

# Animal Reproduction

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## Overview of Animal Reproduction

### **Both sexual and asexual reproduction occur in the animal kingdom**

- **Asexual reproduction:** The genes of new individual all come from one parent without the fusion of egg and sperm.
  - Asexual reproduction is most advantageous in stable and favorable environments:
    - Creation numerous offspring in a short amount of time.
    - Perpetuation successful genotypes precisely.
- **Sexual reproduction:** the creation of offspring by the fusion of **haploid gametes** to form a **diploid zygote** (fertilized egg).
  - **Ovum** (female gamete) and **spermatozoon** (male gamete) are formed by **meiosis**.
  - Sexual reproduction increases **genetic variability** among offspring by generating unique combinations of genes inherited from two parents.
  - Sexual reproduction producing offspring with varying phenotypes may enhance the reproductive success of parents in a fluctuating environment.

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

- **Fission:** Separation of a parent into two or more individuals of equal size.
- **Budding:** New individual split off from existing ones.
- **Fragmentation,** the breaking of the body into several pieces, each of which develops into a complete adult: polychaetes.
  - Fragmentation must be accompanied by **regeneration,** the regrowth of lost body parts.
- **Gemmules:** Several types of cells migrate together within the sponge and become surrounded by a protective coat.

## **Reproductive cycles and patterns vary extensively among animals**

- The periodic nature of reproduction allows animals to conserve resources and reproduce when more energy is available, and when environmental conditions (e.g., temperature) favor the survival of offspring: Reproductive cycle of sheep only occur during fall and early winter, so lambs are born in the spring.
  
- **Parthenogenesis**: the egg develops directly without being fertilized. The adults produced by parthenogenesis are often haploid, and their cells do not undergo meiosis in forming new gametes, e.g., bees and ants.
  1. Imitate courtship and mating behavior in whiptail lizard: female behavior occurring when the level of the female sex hormone estrogen is rising prior to ovulation (the release of eggs) and male behavior occurring after ovulation when the level of estrogen drops.
  2. Alternation between parthenogenesis and sexual reproduction: aphids, rotifers, and daphnia.
  
- **Dieocious**
  
- **Hermaphroditism**: Each individual has both functional male and female reproductive systems, e.g., barnacles and earthworms
  - Sequential hermaphroditism: an individual reverses its sex during its lifetime.
    - **Protogynous** (female first): male defends the harem against intruders.
    - **Protandrous** (male first): production of huge numbers.

## Mechanisms of Sexual Reproduction

**Internal and external fertilization both depend on mechanisms ensuring that mature sperm encounter fertile eggs of the same species**

### **- External fertilization:**

- The parents actually do not make physical contact: timing is crucial to ensure that mature sperm encounter ripe eggs.

- The eggs are shed by the female and fertilized by the male in the environment which fertilized egg can develop without desiccation or heat stress: almost exclusively in moist habitats.
- **Internal fertilization:**
  - Sophisticated reproductive system: sperm storage and delivery
  - Cooperative behavior is required to make copulation possible.
  - Sperm are deposited in (or nearby) the female reproductive tract, and egg and sperm unite within the body of the female.
- **Courtship behavior** acts as a mutual trigger for the release of gametes, with two effects:
  1. The probability of successful fertilization is increased.
  2. The choice of mates may be somewhat selective.
- **Pheromones:** communication signals between animals of the same species such as mate attractants, territorial markers, or alarm substances.
  - Small, volatile molecule disperses easily into the environment: 1 molecule of pheromone in  $10^{17}$  molecules of other gases in air.
  - Whether human being uses pheromones to communicate?

**Species with internal fertilization usually produce fewer zygotes but provide more parental protection than species with external fertilization**

**Complex reproductive systems have evolved in many animal phyla**

- Parasites have simple body plan with complex reproductive system.
- **Gonad:** gamete-producing organ in most animals
- **Spermatheca:** sperm storage sac
- **Cloaca:** the digestive, excretory, and reproductive systems have common opening to the outside in many non-mammalian.
- Many nonmammalian vertebrates do not have well-developed penis and simply evert the cloaca to ejaculate.

