

# CHAPTER 12 CHROMOSOMAL PATTERNS OF INHERITANCE

## Chapter Outline

### 12.1 Chromosomal Inheritance

#### A. Chromosomal Theory of Inheritance

1. Genes are located on chromosomes; behavior of chromosomes and genes is therefore similar during sexual reproduction.
2. Chromosomes can be categorized as two types:
  - a. **Autosomes** are non-sex chromosomes that are the same number and kind between sexes.
  - b. **Sex chromosomes** determine if the individual is male or female.
3. Sex chromosomes in the human female are XX; those of the male are XY.
4. Males produce X-containing and Y-containing gametes; therefore males determine the sex of offspring.
5. Besides genes that determine sex, sex chromosomes carry many genes for traits unrelated to sex.
6. **X-linked gene** is any gene located on X chromosome; used to describe genes on X chromosome that are missing on the Y chromosome.

#### B. X-Linked Alleles

1. Work with fruit flies by Thomas Hunt Morgan (Columbia University) confirmed genes were on chromosomes.
  - a. Fruit flies are easily and inexpensively raised in common laboratory glassware.
  - b. Females only mate once and lay hundreds of eggs.
  - c. The fruit fly generation time is short, allowing rapid experiments.
2. Fruit flies have an XY system similar to the human system; therefore experiments are similar to the human situation.
  - a. Newly discovered mutant male fruit fly had white eyes.
  - b. Cross of the hybrids from the white-eyed male crossed with a dominant red-eyed female yielded the expected 3:1 red-to-white ratio; however, all of the white-eyed flies were males!
  - c. An allele for eye color on the X but not on the Y chromosome supports the results of this cross.
  - d. Behavior of this allele corresponds to the behavior of the chromosome; this confirmed the chromosomal theory of inheritance.
3. X-Linked Problems
  - a. X-linked alleles are designated as superscripts to the X chromosome.
  - b. Heterozygous females are **carriers**; they do not show the trait but can pass it on.
  - c. Males are never carriers but express the one allele on the X chromosome, whether it is dominant or recessive.
  - d. One form of color-blindness is X-linked recessive.

#### C. Human X-Linked Disorders

1. More males have X-linked traits because recessive alleles on the X chromosome in males are expressed in males.
2. Color Blindness
  - a. Color blindness can be an X-linked recessive disorder involving mutations of genes coding for green or red sensitive cone cells, resulting in an inability to perceive green or red, respectively; the pigment for blue-sensitive protein is autosomal.
  - b. About 8% of Caucasian men have red-green color blindness.
3. Muscular Dystrophy
  - a. Duchenne muscular dystrophy is the most common form and is characterized by wasting away of muscles, eventually leading to death; it affects one out of every 3,600 male births.
  - b. This X-linked recessive disease involves a mutant gene that fails to produce protein dystrophin.
  - c. Symptoms (e.g., waddling gait, toe walking, frequent falls, difficulty in rising) soon appear.
  - d. Muscle weakens until the individual is confined to wheelchair; death usually occurs by age 20.
  - e. Affected males are rarely fathers; the gene passes from carrier mother to carrier daughter.
  - f. Lack of dystrophin protein causes calcium ions to leak into muscle cells; this promotes action of

- an enzyme that dissolves muscle fibers.
    - g. As body attempts to repair tissue, fibrous tissue forms and cuts off blood supply.
    - h. A test now detects carriers of Duchenne muscular dystrophy; treatments are under research.
  - 3. Hemophilia
    - a. About one in 10,000 males is a hemophiliac with impaired ability of blood to clot.
    - b. Hemophilia has two types: Hemophilia A is due to absence of clotting factor IX; Hemophilia B is due to absence of clotting factor VIII.
    - c. Hemophiliacs bleed externally after an injury and also suffer internal bleeding around joints.
    - d. Hemorrhages stop with transfusions of blood (or plasma) or concentrates of clotting protein.
    - e. Factor VIII is now available as a genetic engineering product.
    - f. Of Queen Victoria's 26 offspring, five grandsons had hemophilia and four granddaughters were carriers.
  - 4. Fragile X Syndrome
    - a. In this case, the X chromosome is nearly broken; most often found in males.
    - b. This affects one in 1,500 males and one in 2,500 females.
    - c. As children, they are often hyperactive or autistic with delayed or repetitive speech.
    - d. As adults, males usually have larger testes, unusually protruding ears, and other symptoms.
    - e. However, about one-fifth of males with fragile X do not show symptoms.
    - f. Fragile X passes from a symptomless male carrier to grandson.
    - g. It has been traced to excessive repeats of base triplet CGG (cytosine, guanine, guanine); up to 230 copies compared to normal 6–to–50 copies.

## 12.2 Gene Linkage

### A. Linkage Groups

1. Fruit flies have four pairs of chromosomes to hold thousands of genes; therefore each chromosome must hold many genes.
2. All alleles on a chromosome form a **linkage group** that stays together except when crossing over.
3. Crossing-over causes **recombinant gametes** and at fertilization, recombinant phenotypes.
4. Linked alleles do not obey Mendel's laws because they tend to go into the gametes together.

### B. Chromosome Mapping

1. The percentage of recombinant phenotypes measures distance between genes to map the chromosomes.
2. Crosses involving linked genes do not give same results as unlinked genes.
3. A heterozygote forms only two types of gametes and produces offspring with only two phenotypes.

### C. Linkage Data

1. Linked genes indicate the distance between genes on the chromosomes.
2. If 1% of crossing-over equals one map unit, then 6% recombinants reveal 6 map units between genes.
3. If crosses are performed for three alleles on a chromosome, only one map order explains map units.
4. Humans have few offspring and a long generation time, and it is not ethical to designate matings; therefore biochemical methods are used to map human chromosomes.

