention of pregnancy, can be achieved in a number of ways
- Contraceptive methods fall into three categories:
  - Preventing release of eggs and sperm
  - Keeping sperm and egg apart
  - Preventing implantation of an embryo

Figure 46.20


MALE
FEMALE
Method
Event
Event
Method
Production of sperm
Production of primary oocytes
Vasectomy
Combination birth control pill (or injection, patch, or vaginal ring)
Sperm transport down male duct system
Oocyte development and ovulation
Abstinence
Abstinence
Condom
Female condom
Coitus interruptus (very high failure rate)
Sperm deposited in vagina
Capture of the oocyte by the oviduct
Tubal ligation
Spermicides; diaphragm; progestin alone (as minipill or injection)
Sperm movement through female reproductive tract
Transport of oocyte in oviduct
Meeting of sperm and oocyte in oviduct
Morning-after pill; intrauterine device (IUD)
Union of sperm and egg
Implantation of blastocyst in endometrium

- The rhythm method, or natural family planning, is to refrain from intercourse when conception is most likely; it has a pregnancy rate of 10–20%
- Coitus interruptus, the withdrawal of the penis before ejaculation, is unreliable
- Barrier methods block fertilization with a pregnancy rate of less than 10%
  - A condom fits over the penis
  - A diaphragm is inserted into the vagina before intercourse

- Intrauterine devices (IUDs) are inserted into the uterus and interfere with fertilization and implantation; the pregnancy rate is less than 1%
- Female **birth control pills** are hormonal contraceptives with a pregnancy rate of less than 1%
- Latex condoms are the only contraceptives that are effective in preventing the spread of sexually transmitted diseases

- Sterilization is permanent and prevents the release of gametes
  - **Tubal ligation** ties off the oviducts
  - **Vasectomy** ties off the vas deferens
- **Abortion** is the termination of a pregnancy
- Spontaneous abortion, or miscarriage, occurs in up to one-third of all pregnancies
- The drug RU486 terminates a pregnancy nonsurgically within the first 7 weeks

