Chapter 46

Animal Reproduction

Lecture Outline

Overview: Pairing Up for Sexual Reproduction

- As humans, we tend to think of reproduction in terms of the mating of males and females and the fusion of sperm and eggs.
  - However, animal reproduction takes many forms.
  - In some species, individuals change their sex during their lifetime, whereas in others, such as sea slugs, an individual is both male and female.
  - There are animals that can fertilize their own eggs, as well as others that can reproduce without any form of sex.
  - For certain species, such as honeybees, only a few individuals within a large population reproduce.
- A population outlives its members only by reproduction, the generation of new individuals from existing ones.

Concept 46.1 Both asexual and sexual reproduction occur in the animal kingdom

- **Sexual reproduction** is the formation of offspring by the fusion of haploid gametes to form a diploid **zygote**.
  - The female gamete, the unfertilized **egg**, is a large and nonmotile cell.
  - The male gamete is the **sperm**, which is usually small and motile.
- **Asexual reproduction** is the formation of individuals whose genes come from a single parent.
  - There is no fusion of sperm and egg.
  - Reproduction relies entirely on mitotic cell division.

Diverse mechanisms of asexual reproduction enable animals to produce identical offspring rapidly.

- Many invertebrates reproduce asexually by **fission**, in which a parent separates into two or more approximately equal-sized individuals.
- **Budding** is a form of asexual reproduction in which new individuals split off from existing ones.
  - Stony corals, which can grow to be more than 1 m across, are cnidarian colonies of thousands of connected individuals.

- In another form of asexual reproduction, invertebrates such as sponges release specialized groups of cells that grow into new individuals.
- In *fragmentation,* the body breaks into several pieces, followed by *regeneration* of lost body parts.
    - If more than one piece grows and develops into a new animal, the result is reproduction.
    - Numerous sponges, cnidarians, bristle worms, and sea squirts reproduce by fragmentation and regeneration.
- In **parthenogenesis**, an egg develops without being fertilized.
    - Among invertebrates, parthenogenesis occurs in species of bees, wasps, and ants, producing either haploid or diploid progeny.
    - If haploid, offspring develop into adults that produce eggs or sperm without meiosis.
    - Male (drone) honeybees are fertile haploid adults that arise by parthenogenesis, while female honeybees, including both the sterile workers and the fertile queens, are diploid adults that develop from fertilized eggs.
- Parthenogenesis has been observed in about one in a thousand vertebrate species.
    - Recently, a female Komodo dragon and hammerhead shark produced parthenogenetic offspring in captivity, despite being kept apart from males.

Sexual reproduction is an evolutionary enigma.

- Sex must enhance reproductive success or survival or it would rapidly disappear.
- Consider an animal population in which half the females reproduce sexually and half reproduce asexually, producing two offspring each.
- The two offspring of the asexual female are both daughters, each able to give birth to more reproductive daughters.
- In contrast, half of the sexual female's offspring are male.
- The number of sexual offspring remains the same at each generation because both a male and a female are required to reproduce.
- Thus the asexual condition increases in frequency at each generation.
- Despite this "twofold cost," sex is maintained in the vast majority of eukaryotic organisms.
- Most hypotheses about the advantages of sex focus on the unique combinations of parental genes formed during meiotic recombination and fertilization.
- By producing diverse offspring, sexual reproduction may enhance the reproductive success of parents when environmental factors, such as pathogens, change rapidly.
    - Asexual reproduction would be most advantageous in stable, favorable environments.
- Beneficial gene combinations arising through recombination may speed up adaptation.
    - The theoretical advantage of this is significant only when the rate of beneficial mutations is high and the population size is small.
- Shuffling of genes during sexual reproduction may allow populations to rid themselves of harmful genes more readily.
- Experiments to test these and a range of other hypotheses are under way in many laboratories.

Most animals exhibit variation in reproductive activity.

- Most animals exhibit cycles in reproductive activity, usually related to changing seasons.
- Animals can thus conserve resources and reproduce when more energy is available and when environmental conditions favor the survival of offspring.
    - For example, ewes (female sheep) have a reproductive cycle lasting 15–17 days.
    - **Ovulation**, the release of mature eggs, occurs at the midpoint of each cycle.
    - The ewes give birth to lambs in the early spring, the time when their chances of survival are optimal.
- Reproductive cycles are controlled by hormones, which are regulated by environmental cues such as changes in day length, seasonal temperature, rainfall, and lunar cycles.
- Because seasonal temperature is often an important cue for reproduction, climate change can decrease reproductive success.
    - Researchers in Denmark have demonstrated just such an effect on caribou (wild reindeer).
    - In spring, caribou migrate to calving grounds to eat sprouting green plants, give birth, and care for their new calves. Changes in the length of daylight trigger the migration, while the seasonal rise in temperature that thaws the tundra causes plants to sprout.
    - Prior to 1993, the arrival of the caribou at the calving grounds coincided with the brief period during which the plants were nutritious and digestible.
    - Between 1993 and 2006, average spring temperatures in the calving grounds increased by more than 4°C, and the plants now sprout two weeks earlier.
    - Since the length of daylight is unaffected by climate change, the timing of the caribou migration has not changed. The result is a timing mismatch between new plant growth and caribou birthing.
    - Without adequate nutrition for the nursing females, production of caribou offspring has declined by 75%.
- Reproductive cycles are also found among animals that can reproduce both sexually and asexually such as the water flea *Daphnia*.
    - *Daphnia* reproduce by parthenogenesis under favorable conditions and sexually during times of environmental stress.
- A different type of reproductive cycle is found among animals that only reproduce asexually.
    - Several genera of fishes, amphibians, and lizards engage in a form of parthenogenesis that produces diploid "zygotes."
- Fifteen species of whiptail lizards reproduce exclusively by parthenogenesis.
    - There are no males in these species, but the lizards carry out courtship and mating behaviors typical of sexual species of the same genus.
    - During the breeding season, one female of each mating pair mimics a male.
    - An individual adopts female behavior prior to ovulation, when the level of the female sex hormone estradiol is high, then switches to male-like behavior after ovulation, when the level of progesterone is high.
    - Ovulation is more likely to occur if the individual is mounted during the critical time of the hormone cycle; isolated lizards lay fewer eggs than those that go through the motions of sex.

