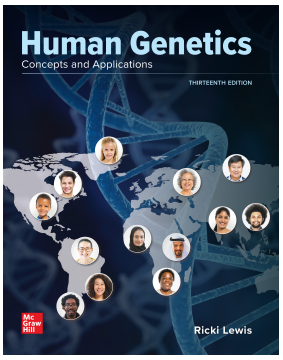
Because learning changes everything.®




## Chapter 3
Meiosis, Development, and Aging Cells

Thirteenth Edition

Ricki Lewis



1

## Learning Outcomes

1. Describe the structures of the male and female reproductive systems.
2. Explain why meiosis is necessary to reproduce.
3. Summarize the events of meiosis.
4. List the steps in sperm and oocyte formation.
5. Describe early prenatal development.
6. Explain how the embryo differs from the fetus.
7. Define *critical period*.
8. List some teratogens.
9. Describe common diseases that begin in adulthood.
10. Explain how rapid aging syndromes occur.



2

## Human Development

Genes orchestrate our physiology after conception through adulthood.

First cell forms when a **sperm** from a male and an **oocyte** from a female join.

- Sperm and oocytes are **gametes.**

Each reproductive system has:

- Paired structures, called gonads
- Tubular structures that transport these cells
- Hormones and secretions that control reproduction



3

## The Male Reproductive System 1

Sperm cells are made in the seminiferous tubules of the **testes.**

Sperms mature, stored in the epididymis.

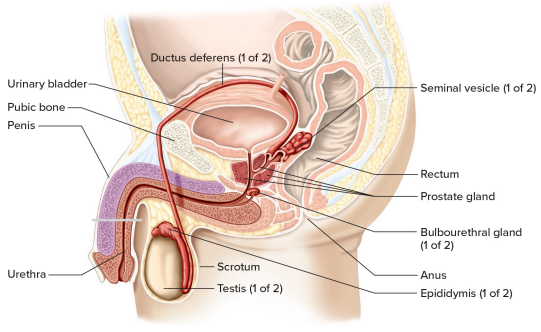
The prostate gland, seminal vesicles, and bulbourethral glands add secretions to form the seminal fluid.

Sperm from each ductus deferens exit through the urethra and out the penis.



4

## The Male Reproductive System 2




Access the text alternative for slide images.



5

## The Female Reproductive System 1

Oocytes mature in the **ovaries.**

Each month, an ovary releases an oocyte into one of two uterine tubes.

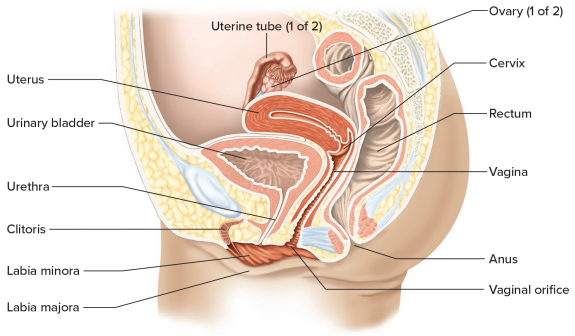
- The oocyte is fertilized, it continues to the uterus where it divides and develops.
- If it is not fertilized, the body expels it, along with the uterine lining via the menstrual flow.

Hormones control the cycle of oocyte maturation and the preparation of the uterus to nurture a fertilized ovum.



6

## The Female Reproductive System 2




Access the text alternative for slide images.

 7

7

## Meiosis 1

Gametes form from special cells called germ line cells

Meiosis is a cell division that halves the chromosome number

- **Homologous pairs** have the same genes in the same order but carry different alleles, or variants, of the same gene

Gametes are **haploid** and somatic cells are **diploid** for each chromosome

Absence of meiosis could lead to genetically overloaded cells

Mixes up trait combinations

Provides genetic diversity which can enable a population to survive an environmental challenge

 8

8

## Meiosis 2

Consists of two divisions:

- **Meiosis I** = The **reduction division**
  - Reduces the number of chromosomes from 46 to 23
- **Meiosis II** = The **equational division**
  - Produces four cells from the two produced in Meiosis I

Note:

- As in mitosis, meiosis occurs after an interphase period when DNA is replicated (doubled)
- Each division contains a prophase, a metaphase, an anaphase, and a telophase