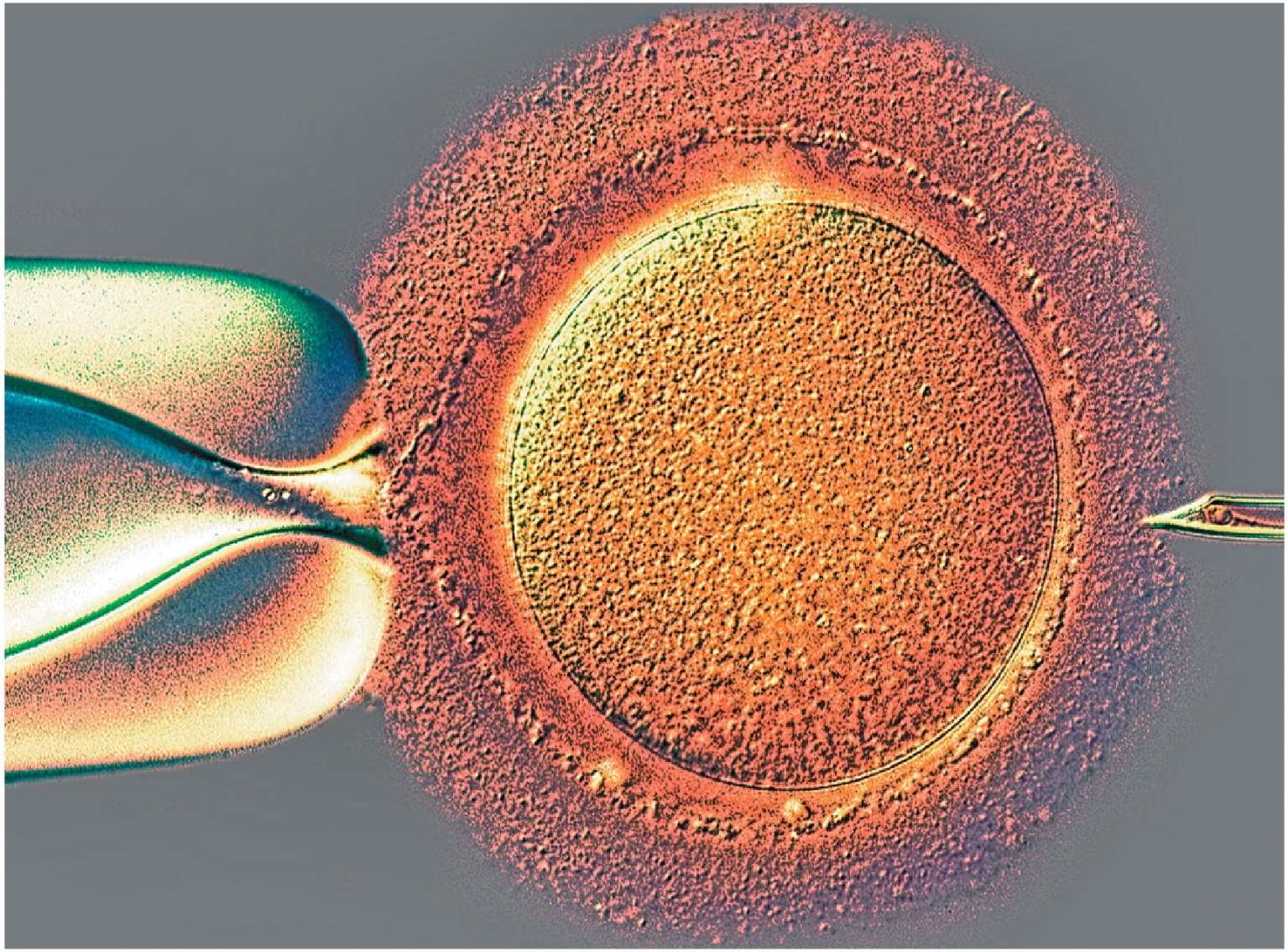
Modern Reproductive Technologies

- Recent advances make it possible to address many reproductive problems including genetic diseases and infertility

Infertility and In Vitro Fertilization

- Causes of infertility are quite varied, with men and women equally affected
- Among preventable causes of infertility, STDs are most significant
- ***In vitro* fertilization (IVF)** mixes eggs with sperm in culture dishes and returns the embryo to the uterus
- Sperm or sperm nuclei can also be injected directly into an oocyte

Figure 46.21



Detecting Disorders During Pregnancy

- Ultrasound imaging can be used to detect fetal size and condition
- Amniocentesis and chorionic villus sampling use a needle to obtain fetal cells for genetic analysis
- The mother's blood contains DNA from the embryo; thus a sample of maternal blood can be used to analyze the genome of the fetus

- Almost all detectable disorders are untreatable in the uterus; many cannot be corrected after birth
- Genetic testing of the fetus poses ethical questions and can present parents with difficult decisions

Figure 46.UN01

Data from the Experiment

Chromosome Set	Appearance of Genitalia	
	No Surgery	Embryonic Gonad Removed
XY (male)	Male	Female
XX (female)	Female	Female

Data from A. Jost, Recherches sur la differenciation sexuelle de l'embryon de lapin (Studies on the sexual differentiation of the rabbit embryo), *Archives d'Anatomie Microscopique et de Morphologie Experimentale* 36:271–316 (1947).