## Mammalian Reproduction

### **Human reproduction involves intricate anatomy and complex behavior**

#### Reproductive anatomy of the human male

- **Testes** (singular testis):
  - **Seminiferous tubules**: tightly coiled tubes for sperm production.
  - **Leydig cells**: secreting hormones (**testosterone** and other **androgens**)
  - Sperm production cannot occur at normal body temperatures in most mammals: testes hang outside the abdominal cavity in the **scrotum**, which temperature is about 2°C below the abdominal cavity.
- **Epididymis**: the site of sperm storage and their final maturation.
  - **Vas deferens**: During ejaculation, the sperm are propelled from the epididymis through the muscular vas deferens.
  - **Ejaculatory duct**: a short duct joins two vas deferens ducts, and opens into the urethra.
- **Urethra**: the draining tube for both the excretory system and the reproductive system runs through the penis and opens to the outside at the tip of the penis.
- **Seminal vesicles**:
  - The seminal vesicles fluid is thick, yellowish and alkaline (neutralizing the natural acidity of the vagina) containing mucus, ascorbic acids, fructose (energy for the sperm), a coagulating enzyme, and **prostaglandins**.
  - Prostaglandins in the female reproductive tract can stimulate contractions of the uterine muscles, which help move the semen up the uterus.
- **Prostate gland**: the largest semen-secreting glands.
  - Prostatic fluid is thin and milky, contains anticoagulant enzyme and citrate.
  - When first ejaculated, the semen coagulates, making it easier for uterine contraction to move it along; then anticoagulants liquify the semen, and the sperm begin swimming through the female tract.
  - The most common medical problems of men over age 40.
  - Prostate cancer is one of the most common cancers in men.

- **Bulbourethral glands**, a pair of small glands along the urethra below the prostate, secrete clear mucus to neutralize acidic urine remaining in the urethra.
- Bulbourethral fluid does carry some sperm released before ejaculation, which causes the high failure rate of the withdrawal method of birth control.
- **Penis** in human is composed of three cylinders of spongy erectile tissue derived from modified veins and capillaries. During sexual arousal, this tissue fills with blood from the arteries.
- **Baculum**: a bone stiffens the penis in some mammals.
- **Glans penis**: sensitive to stimulation. The human glans is covered by a fold of skin, **prepuce**, which can be removed by circumcision.
- Temporary **impotence**, a reversible inability to achieve an erection, can result from alcohol consumption, certain drugs, and emotional problems.
- Penile implant devices
- **Viagra** promotes the action of the local regulator **nitric oxide (NO)**, enhancing relaxation of smooth muscles in the blood vessels of the penis.

### Reproductive anatomy of the human female

- **Ovary**: Each ovary is enclosed in a tough protective capsule and contains many **follicles**.
- A follicle consists of one egg cell surrounded by one or more layers of follicle cells, which nourish and protect the developing egg cell.
- About 400,000 follicles are formed in woman at birth. After puberty, usually one follicle matures and releases its egg during each **menstrual cycle**.
- **Ovulation**: the egg is expelled from the follicle.
- **Corpus luteum**: After ovulation, the remaining follicular tissue grows within the ovary. The corpus luteum secretes **progesterone** and additional **estrogen**. If the egg is not fertilized, the corpus luteum disintegrates, and a new follicle matures in the next cycle.