- These parthenogenetic lizards evolved from species having two sexes, and they still require certain sexual stimuli for maximum reproductive success.
- Sexual reproduction presents a problem for sessile or burrowing animals or parasites that may have difficulty encountering a member of the opposite sex.
- An evolutionary solution to this problem is **hermaphroditism**, in which one individual functions as both a male and a female.
    - Some hermaphrodites can self-fertilize, but most mate with another member of the same species.
    - In such a mating, each individual receives and donates sperm, resulting in twice as many offspring as would be produced if only one set of eggs were fertilized.
- Another reproductive pattern involves sex reversal, in which an individual changes its sex during its lifetime.
- The bluehead wrasse *(Thalassoma bifasciatum)* exhibits sex reversal from female to male.
    - This coral reef fish lives in harems consisting of a single male and several females.
    - When the male dies, a female wrasse undergoes sex reversal and becomes the new male.
- It is the largest (and usually oldest) female in the harem that undergoes sex reversal.
    - What advantage did this offer in evolution of this wrasse? Because it is the male that defends a harem against intruders, a larger size may be more important for males than females in ensuring successful reproduction.
- Certain oyster species also undergo sex reversal from male to female.
    - Oysters reproduce as males and then later become female.
    - Because the number of gametes produced generally increases with size much more for females than for males, sex reversal in this direction maximizes gamete production.
    - The result is enhanced reproductive success: Because oysters are sedentary animals and release their gametes into the surrounding water rather than mating directly, releasing more gametes tends to result in more offspring.

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

- **Fertilization**, the union of sperm and egg, can be internal or external.
- In **external fertilization**, eggs and sperm are both released into the environment.
- In species with **internal fertilization**, sperm are deposited in or near the female reproductive tract, and fertilization occurs within the tract.

Successful fertilization requires careful timing.

- A moist habitat is required for external fertilization, to prevent gametes from drying out and to allow the sperm to swim to the eggs.
- In species with external fertilization, timing is crucial to ensure that mature sperm and eggs encounter one another.

- Individuals clustered in the same area may release their gametes into the water at the same time in response to chemical signals or environmental cues, a process known as *spawning*.

- When external fertilization is not synchronous across a population, individuals may engage in mating behaviors that lead to fertilization of the eggs of one female by one male.
  - This allows mate choice and, by triggering the release of both sperm and eggs, increases the probability of successful fertilization.
- Internal fertilization is an adaptation to terrestrial life that enables sperm to reach an egg in a dry environment.
  - Internal fertilization requires cooperative and sophisticated reproductive systems, including copulatory organs that deliver sperm and receptacles for sperm storage and transport.
- Mating animals may use *pheromones*, chemical signals released by one organism that influence the behavior or physiology of other individuals of the same species.
  - Pheromones are small, volatile or water-soluble molecules that disperse into the environment and, like hormones, are active in minute amounts.
  - Many pheromones function as male attractants.

Developing embryos are protected in various ways.

- All species produce more offspring than survive to reproduce.
- Species with external fertilization tend to produce very large numbers of gametes, but few survive.
- Internal fertilization tends to involve the production of fewer zygotes with higher survival.
  - Eggs fertilized internally are sheltered from potential predators.
  - Internal fertilization is often associated with mechanisms that provide greater protection of the embryos and parental care of the young.
- The internally fertilized eggs of many species of terrestrial animals exhibit adaptations that protect against water loss and physical damage during their external development.
  - In birds and other reptiles, as well as monotremes, the zygote is protected by a shell and a set of internal membranes.
  - The fertilized eggs of fishes and amphibians have a gelatinous coat and lack internal membranes.
- Some animals retain the embryo within the female reproductive tract.
- Marsupial mammals retain their embryos in the uterus for only a short time.
  - The embryos crawl out and complete fetal development attached to a mammary gland in the mother's pouch.
- The embryos of eutherian mammals develop entirely within the uterus, nourished by the mother's blood supply through the placenta.
  - The embryos of some fishes and sharks also complete development internally, but without nutrient exchange between mother and young.
- Many animals provide parental care to their offspring.
  - Birds feed their young; mammals nurse their offspring.

- A female gastric brooding frog carried her tadpoles in her stomach until they undergo metamorphosis and hop out of her mouth as young frogs. The frogs are now extinct.
- Many invertebrates also provide parental care.

Animals show variation in reproductive systems.