Figure 46.UN02

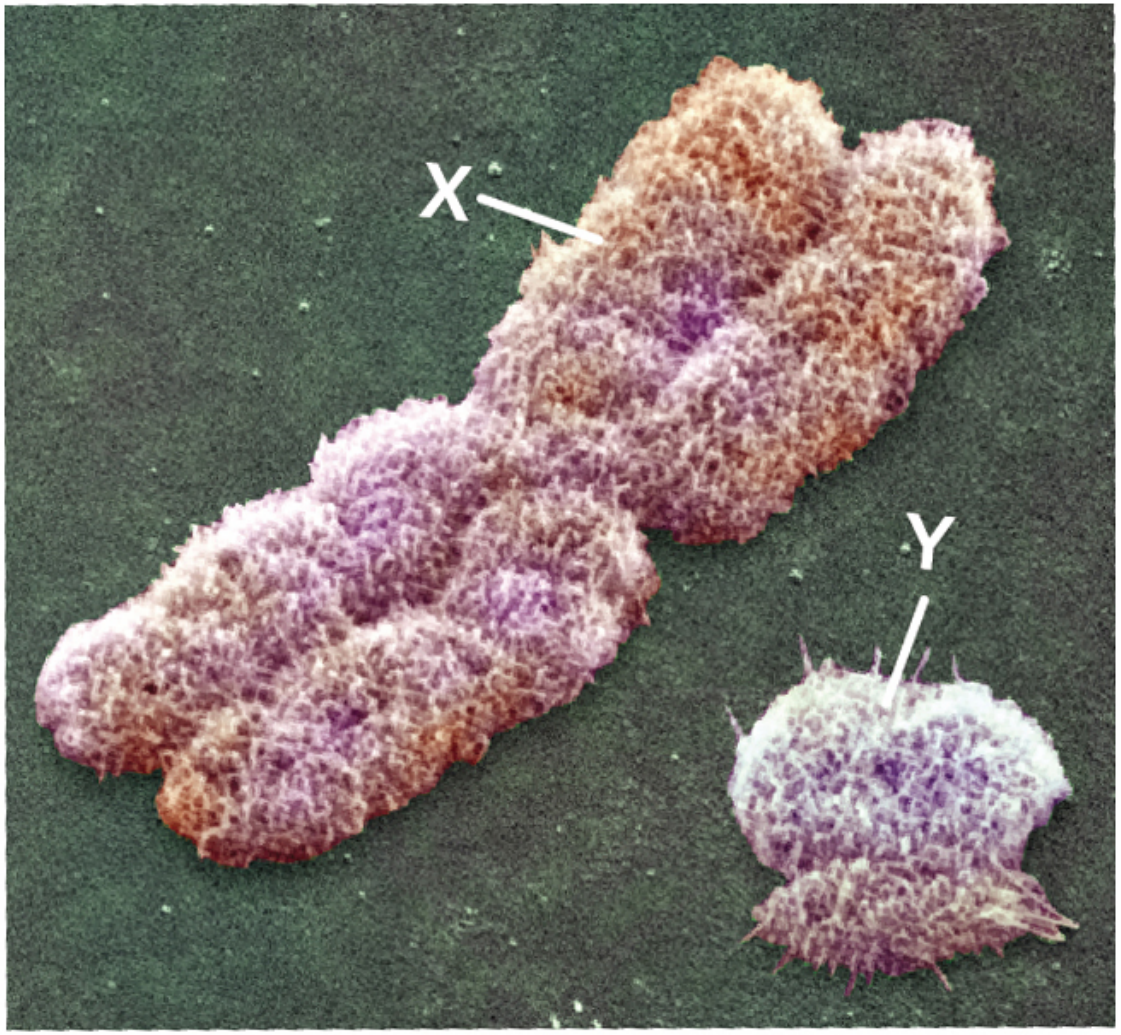


Figure 46.UN03