- **Oviduct** (fallopian tube): a funnel-like opening, and cilia on the inner epithelium lining the duct help to collect the egg cell by drawing fluid from the body cavity into the duct.
- **Uterus (womb)**: a thick, muscular organ houses the embryo and fetus.
  - **Endometrium**: the inner lining of the uterus is richly supplied with blood vessels.
  - **Cervix**: The narrow neck of the uterus, which opens into the vagina.
- **Vagina**: a thin-walled chamber forms the birth canal.
  - **Vestibule**: two pairs of skin (**labia majora**, and **labia minora**) externally cover vaginal orifice and the opening of the urethra.
  - **Hymen**: A thin membrane covers the vaginal orifice - no known function.
- **Clitoris**: A small bulb of erectile tissue, the female equivalent of glans penis.
- **Bartholin's glands** located near the vaginal opening, secret mucus into vestibule, keeping it lubricated to facilitating intercourse.
- **Mammary gland** (breast): not part of the reproductive tract.
  - **Alveoli**: A series of small sacs of epithelial tissue that secrete milk.
  - **Lactiferous** (milk) **ducts** and nipple: The lack of estrogen in males prevents the development of both the secretory apparatus and the fat deposits.

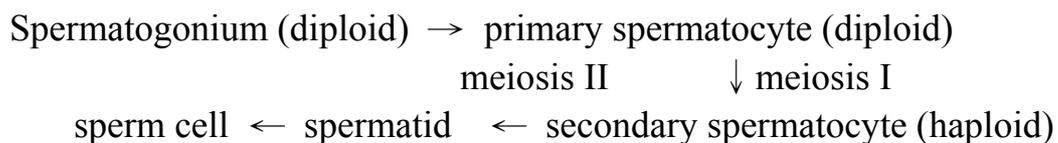
### Human sexual response: Mating behaviors

- The **sexual response cycle** can be divided into four phases:
  1. **Excitement**: preparation of the vagina and penis for **coitus**.
    - **Vasocongestion** (erection of the penis and clitoris), **myotonia** (nipple erection and tension of the arms and legs), enlargement of the testes, labia, and breasts, as well as vaginal lubrication
  2. **Plateau**: breathing increases and heart rate rises
    - In females, the outer third of the vagina becomes vasocongested, while the inner two-thirds becomes slightly expanded. This change forms a depression that receives sperm at the back of the vagina.

3. **Orgasm:** rhythmic, involuntary contractions of the reproductive structures in both sexes usually last only a few seconds.
  - Male orgasm: Contraction of the glands and ducts of the reproductive tract deposits semen in the urethra. And then ejaculation occurs when the urethra contracts to expel the semen.
  - Female orgasm: the uterus and outer vagina contract.
4. **Resolution:** Vasocongested organs return to their normal size and color, and muscles relax.

**Spermatogenesis and oogenesis both involve meiosis but differ in three significant ways**

- **Spermatogenesis:** The precursor cells of sperm continue to divide by mitosis in seminiferous tubules throughout the reproductive years of a male.



- A man can ejaculate daily 2 to 5 ml of semen (100 to 650 x 10<sup>6</sup> sperm/ml).
- The structure of a spermatozoon (sperm cell)
  - **Acrosome:** containing enzymes that help the sperm penetrate the egg.
  - Mitochondria: providing ATP for movement of the tail, a flagellum.
- **Oogenesis:** development of ova (mature, unfertilized egg cells)
  - During the meiotic divisions of oogenesis, **cytokinesis** is unequal, with almost all the cytoplasm monopolized by a single daughter cell. This large cell goes on to form the **ovum**, and the three smaller cells form **polar bodies**, soon degenerate.
  - At birth, ovary already contains all the immature egg cells it will ever have.
  - After puberty, a few oogonium (diploid) formed primary oocytes undergo the first meiotic division within growing follicles during each ovarian cycle. The egg released during ovulation is not actually a mature ovum. In humans, penetration of the egg by the sperm triggers the second meiotic division to actually complete the oogenesis.