- A group of cells dedicated to serve as precursors for ova and sperm is often established very early in embryo formation.
  - Cycles of growth and mitosis *amplify* the number of cells available for making eggs or sperm.
- The simplest reproductive systems do not even contain discrete **gonads**, the organs that produce gametes in most animals.
  - Most polychaete worms have separate sexes but lack distinct gonads; eggs and sperm develop from undifferentiated cells lining the coelom.
  - Mature gametes may be shed through the excretory openings, or the swelling mass of eggs may split a portion of the body open, spilling the eggs into the environment.
- Most animals possess sets of accessory tubes and glands that carry, nourish, and protect the gametes and sometimes the developing embryos.
- Most insect species have separate sexes with complex reproductive systems.
  - In males, sperm develop in a pair of testes and are passed along a coiled duct to two seminal vesicles for storage.
  - During mating, sperm are ejaculated into the female reproductive system.
  - Eggs develop in a pair of ovaries and are conveyed through ducts to the uterus, where fertilization occurs.
  - In many insect species, the female reproductive system includes a **spermatheca**, a sac in which sperm may be stored for extended periods and released under appropriate conditions.
- In many nonmammalian vertebrates, the digestive, excretory, and reproductive systems have a common opening to the outside, the **cloaca**, which was present in ancestral vertebrates.
- Most mammals have a separate opening for the digestive tract; most female mammals have separate openings for the excretory and reproductive systems.
- In most vertebrates, the uterus is partly or completely divided into two chambers.
  - In mammals (including humans) that produce only one or a few young at a time, birds, and many snakes, the uterus is a single structure.
- Male reproductive systems differ mainly in the copulatory organs.
  - Many nonmammalian vertebrates lack a penis and turn the cloaca inside out to ejaculate.
- Animals often mate with more than one member of the other sex; monogamy is relatively rare.
  - However, mechanisms have evolved to diminish the chance of a female mating successfully with another male.
  - Some male insects transfer secretions that make a female less receptive to courtship, thus reducing the likelihood of her mating again.

- Researchers have found that females may influence the relative reproductive success of their mates.
    - Rhonda Snook and David Hosken, collaborators working in the United Kingdom and Switzerland, studied female fruit flies that copulated with one male and then another.
    - The researchers found that female fruit flies play a major role in determining the reproductive outcome of multiple matings.
- The processes by which gametes and individuals compete during reproduction are only partly understood and remain a vibrant research area.

Concept 46.3 Reproductive organs produce and transport gametes

Human reproduction involves intricate anatomy and complex behavior.

- The reproductive anatomy of the human female includes external and internal reproductive structures.
    - The external reproductive structures consist of two sets of labia surrounding the clitoris and vaginal opening.
    - The internal reproductive organs consist of a pair of gonads, which produce eggs and reproductive hormones, and a system of ducts and chambers, which receive and carry gametes and house the embryo and fetus.
- The **ovaries**, the female gonads, flank the uterus and are held in place by ligaments.
- Each ovary contains many **follicles**, consisting of an **oocyte** surrounded by support cells.
    - The follicles nourish and protect the oocyte during **oogenesis**, the formation and development of an ovum.
    - At birth, a woman's ovaries contain 1–2 million follicles. About 500 fully mature between puberty and menopause.
- Usually one follicle matures and releases its egg during each menstrual cycle in the process of ovulation.
    - Prior to ovulation, cells of the follicle produce the primary female sex hormone, estradiol.
    - After ovulation, the remaining follicular tissue develops into the **corpus luteum**, which secretes additional estrogens and progesterone to help maintain the uterine lining during pregnancy.
    - If pregnancy does not occur, the corpus luteum disintegrates and a new follicle matures during the next cycle.
- At ovulation, the egg is released into the abdominal cavity near the opening of the **oviduct**.
- The cilia-lined funnel-like opening of the oviduct draws in the egg.
    - Cilia and the wavelike contractions of the oviduct convey the egg through the oviduct to the **uterus**.
- The highly vascularized inner lining of the uterus is called the **endometrium**.
- The neck of the uterus, the **cervix,** opens into the vagina.
- The **vagina** is a muscular, elastic chamber that forms the birth canal and is the repository for sperm during copulation.

- The vagina opens to the outside at the **vulva**, the collective term for the external female genitalia.

- A pair of thick, fatty **labia majora** enclose and protect the rest of the vulva.
  - The vaginal and urethral opening are located within a cavity bordered by by a pair of slender folds called the **labia minora**.
  - Until ruptured by sexual intercourse or vigorous physical activity, the vaginal opening is partially covered by a thin sheet of tissue called the **hymen**.
- Located at the upper intersection of the labia minora, the **clitoris** consists of erectile tissue supporting a rounded **glans** covered by a small hood of skin, the **prepuce**.
- During sexual arousal, the clitoris, vagina, and labia minora all engorge with blood and enlarge.
  - Sexual arousal also induces the vestibular glands near the vaginal opening to secrete lubricating mucus, thereby facilitating intercourse.
- **Mammary glands** are present in both sexes but normally produce milk only in females.
  - Within the glands, small sacs of epithelial tissue secrete milk, which drains into a series of ducts that open at the nipple.
  - The breasts contain connective and fatty tissue in addition to the mammary glands.
  - Because the low level of estradiol in males prevents the development of the fat deposits, male breasts remain small.
- The male's external reproductive organs consist of the scrotum and penis.
- The internal reproductive organs consist of gonads that produce sperm and reproductive hormones, accessory glands that secrete products essential to sperm movement, and ducts to carry the sperm and glandular secretions.
- The male gonads, or **testes**, produce sperm in highly coiled tubes called **seminiferous tubules**.
  - **Leydig cells** scattered in connective tissue between the tubules produce testosterone and other androgens.
- The **scrotum,** a fold in the body wall, maintains testis temperature about 2^0C below that of the rest of the body.
- The testes develop in the body cavity and descend into the scrotum just before birth.
  - A testis within a scrotum is a *testicle*.
  - In many rodents, the testes are drawn back into the cavity between breeding seasons, interrupting sperm maturation.
  - Some mammals whose body temperature is low enough to allow sperm maturation—such as monotremes, whales, and elephants—retain the testes in the abdominal cavity.
- From the seminiferous tubules of the testes, the sperm pass through the coiled tubules of the **epididymis**.
  - It takes 3 weeks for sperm to pass through the 6-m-long tubules of each epididymis.
  - During this passage, sperm complete their maturation and become motile.
  - Sperm acquire the ability to fertilize an egg only when exposed to the chemical environment of the female reproductive system.