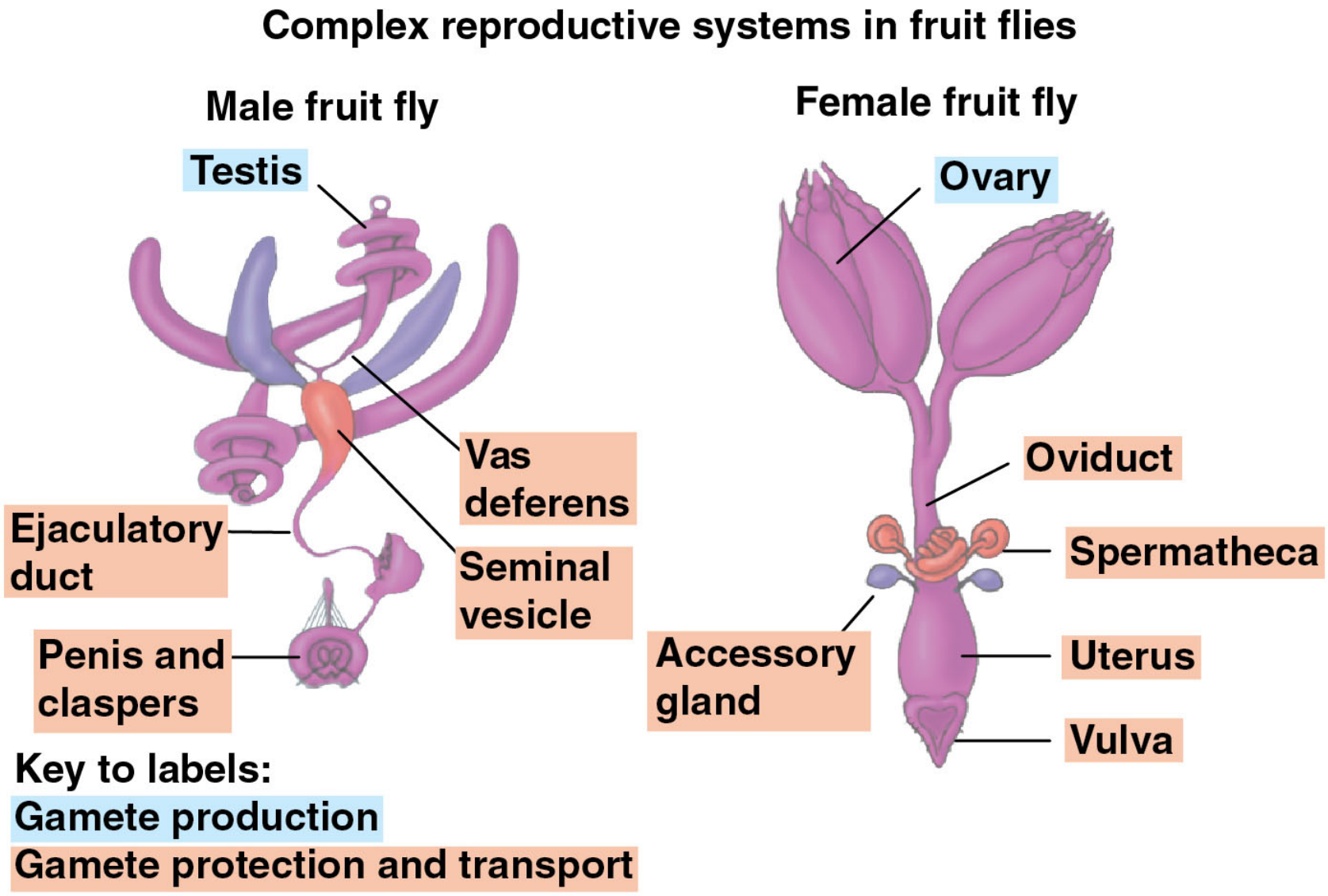


Figure 46.UN04

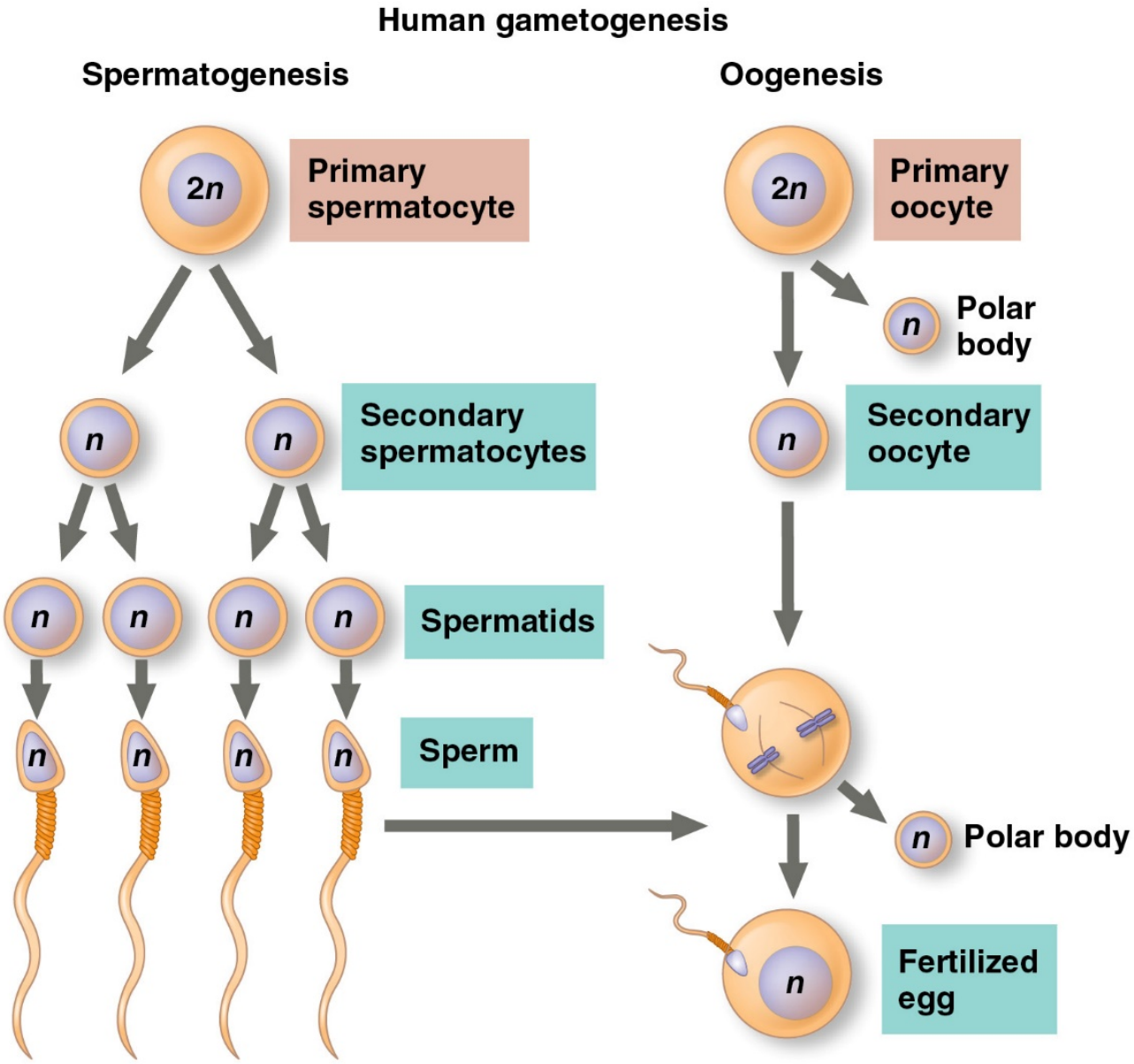