 9

9

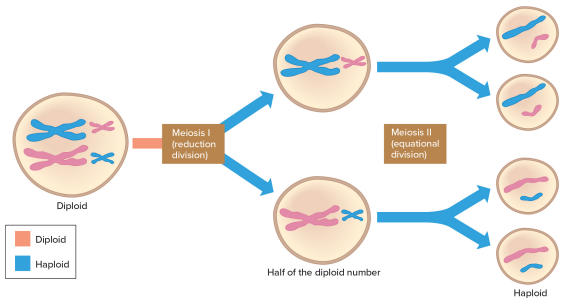
## Mitosis vs Meiosis

| Mitosis | Meiosis |
|---|---|
| One division | Two divisions |
| Two daughter cells per cycle | Four daughter cells per cycle |
| Daughter cells genetically identical | Daughter cells genetically different |
| Chromosome number of daughter cells same as that of parent cell (2*n*) | Chromosome number of daughter cells half that of parent cell (1*n*) |
| Occurs in somatic cells | Occurs in germline cells |
| Occurs throughout life cycle | In humans, completes after sexual maturity |
| Used for growth, repair, and asexual reproduction | Used for sexual reproduction, producing new gene combinations |

 10

10

## Overview of Meiosis

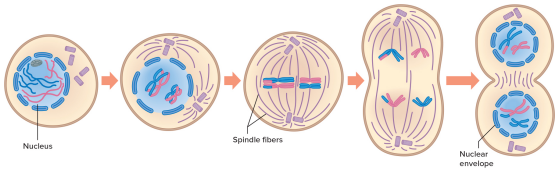



Access the text alternative for slide images.

 11

11

## Meiosis I




**Prophase I (early)** Synapsis and crossing over occurs.

**Prophase I (late)** Chromosomes condense, become visible. Spindle forms. Nuclear envelope fragments. Spindle fibers attach to each chromosome.

**Metaphase I** Paired homologous chromosomes align along equator of cell.

**Anaphase I** Homologous chromosomes separate to opposite poles of cell.

**Telophase I** Nuclear envelopes partially assemble around chromosomes. Spindle disappears. Cytokinesis divides cell into two.

Access the text alternative for slide images.

 12

12

## Prophase I 1

A spindle forms.

Homologs pair-up and undergo **crossing over.**

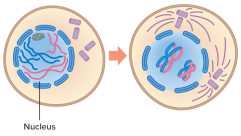
Chromosomes condense.

Synapsed chromosomes separate but remain attached at a few points.

 13

13

## Prophase I 2




Prophase I (early) Prophase I (late)

**Prophase I (early)**

- Synapsis and crossing over occurs.

**Prophase I (late)**

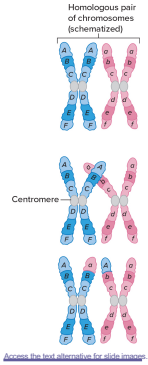
- Chromosomes condense, become visible. Spindle forms. Nuclear envelope fragments. Spindle fibers attach to each chromosome.

Access the text alternative for slide images.

 14

14

## Crossing Over




Access the text alternative for slide images.

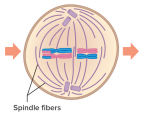
 15

15

## Metaphase I

Homologous pairs align along the equator of the cell.

Random alignment of chromosomes causes **independent assortment** of the genes that they carry.




Metaphase I

**Metaphase I**

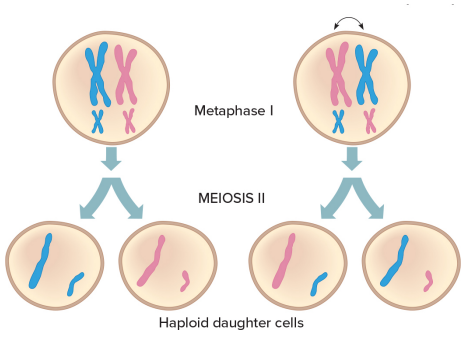
- Paired homologous chromosomes align along equator of cell.

Access the text alternative for slide images.

 16

16

## Independent Assortment




Access the text alternative for slide images.

 17

17

## Anaphase I and Telophase I 1

Homologs separate in anaphase I

- Unlike in mitosis, the centromeres of each replicated chromosome in meiosis I remain together.

Homologs move to opposite poles by telophase I

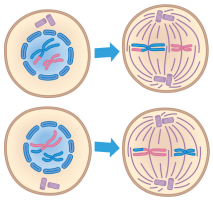
Note:

- During a second interphase, chromosomes unfold into thin threads.
- Proteins are manufactured, but DNA is not replicated a second time.

 18

18

## Anaphase I and Telophase I 2



### Anaphase I

- Homologous chromosomes separate to opposite poles of cell.