- **Ejaculation** propels sperm from each epididymis through a muscular duct, the **vas deferens**.
  - Each vas deferens extends behind the urinary bladder and joins with a duct from the seminal vesicle to form an **ejaculatory duct**, which opens into the **urethra**.
  - The urethra drains both the excretory and reproductive systems at the tip of the penis.
- Accessory sex glands add secretions to **semen.**
- A pair of **seminal vesicles** contributes about 60% of total semen volume.
- Seminal fluid is thick, yellowish, and alkaline.
  - It contains mucus, fructose (an energy source for sperm), a coagulating enzyme, ascorbic acid, and prostaglandins.
- The **prostate gland** secretes directly into the urethra.
  - Prostatic fluid is thin and milky, containing anticoagulant enzymes and citrate, a sperm nutrient.
  - Prostate problems are common in men older than 40, with benign prostate enlargement in virtually all men older than 70. Prostate cancer is one of the most common cancers in men.
- The *bulbourethral glands* are a pair of small glands along the urethra below the prostate.
  - Prior to ejaculation, the bulbourethral glands secrete clear mucus that neutralizes any acidic urine remaining in the urethra.
  - Bulbourethral fluid also carries some sperm released before ejaculation, which is one reason the withdrawal method of birth control has a high failure rate.
- The human **penis** contains the urethra as well as three layers of spongy erectile tissue.
- During sexual arousal, the erectile tissue fills with blood from arteries.
  - The increasing pressure seals off the veins that drain the penis, causing it to engorge with blood.
- The engorgement of the penis with blood causes an erection, essential for the insertion of the penis into the vagina.
- Temporary impotence can result from the consumption of alcohol or other drugs, emotional problems, and aging.
  - Long-term erectile dysfunction can be treated with drugs such as Viagra, which promote the vasodilating action of the local regulator NO (nitric oxide), enhancing relaxation of smooth muscles in the blood vessels of the penis and allowing blood to enter the erectile tissue and sustain an erection.
- The penis of some mammals possesses a **baculum**, a bone that helps stiffen the penis.
- A male usually ejaculates 2–5 mL of semen, with each milliliter containing 70–130 million sperm.
- The main shaft of the penis is covered by relatively thick skin; the sensitive head, or glans, is covered by thinner skin.
  - The glans is covered by the foreskin, or prepuce, which may be removed by circumcision.

Reproduction in mammals involves two distinct types of gametes.

- Many of the differences in reproductive anatomy between males and females reflect the distinct structure and function of the two types of gametes.
    - Sperm are small and motile and must pass from the male to the female.
    - Eggs provide the initial food stores for the embryo. They are large and carry out their function within the female reproductive system.
- Eggs must mature in synchrony with the tissues of the female reproductive system that support the fertilized embryo.
- Egg and sperm development involves distinct patterns of meiotic division during **gametogenesis**, the production of gametes.
- **Spermatogenesis**, the formation and development of sperm cells, is a continuous and prolific process in the adult male.
    - Hundreds of millions of sperm are produced each day within tubules coiled in two testes.
    - For a single sperm, the process takes about seven weeks from start to finish.
- **Oogenesis** is the development of mature oocytes (eggs).
    - Immature eggs form in the ovary of the female embryo, but they do not complete their development until years, and often decades, later.
- Spermatogenesis differs from oogenesis in three major ways.
    1. In spermatogenesis, all four products of meiosis develop into mature gametes. In oogenesis, cytokinesis during meiosis is unequal, with almost all the cytoplasm segregated to a single daughter cell. This large cell becomes the egg; the other products of meiosis, smaller cells called polar bodies, degenerate.
    2. Spermatogenesis occurs throughout adolescence and adulthood. During oogenesis in human females, mitotic divisions are complete before birth and the production of mature gametes ceases at about age 50.
    3. Spermatogenesis produces mature sperm from precursor cells in a continuous sequence, whereas oogenesis has long interruptions.

Concept 46.4 The interplay of tropic and sex hormones regulates mammalian reproduction

The coordinated actions of hormones from the hypothalamus, anterior pituitary, and gonads govern human reproduction.

- The hypothalamus secretes gonadotropin-releasing hormone (GnRH), which directs the anterior pituitary to secrete the gonadotropins, follicle-stimulating hormone (FSH) and luteinizing hormone (LH).
    - These two hormones regulate gametogenesis directly, through target tissues in the gonads, and indirectly, through the regulation of sex hormone production.
- The principal sex hormones are steroid hormones: in males, androgens, especially testosterone, and in females, estrogens, especially estradiol, and progesterone.
    - The sex hormones regulate gametogenesis directly and indirectly.
- In many vertebrates, androgens are responsible for male vocalizations, such as the territorial songs of birds and the mating calls of frogs.

- During development of the human embryo, androgens direct the appearance of the primary sex characteristics of males, the structures directly involved in reproduction.
    - These include the seminal vesicles and other ducts as well as the external reproductive anatomy.
- At puberty, sex hormones in both males and females induce the formation of secondary sex characteristics, the physical and behavioral features that are not directly related to the reproductive system.
- In males, androgens cause deepening of the voice, development of facial and pubic hair, and growth of muscle (through stimulation of protein synthesis).
    - Androgens also promote specific sexual behaviors and sex drive as well as increase general aggressiveness.
- In females, estradiol stimulates breast and pubic hair development.
    - Estradiol also influences female sexual behavior, induces deposition of fat in the breasts and hips, increases water retention, and alters calcium metabolism.