## **A complex interplay of hormones regulates reproduction**

### The Male Pattern

- Male sex hormones: **Androgens** (testosterone is the most important) are responsible for the primary and secondary sex characteristics of the male.
- The primary sex characteristics: development of the vasa deferentia, the external reproductive structure, and sperm production.
- The secondary sex characteristics are not directly related to the reproductive system: deepening of the voice; the male distributions of armpit, facial, and pubic hair; and muscle growth (androgens stimulate protein synthesis).
- Androgens increase general aggressiveness and are responsible for such actions as singing in birds and calling by frogs.
- Hormones from the **anterior pituitary** and **hypothalamus** control both androgen secretion and sperm production by the testes.

### The Female Pattern

- **Menstrual cycle** (MC) and **estrous cycle** (EC) occur in female mammals:
  - In both cases, ovulation occurs at a time in the cycle after the endometrium has started to thicken and has become more extensively vascularized.
  - Difference between the two types of cycles:
    - The fate of the uterine lining if pregnancy does not occur:
    - More pronounced behavioral changes during EC than during MC.
    - Stronger effects of season and climate on estrous cycles.
- **Menstrual cycle**: Humans and many other primates
  - **Menstruation**: the endometrium is shed from the uterus through the vagina in a bleeding - the first day of bleeding is designated as day 1 of the cycle.
    1. **Menstrual flow phase**: bleeding usually persists for a few days.
    2. **Proliferative phase**: the endometrium begins to thicken for a week or two.
    3. **Secretory phase**: about two weeks in duration, the endometrium continues to thicken, becomes vascularized, and secretes a fluid rich in glycogen.

- **Estrous cycle:** In other mammals, because uterus reabsorbs the endometrium, no bleeding occurs.
  
- Human females can accept sexual activity anytime, but most mammals copulate only around the period of ovulation: This period of sexual activity is called **estrus** or **heat**, because the body temperature increases slightly.
- The length and frequency of reproductive cycles vary among mammals: The estrous cycle of the rat is only 5 days. Dogs have one cycle per year, but elephants have several cycles per year.
  
- **Ovarian cycle:** paralleling the menstrual cycle
  1. **Follicular phase:**
    - Several follicles in the ovary begin to grow: Their egg cells enlarge, and the coat of follicle cells becomes multi-layered.
    - Of the growing follicles, only one usually continues to enlarge and mature, while the others disintegrate.
    - The maturing follicle develops an internal fluid-filled cavity and grows large, forming a bulge near the surface of the ovary.
  2. **Ovulatory phase:**
  3. **Luteal phase:** The follicular tissue that remains in the ovary after ovulation is transformed into the **corpus luteum**.
  
- Hormones coordinate the menstrual and ovarian cycles.
  - The ovarian cycle synchronized with the menstrual cycle: Estrogen is a hormonal signal to the uterus, causing the endometrium to thicken. Thus, the follicular phase of the ovarian cycle is coordinated with the proliferative phase of the menstrual cycle.

- During the follicular phase of the ovarian cycle:
  - The **pituitary** secretes relatively small quantities of **FSH** and **LH** in response to stimulation by **GnRH** from the **hypothalamus**, which was stimulated by **estrogen**. At this time, the cells of immature follicles in the ovary have receptors for FSH, but not for LH. The FSH stimulates the growth of follicles and to secrete estrogen.
- During the ovulatory phase:
  - The increase in LH concentration caused by increased estrogen secretion from the growing follicle. Meanwhile, The follicles express LH receptors.
- During the luteal phase of the ovarian cycle (following ovulation):
  - LH stimulates the follicular tissue form the **corpus luteum**.
  - The corpus luteum secretes **estrogen** and **progesterone**.
  - The progesterone and estrogen together exerts negative feedback on the **hypothalamus** and **pituitary**, inhibiting the secretion of the LH and FSH.
  - The decreasing of LH causes the corpus luteum to disintegrate which decline the concentrations of estrogen and progesterone.
  - The dropping levels of ovarian hormones liberate the hypothalamus and pituitary from the inhibitory effects of these hormones. The pituitary then begins to secrete enough FSH to stimulate the growth of new follicles in the ovary, initiating the follicular phase of the next ovarian cycle.
  