### Telophase I

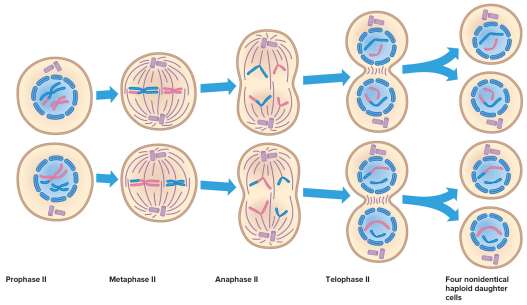
- Nuclear envelopes partially assemble around chromosomes. Spindle disappears. Cytokinesis divides cell into two.

Access the text alternative for slide images.

 19

19

## Meiosis II




Access the text alternative for slide images.

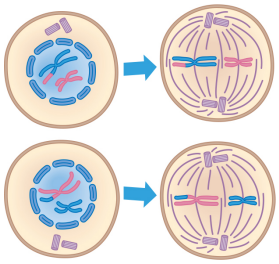
 20

20

## Prophase II and Metaphase II

Chromosomes are again condensed and visible.

Chromosomes align along the equator of the cell.



Access the text alternative for slide images.

 21

21

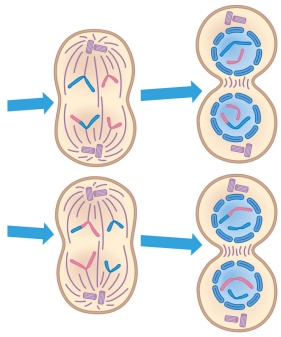
## Anaphase II and Telophase II

Centromeres divide

Newly formed, unreplicated chromosomes, move to opposite poles

Nuclear envelope reforms

Separate into individual cells



Access the text alternative for slide images.

 22

22

## Results of Meiosis 1

Four nonidentical haploid daughter cells

- Each carries a new assortment of genes and chromosomes that hold one copy of the genome

Access the text alternative for slide images.

 23

23

## Results of Meiosis 2

Meiosis generates astounding genetic variety.

- A person can produce $2^{23}$ (8,388,6082) possible combinations of chromosomes

Thus, fertilization of gametes can generate more than 70 trillion (8,388,608 × 8,388,608) genetically unique individuals!

Crossing over contributes almost limitless genetic diversity.

 24

24

## Gametes Mature

Meiosis happens in both sexes, but different distributions of cell components create the distinctions between sperm and oocytes.

The gametes of the maturing male and female proceed through similar stages as they form, but with vastly different timetables.

- A male begins manufacturing sperm at puberty and continues throughout life, whereas a female begins meiosis when she is a fetus.
- Meiosis in the female completes only if a sperm fertilizes an oocyte.

 25

25

## Spermatogenesis 1

A diploid **spermatogonium** divides by mitosis to produce a stem cell and another cell that specializes into a mature sperm.

In meiosis I, the primary spermatocyte produces two haploid **secondary spermatocytes.**

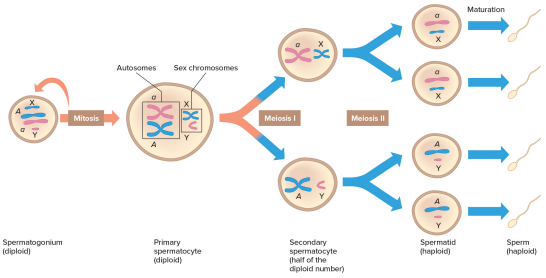
In meiosis II, each secondary spermatocyte produces two equal-sized **spermatids.**

Spermatids then mature into tadpole-shaped **spermatozoa.**

 26

26

## Spermatogenesis 2

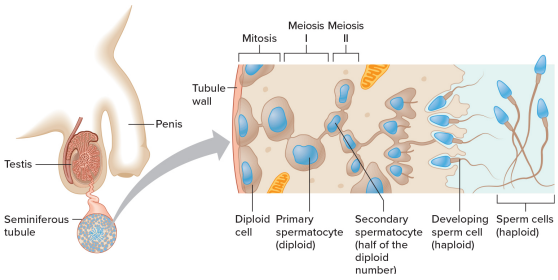



Access the text alternative for slide images.

 27

27

## Spermatogenesis 3

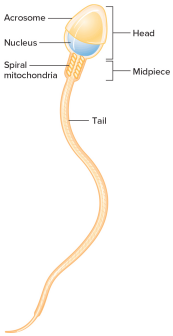



Access the text alternative for slide images.

 28

28

## Sperm Structure




Access the text alternative for slide images.