Two closely linked cycles characterize reproduction in human females.

- On reaching sexual maturity, human males carry out gametogenesis continuously, while human females produce gametes in cycles.
    - Ovulation occurs after the endometrium has started to thicken and develop a rich blood supply, preparing the uterus for the possible implantation of an embryo.
    - If pregnancy does not occur, the uterine lining is sloughed off, and another cycle begins.
    - The cyclic shedding of the endometrium from the uterus, which occurs in a flow through the cervix and vagina, is called **menstruation**.
- The **menstrual** or **uterine cycle** refers to the changes that occur in the uterus.
    - Menstrual cycles average 28 days (although cycles vary, ranging from 20 – 40 days).
- Cyclic events in the ovaries define the **ovarian cycle**.
- Hormone activity links the two cycles, resulting in the synchronization of ovarian follicle growth and ovulation with the establishment of a uterine lining that can support embryonic development.
- The reproductive cycle begins with the release from the hypothalamus of GnRH, which stimulates the pituitary to secrete small amounts of FSH and LH.
- FSH stimulates follicle growth, aided by LH, and the cells of the growing follicles start to make estradiol.
- There is a slow increase in the secretion of estradiol during the **follicular phase**, the part of the ovarian cycle in which follicles grow and oocytes mature.
    - Low levels of estradiol inhibit secretion of the pituitary hormones, keeping FSH and LH levels low.
- The secretion of estradiol by the growing follicle rises sharply, and levels of FSH and LH shoot up.
    - The high concentration of estradiol stimulates the secretion of gonadotropins by acting on the hypothalamus to increase its output of GnRH, stimulating the secretion of FSH and LH.

- LH secretion is especially high because the high concentration of estradiol increases the sensitivity of LH-releasing cells in the pituitary to GnRH.
    - Follicles also respond more strongly to LH at this stage because more of their cells have receptors for this hormone.
    - The increase in LH concentration caused by increased estradiol secretion from the growing follicle is a rare example of positive feedback.
- LH induces the final maturation of the follicle and ovulation, which takes place about a day after the LH surge.
    - The follicle and adjacent wall of the ovary rupture, releasing the secondary oocyte.
- Following ovulation, during the **luteal phase** of the ovarian cycle, LH stimulates the transformation of the follicle into the corpus luteum, a glandular structure.
- Under continued stimulation by LH, the corpus luteum secretes progesterone and estradiol.
- As the levels of these hormones rise, they exert negative feedback on the hypothalamus and pituitary, inhibiting the secretion of LH and FSH.
    - This negative feedback prevents another egg from maturing when a pregnancy may already be underway.
- Near the end of the luteal phase, the corpus luteum disintegrates, causing estradiol and progesterone levels to decline.
- The pituitary and hypothalamus are liberated from the inhibitory effects of these hormones.
    - The pituitary begins to secrete enough FSH to stimulate the growth of new follicles in the ovary, initiating the next ovarian cycle.
- Prior to ovulation, ovarian steroid hormones stimulate the uterus to prepare for the prospect of an embryo. This starts the uterine cycle.
- Estradiol secreted in increasing amounts by growing follicles signals the endometrium to thicken.
    - The follicular phase of the ovarian cycle is thus coordinated with the **proliferative phase** of the uterine cycle.
- After ovulation, estradiol and progesterone secreted by the corpus luteum stimulate development and maintenance of the uterine lining, including enlargement of arteries and growth of endometrial glands.
    - The glands secrete a nutrient fluid that can sustain an early embryo before it implants in the uterine lining.
    - The luteal phase of the ovarian cycle is coordinated with the **secretory phase** of the uterine cycle.
- The rapid drop in ovarian hormones as the corpus luteum disintegrates causes arteries in the endometrium to constrict, depriving it of blood.
    - Much of the uterine lining disintegrates, and the uterus, in response to prostaglandin secretion, contracts.
    - Small blood vessels in the endometrium constrict, releasing blood that is shed along with endometrial tissue and fluid.
    - The result is menstruation, or the **menstrual flow phase** of the uterine cycle, and the beginning of a new cycle.

- During menstruation, new ovarian follicles begin to grow.
  - The first day of menstruation is designated day 1 of the new uterine and ovarian cycle.
- About 7% of reproductive-age women suffer from **endometriosis**, a disorder in which some cells of the uterine lining migrate to an abdominal location that is abnormal or **ectopic**.
- In its new location, the ectopic tissue still responds to stimulation by hormones in the bloodstream, swelling and breaking down each ovarian cycle, and leading to pelvic pain and bleeding into the abdomen.
  - Treatments for endometriosis, involving hormonal therapy or surgery, lessen discomfort.
  - Research is directed at learning why endometriosis occurs.

Menopause is the cessation of ovulation and menstruation.