## 12.3 Changes in Chromosome Numbers

### A. Mutations

1. Changes in chromosomes or genes that pass to offspring if they occur in gametes.
2. Mutations increase the amount of variation among offspring.
3. Chromosomal mutations include changes in chromosome number and structure.

### B. Polyploidy

1. Eukaryotes with more than the  $2n$  number of chromosomes are polyploids.
2. Terms indicate how many sets of chromosomes are present: (triploids  $[3n]$ , tetraploids  $[4n]$ , etc.).
3. Polyploidy does not increase variation in animals; judging from trisomies, it would be lethal.
4. Polyploidy is a major evolutionary mechanism in plants; it is probably involved in 47% of flowering plants including major crops.
5. Hybridization in plants can result in doubled number of chromosomes; an even number of chromosomes can undergo synapsis during meiosis; successful polyploidy results in a new species.

### C. Monosomy and Trisomy

1. **Monosomy** ( $2n - 1$ ) occurs when an individual has only one of a particular type of chromosome.
2. **Trisomy** ( $2n + 1$ ) occurs when an individual has three of a particular type of chromosome.
3. **Nondisjunction** is the failure of chromosomes to separate; it is more common during meiosis.

4. Monosomy and trisomy occur in plants and animals; in autosomes of animals, it is generally lethal.
5. **Down syndrome** is most common autosomal trisomy, involves chromosome 21.
  - a. Most often, Down syndrome results in three copies of chromosome 21 due to nondisjunction during gametogenesis.
  - b. In 23% of cases, the sperm had the extra chromosome 21.
  - c. In 5% of cases, there is translocation with chromosome 21 attached to chromosome 14; this translocation could have occurred generations earlier and is not age-related.
  - d. Chances of a woman having a Down syndrome child increase with age, starting at age 40.
  - e. Chorionic villi sampling testing or amniocentesis and karyotyping detects a Down syndrome child; however, risks for young women exceed likelihood of detection.
  - f. A Down syndrome child has tendency for leukemia, cataracts, faster aging, and mental retardation.
  - g. *Gart* gene, located on bottom third of chromosome 21, leads to high level of purines and is associated with mental retardation; future research may lead to suppression of this gene.

#### D. Changes in Sex Chromosome Number

1. Nondisjunction during oogenesis can result in too few or too many X chromosomes; nondisjunction during spermatogenesis can result in missing or too many Y chromosomes
2. **Turner syndrome** females have only one sex chromosome, an X.
  - a. Turner females are short, have a broad chest and folds of skin on back of neck.
  - b. Ovaries of Turner females never become functional; therefore, females do not undergo puberty.
  - c. They usually have normal intelligence and can lead fairly normal lives with hormone supplements.
3. **Klinefelter syndrome** males have one Y chromosome and two or more X chromosomes.
  - a. Affected individuals are sterile males; the testes and prostate are underdeveloped.
  - b. Individuals have large hands and feet, long arms and legs, and lack facial hair.
  - c. Presence of the Y chromosome drives male formation but more than two X chromosomes may result in mental retardation.
  - d. Barr body, usually only seen in female cell nuclei, is seen in this syndrome due to the two X chromosomes.
4. **Poly-X** females have three or more X chromosomes and extra Barr bodies in the nucleus.
  - a. There is no increased femininity; most lack any physical abnormalities.
  - b. XXX individuals are not mentally retarded but may have delayed motor and language development; XXXX females are usually tall and severely mentally retarded.
  - c. Many experience menstrual irregularities but many menstruate regularly and are fertile.
5. **Jacobs syndrome (XXY)** are males with two Y chromosomes instead of one.
  - a. This only results from nondisjunction during spermatogenesis.
  - a. Males are usually taller than average, suffer from persistent acne, and tend to have speech and reading problems.
  - b. Earlier claims that XYY individuals were likely to be aggressive were not correct.

### 12.4 Changes in Chromosome Structure

#### A. Changes in Chromosomal Structure

1. Environmental factors including radiation, chemicals, and viruses, can cause chromosomes to break; if the broken ends do not rejoin in the same pattern, this causes a change in chromosomal structure.

#### B. Examples of Changes in Chromosomal Structure

1. **Deletion:** a type of mutation in which an end of a chromosome breaks off or when two simultaneous breaks lead to the loss of a segment.
2. **Translocation:** a chromosomal segment is removed from one chromosome and inserted into another, nonhomologous chromosome; In Down syndrome, 5% of cases are due to a translocation between chromosome 21 and 14, a factor that runs in the family of the father or mother.
3. **Duplication** is the presence of a chromosomal segment more than once on the same chromosome.
  - a. A broken segment from one chromosome can simply attach to its homologue or unequal crossing-over may occur.

- b. Duplication may also involve an **inversion** where a segment that has become separated from the chromosome is reinserted at the same place but in reverse; the position and sequence of genes are altered.

### C. Human Syndromes

#### 1. Deletion Syndromes

- a. Williams syndrome occurs when chromosome 7 loses an end piece: children look like pixies, have poor academic skills but good verbal and musical skills; lack of elastin causes cardiovascular problems and skin aging.
- b. Cri du chat syndrome is deletion in which an individual has a small head, is mentally retarded, has facial abnormalities, and abnormal glottis and larynx resulting in a cry resembling that of a cat.

#### 2. Translocation Syndromes

- a. If a translocation results in the normal amount of genetic material, the person will remain healthy; if a person inherits only one of the translocated chromosomes, that person may have only one allele or three alleles rather than the normal two.
- b. In Alagille syndrome, chromosomes 2 and 20 exchange segments, causing a small deletion on chromosome 20 that may produce some abnormalities.