- **Menopause**: the cessation of ovulation and menstruation between the ages of 46 and 54 in human females.
  - Ovaries lose their responsiveness to gonadotropins, and decline to produce estrogens.
  - Rare phenomenon in most species: providing better care for her offspring?

**Embryonic and fetal development occur during pregnancy in humans and other eutherian (placental) mammals**

## From Conception to Birth

- **Conception**: the fertilization of the egg by a spermatozoon.
  - **Pregnancy (gestation)**: carrying one or more developing embryos in the uterus.
    - Human pregnancy averages 266 days (38 weeks) from conception.
    - Human gestation can be divided into three trimesters (about 3 months each):
      1. The first trimester:
        - Rapid change for the baby:
          - A. The egg is fertilized by the sperm in the oviduct, and the cleavage, or cell division, begins about 24 hours after fertilization. Then the fertilized egg is moved to the uterus (takes 3 to 5 days).
          - B. One week after fertilization, the zygote has developed into a hollow ball of cells, **blastocyst**, which implants into the endometrium.
          - C. Tissues grow out from the embryo and mingle with endometrium to form **placenta** containing embryonic and maternal blood vessels.
        - Rapid change for the mother: The embryo secretes hormones to signal its presence.
          - Human chorionic gonadotropin (HCG) like LH maintains estrogen and progesterone secretion by the corpus luteum. In the absence of HCG, menstruation and spontaneous abortion of the embryo occur.
          - In the maternal blood, high levels of HCG are excreted in the urine, which can be detected in pregnancy tests.
- The first trimester is the main period of organogenesis:
  - The heart begins beating by the fourth week. At the eighth week, all the major structures of the adult are present in rudimentary form. At this point, the embryo (fetus) is only 5 cm.
  - Because of its rapid organogenesis, the embryo is most sensitive to such threats as radiation and drugs that can cause birth defects.

- The second trimester
  - A. The fetus is about 30 cm and the mother can feel its active movement.
  - B. HCG declines, the corpus luteum deteriorates, and the placenta secretes its own progesterone to maintain the pregnancy.
  - C. The uterus will grow enough for the pregnancy to become obvious.
- The third and final trimester
  - A. The fetus grows rapidly (about 3-3.5 kg and 50 cm).
  - B. Fetal activities decrease, since the available space within the embryonic membranes is full.
  - C. The mother's abdominal organs become compressed and displaced, leading to frequent urination, digestive blockages, and strain in the back muscles.
  
- **Labor (parturition)** occurs through a series of strong, rhythmic contractions of the uterus.
- **Prostaglandins** from the uterus, **oxytocin** from the posterior pituitary, and nervous reflexes all play roles in regulating labor contractions.

  1. The first stage: the opening of the cervix dilates. Complete dilation of the cervix ends the first stage of labor.
  2. The second stage: the birth of the baby. The continued strong contractions force the fetus down and out of the uterus and vagina. The umbilical cord is commonly cut and clamped at this time.
  3. The final stage: the expulsion of the placenta.

  
- **Lactation:**
  1. After birth, decreasing levels of progesterone free the anterior pituitary from negative feedback and allow prolactin secretion.
  2. Prolactin stimulates milk production after a delay of 2 or 3 days.
  3. The release of milk from the mammary glands is controlled by oxytocin.

## Reproductive Immunology

- **Physical barrier:** A protective layer, trophoblast prevents the embryo from contacting maternal tissue. The trophoblast, which develops from the cells of the blastocyst and penetrates the endometrium, is foreign to the mother.
- The trophoblast produces a chemical signal that induces development of a special type of white blood cell in the uterus that prevents other white cells from mounting an attack on the foreign tissue.
- If the initial immune response is too weak to trigger suppression, then the persistent immunological attack on the foreign tissue may lead to spontaneous abortion of the embryo.