- After about 500 cycles, **menopause** usually occurs in women between ages 46 and 54.
  - During these years, the ovaries lose their responsiveness to FSH and LH, and menopause results from a decline in estradiol production by the ovary.
- In most species, females and males retain their reproductive capacity throughout life.
- One evolutionary hypothesis for human menopause is that cessation of reproduction allowed a woman to provide better care for her children and grandchildren, thus increasing the chance of survival of individuals bearing her genes and increasing her fitness.
- In all female mammals, the endometrium prior to ovulation, but only humans and some other primates have menstrual cycles.
- Other mammals have **estrous cycles**. If pregnancy does not occur, the uterus reabsorbs the endometrium with little fluid flow.
- Estrous cycles are associated with more pronounced behavioral cycles than are menstrual cycles.
  - The period of sexual activity, estrus, is the only time the female is receptive to mating.
  - In contrast, human females may be sexually receptive throughout the menstrual cycle.
- The length and frequency of reproductive cycles vary widely among mammals.
  - Bears and wolves have one estrous cycle per year; elephants have several.
  - Rats have estrous cycles throughout the year, each lasting only five days.
- In males, the FSH and LH secreted in response to GnRH are both required for normal spermatogenesis.
  - FSH promotes the activity of Sertoli cells, cells within the seminiferous tubules that nourish developing sperm.
  - LH regulates Leydig cells, interstitial cells located between the seminiferous tubules.
  - In response to LH, Leydig cells secrete testosterone and other androgens, which promote spermatogenesis within the tubules.
- Two negative-feedback mechanisms maintain androgen production at an optimal level.
  - Testosterone regulates blood levels of GnRH, FSH, and LH through inhibitory effects on the hypothalamus and anterior pituitary.
  - **Inhibin**, a hormone that in males is produced by Sertoli cells, acts on the anterior pituitary gland to reduce FSH secretion.

- Together, these negative-feedback circuits maintain androgen production at optimal levels.

Human sexual response is very complex.

- Testosterone, prolactin, and oxytocin each appear to influence sexual function in males and females, but their precise roles have yet to be defined.
  - The study of human sexual response has largely focused on the physiological changes associated with sexual activity.
- The arousal of sexual interest in humans is complex, involving a variety of psychological as well as physical factors.
- Reproductive structures in the male and female that are quite different in appearance often serve similar functions, reflecting their shared developmental origin.
  - For example, the same embryonic tissues give rise to the glans of the penis and the clitoris, the scrotum and the labia majora, and the skin on the penis and the labia minora.
- The general pattern of human sexual response is similar in both genders.
- Two types of physiological reaction predominate in both sexes: **vasocongestion**, the filling of tissue with blood, and **myotonia**, increased muscle tension.
- Both smooth and skeletal muscles may show sustained or rhythmic contractions, including those associated with orgasm.
- The sexual response can be divided into four phases: excitement, plateau, orgasm, and resolution.
- Excitement prepares the vagina and penis for **coitus**.
  - Vasocongestion leads to erection of the penis and clitoris; enlargement of the testicles, labia, and breasts; and vaginal lubrication.
  - Myotonia may result in nipple erection or tension in the arms and legs.
- In the plateau phase, these responses continue as a result of direct stimulation of the genitalia.
  - In females, plateau includes vasocongestion of the outer third of the vagina, expansion of the inner two-thirds of the vagina, and elevation of the uterus to form a depression that receives sperm at the back of the vagina.
  - Stimulation by the autonomic nervous system increases breathing and heart rate.
- **Orgasm** is characterized by rhythmic, involuntary contractions of the reproductive structures in both sexes.
  - In male orgasm, emission is the contraction of the glands and ducts of the reproductive tract, which forces semen into the urethra, while ejaculation occurs with the contraction of the urethra and expulsion of semen.
  - In female orgasm, the uterus and outer vagina contract, but the inner two-thirds of the vagina do not.
  - Orgasm is the shortest phase of the sexual response cycle, usually lasting only a few seconds.
  - In both sexes, contractions occur at about 0.8-second intervals and may also involve the anal sphincter and several abdominal muscles.
- Resolution completes the cycle and reverses the responses of earlier stages.

- Vasocongested organs return to their normal sizes and colors; muscles relax.
- Most of the changes of resolution are completed in 5 minutes, but some may take as long as an hour.

- Following orgasm, the male enters a refractory period, lasting anywhere from a few minutes to hours, during which erection and orgasm cannot be achieved.
- Female do not experience a refractory period, so multiple orgasms within a short period of time are possible.

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

- In human copulation, 2–5 mL of semen is transferred, with 70–130 million sperm per mL.
- The alkalinity of the semen helps neutralize the acidic environment of the vagina, protecting the sperm and increasing their motility.
- Ejaculated semen coagulates, helping to keep ejaculate in place until sperm reach the cervix.
- In the cervix, anticoagulants liquefy the semen, and the sperm begin swimming through the female tract.
- Fertilization or **conception** occurs in the oviduct.
- Twenty-four hours later, **cleavage** begins. Three to four days after fertilization, the embryo reaches the uterus as a ball of 16 cells.
- By 5 days after fertilization, the **blastocyst** forms as a sphere of cells containing a cavity.
- After a few more days, the blastocyst implants in the endometrium.
- The implanted embryo secretes hormones to control the mother's reproductive system.
  - The embryonic hormone **human chorionic gonadotropin (hCG)** acts like pituitary LH to maintain secretion of progesterone and estrogens by the corpus luteum for the first few months of pregnancy.
  - Some HCG is excreted in the urine, where it can be detected by pregnancy tests.
- In placental mammals, **pregnancy** or **gestation** is the condition of carrying one or more **embryos** in the uterus.
  - A human pregnancy averages 266 days or 38 weeks.
  - Many rodents have gestation periods of 21 days, while cows have a gestation period of 270 days, and elephant gestation lasts 600 days.
- Not all fertilized eggs are capable of completing development; many pregnancies terminate spontaneously due to chromosomal or developmental abnormalities.
- Occasionally, a fertilized egg lodges in the fallopian tube, resulting in a tubal, or ectopic, pregnancy.
  - Such pregnancies cannot be sustained and may rupture the oviduct, resulting in serious internal bleeding.
  - A number of conditions, including endometriosis, increase the likelihood of tubal pregnancy.

- Bacterial infections arising during childbirth, from medical procedures, or as a *sexually transmitted disease* can scar the oviduct, making ectopic pregnancy more likely.