Figure 46.UN05

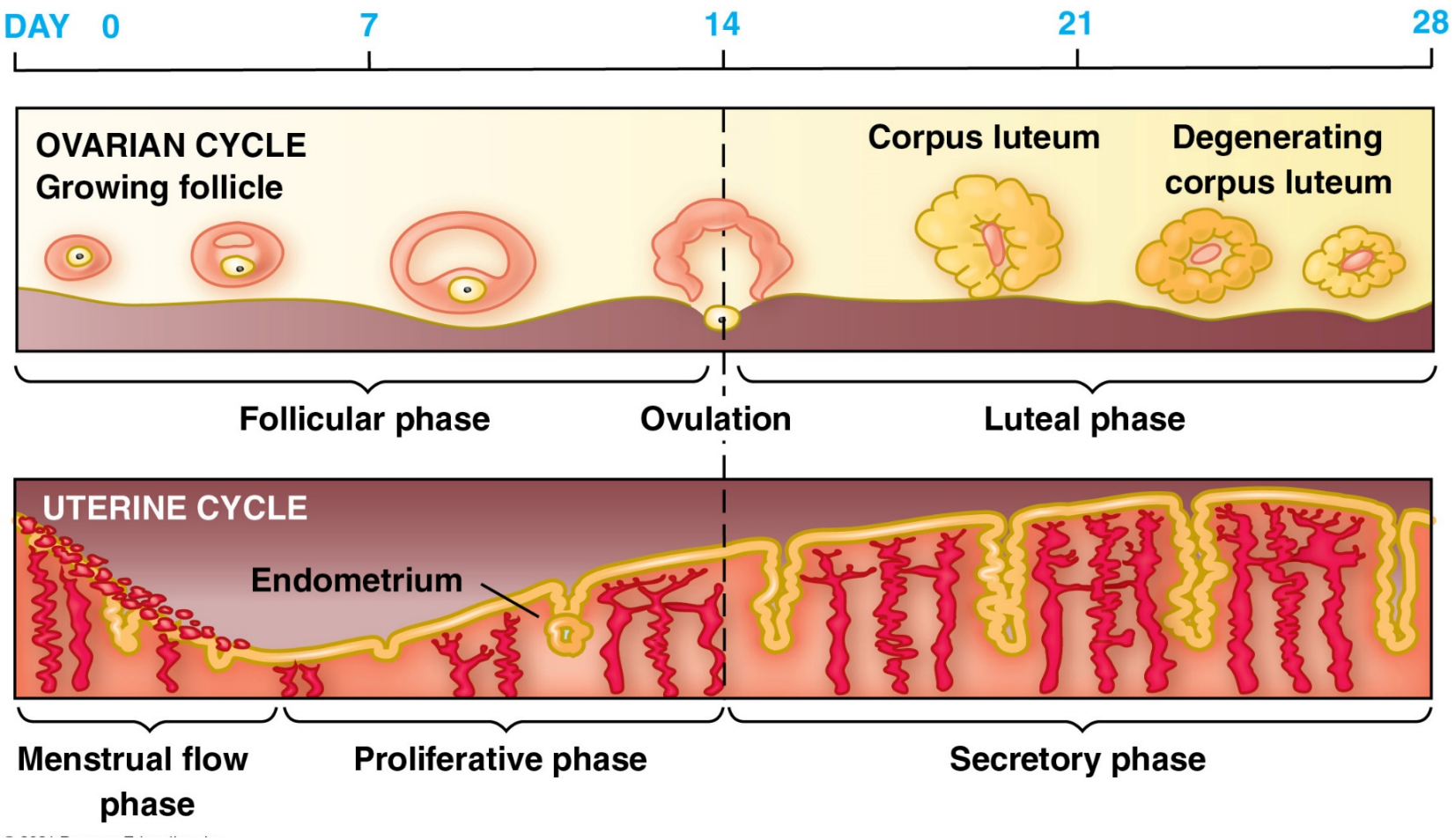


Figure 46.UN06