## Contraception: preventing a pregnancy

- Fertilization can be prevented by abstinence from sexual intercourse or by any of several barriers that keep live sperm from contacting the egg.

### 1. **Temporary abstinence (rhythm method** of birth control):

- Because the egg can survive in the oviduct for 24 to 48 hours and sperm for up to 72 hours, a couple practicing temporary abstinence should not engage in intercourse during the few days before and after ovulation.
- The most effective methods for timing ovulation combine changes in cervical mucus and body temperature during the menstrual cycle.
- Rhythm methods depend on regular menstrual cycles and changes that may not be apparent in all women: less effective than most other methods.

### 2. Barrier methods of contraception: block the sperm from meeting the egg with or without **spermicide** - failure rates of less than 10%.

- **Condom:** natural membrane or latex rubber sheath fits over the penis to collect the semen.
- Latex condoms are the only ones that offer protection against sexually transmitted diseases, including AIDS

- **Diaphragm**: dome-shaped rubber cap fitted into the upper portion of the vagina before intercourse.
- **Cervical cap**: fits tightly around the opening of the cervix, which held in place for a prolonged period by suction
- **Intrauterine device (IUD)** in a variety of shapes can fit into the uterine cavity to prevent implantation of the blastocyst in the uterus by irritating the endometrium. New IUD prevents implantation by delivering synthetic progesterone locally to the endometrium.

### 3. Other methods:

- **Coitus withdrawal**: unreliable - sperm may be present in secretions that precede ejaculation.
- **Chemical contraception**: birth control pills have failure rates of less than 1%, and sterilization is nearly 100% effective.
  - **Birth control pills**
    1. Combinations of synthetic estrogen and progesterone: acting by negative feedback to stop the release of GnRH from hypothalamus and FSH (an estrogen effect) and LH (a progesterone effect) from pituitary.
    2. Minipill (progestin only): Altering woman's cervical mucus to block sperm from entering the uterus
      - In 1990, the FDA approved a long-lasting version: a small patch placed under the skin can dispense progestin for up to five years.
      - Long-term harmful effects of estrogen:
- **Sterilization**: the permanent prevention of gamete release--difficult to reverse.
  - **Tubal ligation** in women: cutting a short section out of the oviduct.
  - **Vasectomy** in men: cutting of the vas deferens to prevent sperm from entering the urethra.

- **Abortion:** termination of a pregnancy in progress.
  - Spontaneous abortion, or miscarriage
  - RU-486 blocks progesterone receptors in the uterus: antagonist.

### **Modern technology offers solutions for some reproductive problems**

- Diagnosis of genetic diseases and congenital disorders of fetus in the uterus.
  - **Ultrasonography:** a noninvasive procedure to detect fetal condition.
  - **Amniocentesis:** a long needle is inserted into the amnion, and a sample of fluid is withdrawn. Fetal cells in the fluid are cultured for 2 to 4 weeks, and the cultured cells can then be analyzed for genetic disorders and chromosomal problems, such as Down syndrome
  - **Chorionic villi sampling:** A small sample of tissue is removed for genetic and metabolic analysis from the chorion, the fetal part of the placenta.
    - This test can be performed earlier in the pregnancy, and obtain results in days rather than weeks, but carries a greater risk than amniocentesis (5~20% versus 1% spontaneous abortions following testing).
- **In vitro fertilization:** First accomplished in 1978 in England
  - Women whose oviducts are blocked can have ova surgically removed from follicles. The ova are then fertilized in Petri dishes in the laboratory. After about 60 hrs, when the embryo has reached the eight-cell stage, it is placed in the uterus and allowed to implant.
- Male chemical contraception:
  - Testosterone block releasing of pituitary gonadotropin, but stimulates spermatogenesis.
  - Estrogens are effective, but also inhibit libido and can be feminizing.