- STDs are the most significant preventable causes of infertility.
  - In women between 15 and 24 years of age, 700,000 cases of chlamydia and gonorrhea are reported annually in the United States.
  - The number of women infected with these STDs is actually significantly higher because most women with these bacterial infections have no symptoms.
  - Among women who remain untreated, up to 40% develop an inflammatory disorder that can lead to infertility or ectopic pregnancies.

Human gestation is divided into three trimesters of three months each.

- For the first 2–4 weeks of development, the embryo obtains nutrients directly from the endometrium.
- The outer layer of the blastocyst, the **trophoblast**, invades the endometrium and later forms the **placenta**, a disk-shaped organ weighing close to 1 kg.
  - The placenta allows diffusion of material between maternal and embryonic circulations, supplying nutrients, providing immune protection, exchanging respiratory gases, and disposing of metabolic wastes for the embryo.
  - Blood from the embryo travels to the placenta through arteries of the umbilical cord and returns via the umbilical vein.
- Splitting of the embryo during the first month of development can result in identical or *monozygotic* twins.
- Fraternal or *dizygotic* twins arise when two follicles mature in a single cycle, leading to separate fertilization and implantation of two genetically distinct embryos.
- **Organogenesis**, the development of the body organs, occurs during the first trimester.
  - By the end of week eight, all the major structures of the adult are present in rudimentary form and the embryo is called a **fetus**.
  - The heart begins beating by the fourth week; a heartbeat can be detected at 8 to 10 weeks.
- By the end of the first trimester, the fetus is well differentiated but only 5 cm long.
- The mother is also undergoing major changes.
  - High levels of progesterone initiate changes in the maternal reproductive system, including increased mucus in the cervix to form a protective plug against infection, growth of the maternal part of the placenta, enlargement of the uterus, and cessation of ovarian and menstrual cycling.
  - The breasts enlarge rapidly and may be tender.
  - About three-fourths of all pregnant women experience nausea during the first trimester.
- The connection between mother and developing fetus via the placenta also allows harmful substances to pass between them.
  - Consuming alcohol during pregnancy poses a major risk: Alcohol that reaches the developing central nervous system of the fetus can cause fetal alcohol syndrome, a disorder that can result in mental retardation and other serious birth defects.
  - Smoking during pregnancy is associated with low birth weight and other health problems.

- During the second trimester, the fetus grows rapidly to 30 cm and is very active.
    - The mother may feel movements during the early part of the second trimester, although fetal activity is not visible through the abdominal wall until one to two months later.
    - Hormonal levels stabilize as hCG levels decline; the corpus luteum deteriorates; and the placenta takes over the secretion of progesterone, which maintains the pregnancy.
- During the third trimester, the fetus grows rapidly to about 3–4 kg in weight and 50 cm in length.
    - Fetal activity may decrease as the fetus fills the space available to it.
    - Maternal abdominal organs become compressed and displaced, leading to frequent urination and digestive blockages.
- Childbirth begins with **labor**, a series of strong, rhythmic uterine contractions that push the fetus and placenta out of the body.
    - Research suggests that labor begins when the fully developed fetus produces hormones and certain lung proteins that initiate an inflammatory response in the mother.
- A complex interplay of local regulators (prostaglandins) and hormones (estradiol and oxytocin) induces and regulates further contractions of the uterus.
    - The action of oxytocin forms a positive feedback loop with uterine contractions stimulating secretion of oxytocin that in turn stimulates further contractions.
- Labor has three stages.
    - The first stage is the thinning and opening up of the cervix.
    - The second stage is the expulsion or delivery of the baby by strong uterine contractions.
    - The third stage is delivery of the placenta.
- Lactation is unique to mammals.
- In response to suckling by the newborn, as well as changes in estradiol levels after birth, the hypothalamus signals the anterior pituitary to secrete prolactin, which stimulates the mammary glands to produce milk.
- Suckling also stimulates the secretion of a posterior pituitary hormone, oxytocin, which triggers release of milk from the mammary glands.
- Reproductive immunologists are working to understand why mammalian mothers do not reject the embryo as a foreign body, despite its paternal antigens.
    - The symptoms of rheumatoid arthritis, an autoimmune disease of the joints, become less severe during pregnancy, suggesting that regulation of the immune system may be altered by pregnancy.

Contraception, the deliberate prevention of pregnancy, can be achieved in several ways.

- Some methods of **contraception** prevent the development or release of female or male gametes; others prevent fertilization by keeping sperm and egg apart; still others prevent implantation of an embryo.
- Fertilization can be prevented by abstinence from sexual intercourse or by any of several barriers that keep sperm and egg apart.
- Temporary abstinence is called the **rhythm method** of birth control.

- With **natural family planning**, couples refrain from intercourse during the time conception is most likely to occur.
- The egg can survive in the oviduct for 24–48 hours and sperm for as long as five days.

- Ovulation can be detected by noting changes in cervical mucus and body temperature during the menstrual cycle.
  - Natural family planning has a pregnancy rate of 10–20%.
  - Some couples use ovulation timing methods to *increase* the probability of conception.
- *Coitus interruptus*, or withdrawal of the penis from the vagina before ejaculation, is an unreliable method of preventing fertilization.
  - Sperm may be present in secretions that precede ejaculation.
- Barrier methods of contraception that block sperm from meeting the egg have pregnancy rates of less than 10%.
  - The **condom** is a thin latex or natural membrane sheath that fits over the penis to collect semen.
  - Latex condoms are the only contraceptives that are highly effective in preventing the spread of sexually transmitted diseases, including AIDS.
  - The **diaphragm** is a dome-shaped rubber cap that fits into the upper portion of the vagina before intercourse.
  - Both condoms and diaphragms are more effective when used in conjunction with a spermicide.
  - Other barrier devices include the vaginal pouch, or "female condom."
- After complete abstinence from sexual intercourse, the most effective means of birth control are sterilization, intrauterine devices (IUDs), and hormonal contraceptives.
  - Sterilization is almost 100% effective.
  - The IUD, with a pregnancy rate of 1% or less, is the most commonly used reversible method of birth control outside the United States.
  - Placed in the uterus by a doctor, the IUD interferes with fertilization and implantation.
- Pregnancy rates of 1% or lower are also achieved with **birth control pills**.
- The most commonly used birth control pills are a combination of a synthetic estrogen and progestin (progesterone-like hormone).
  - This combination acts by negative feedback to stop the release of GnRH by the hypothalamus and thus of FSH and LH by the pituitary.
  - The prevention of LH release prevents ovulation.
  - The inhibition of FSH secretion by the low dose of estrogen in the pills prevents follicles from developing.
  - A similar combination of hormones is also available as an injection, in a ring inserted into the vagina, and as a skin patch.
- Combination birth control pills can also be used in high doses as morning-after pills, which prevent fertilization or implantation with an effectiveness of about 75%.

- A different hormone-based contraceptive contains only progestin, which causes thickening of a woman's cervical mucus to block sperm from entering the uterus.
    - Progestin decreases the frequency of ovulation and causes changes in the endometrium that interfere with implantation if fertilization occurs.
- Hormone-based contraceptives have both beneficial and harmful side effects.
- Female smokers have an increased risk of dying from cardiovascular disease if they use oral contraceptives.
    - Birth control pills slightly increase a woman's risk of abnormal blood clotting, high blood pressure, heart attack, and stroke.
- Despite these increased risks, oral contraceptives eliminate the dangers of pregnancy, and women who take birth control pills have mortality rates about half those of pregnant women.
- The pill also decreases the risks of ovarian and endometrial cancers.
- Research aimed at finding a male contraceptive has focused on hormone combinations that suppress gonadotropin release and thereby block spermatogenesis.
    - Testosterone included in such combinations inhibits reproductive functions of the hypothalamus and pituitary, while maintaining secondary sexual characteristics.
- Sterilization is the permanent prevention of gamete production or release.
- **Tubal ligation** in women usually involves sealing shut or tying off a section of the oviducts to prevent eggs from traveling into the uterus.
- **Vasectomy** in men is the cutting and tying off of each vas deferens to prevent sperm from entering the urethra.
- Both male and female sterilization procedures are relatively safe and free from harmful effects.
    - Secretion of sex hormones and sexual function are unaffected by either procedure, with no change in menstrual cycles in females or ejaculate volume in males.
    - Although tubal ligation or vasectomy are considered permanent, both procedures can be reversed by microsurgery.
- **Abortion** is the termination of a pregnancy in progress.
    - Spontaneous abortion, or *miscarriage*, occurs in as many as one-third of all pregnancies, often before the woman is even aware she is pregnant.
    - Each year, about 850,000 U.S. women have abortions performed by physicians.
- RU486, or mifepristone, is a drug that terminates pregnancy within the first 7 weeks.
    - RU486 blocks progesterone receptors in the uterus, preventing progesterone from maintaining the pregnancy.
    - RU486 is taken with a small amount of prostaglandin to induce uterine contractions.

Genetic diseases and developmental problems can be diagnosed while the fetus is still in the uterus.

- Many genetic diseases and developmental problems can now be diagnosed while the fetus is still in the uterus.
- Ultrasound imaging generates images using sound frequencies above the normal hearing range that are commonly used to analyze the fetus's size and condition.

- In amniocentesis and chorionic villus sampling, a needle is used to remove fetal cells from fluid or tissue surrounding the embryo.
- A blood sample from the mother can contain fetal cells, which can be identified with specific antibodies and then tested for genetic disorders.
    - A few fetal blood cells leak across the placenta into the mother's bloodstream.
- Diagnosing genetic diseases in a fetus poses ethical questions.
    - Most detectable disorders cannot be treated in the uterus; many cannot be corrected even after birth.
    - Parents must decide whether to terminate a pregnancy or to raise a child who may have profound defects and a short life expectancy.

Reproductive technology can help with a number of fertility problems.

- An inability to conceive offspring affects one in ten couples.
- The causes of infertility vary, and the likelihood of a reproductive defects is equal for men and women.
- For women, the risk of reproductive difficulties as well as genetic abnormalities of the fetus increases steadily past age 35; the prolonged period of time oocytes spend in meiosis is largely responsible.
- Hormone therapy may increase sperm or egg production; surgery can correct ducts that have failed to form properly or become blocked.
- Many infertile couples turn to **assisted reproductive technologies**, which involve the surgical removal of eggs (secondary oocytes) from a woman's ovaries after hormonal stimulation.
    - The eggs are fertilized and returned to the woman's body.
    - Unused eggs, sperm, and embryos from such procedures can be frozen for later attempts.
- In ***in vitro*** **fertilization (IVF)**, oocytes are mixed with sperm in culture dishes, the fertilized eggs are incubated until the eight-cell stage, and then the eggs are transferred into the woman's uterus.
- If mature sperm are defective, scarce (fewer than 20 million per milliliter of ejaculate), or even absent, fertility may be restored by **intracytoplasmic sperm injection (ICSI)**.
    - In this procedure, the head of a sperm is drawn up into a needle and injected directly into an oocyte to achieve fertilization.
- Though costly, IVF procedures have enabled hundreds of thousands of couples to conceive children.
- Abnormalities arising as a consequence of the IVF procedure are rare.