 29

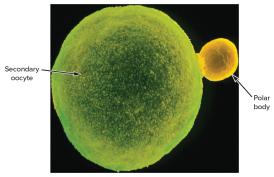
29

## Oogenesis 1

Begins with a diploid **oogonium**

In meiosis I, primary oocyte divides unequally forming a small **polar body** and a large **secondary oocyte**

In meiosis II, the secondary oocyte divides to form another **polar body** and a mature **ovum**




Access the text alternative for slide images.

 Prof. P.M. Motta/Univ. "La Sapienza", Rome/Science Source 30

30

## Oogenesis 2

Unlike spermatogenesis, oogenesis is a discontinuous process.

Oocytes arrest at prophase I until puberty.

After puberty, meiosis I continues in one or several oocytes each month but halts again at metaphase II.

Meiosis is only completed if the ovum is fertilized.

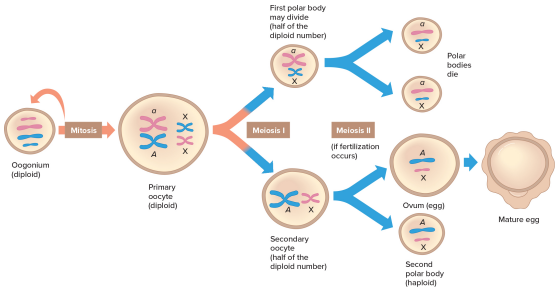
A female ovulates about 400 oocytes between puberty and menopause.

- Most oocytes degrade, because fertilization is so rare.

31

## Oogenesis 3

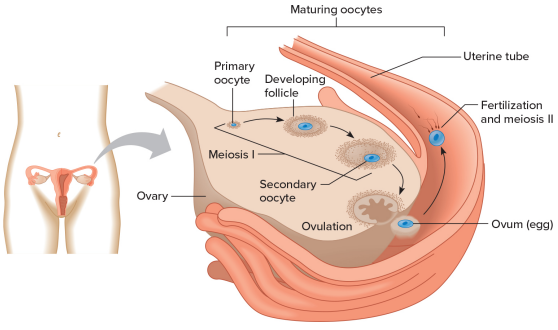



Access the text alternative for slide images.

32

## The Making of Oocytes

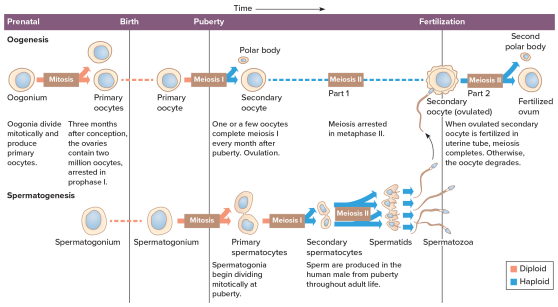



Access the text alternative for slide images.

33

## Oogenesis vs Spermatogenesis




Access the text alternative for slide images.

34

## Meiosis and Mutations

"Paternal age effect" conditions arise from stem cells in testes that divide every 16 days, from puberty on.

- Thus offering many opportunities for DNA replication error that generate a dominant mutation.

Mutations in the fibroblast growth factor receptor (FGFR) arise more frequently in testes as a man ages.

- This skews meiosis, producing problems in skeletal growth.

Genetic errors in oocytes from older women are typically extra or absent chromosomes.

35

## Paternal Age Effect

| Disease | Phenotype |
|---|---|
| Achondroplasia | Short-limbed dwarfism (see figure 5.1a) |
| Crouzan syndrome | Premature fusion of skull bones in infancy, causing wide-spaced and bulging eyes, beaked nose, short upper lip, small upper jaw, and jutting lower jaw |
| Hutchinson-Gilford progeria syndrome | Thin hair, weak bones, tough and wrinkled skin, stiff joints and blood vessel linings |
| Multiple endocrine neoplasia 2 | Cancers of thyroid, parathyroid, and adrenal glands |
| Pfeiffer syndrome | Premature fusion of skull bones in infancy, short and fused fingers and toes |
| Thanatophoric dysplasia | Severe short-limbed dwarfism |

36

## Prenatal Development

A prenatal human is considered an **embryo** for the first 8 weeks, when rudiments of all body parts form.

- The embryonic period begins when the fertilized ovum divides by mitosis.
- During the first week, the embryo is in a "preimplantation" stage because it has not yet settled into the uterine lining.

Prenatal development after the eighth week is the period when structures grow and specialize.

- From the start of the 9th week until birth, the prenatal human organism is a **fetus**.

37

## Fertilization 1

Union of sperm and oocyte

In the female, sperm are capacitated and drawn to the oocyte

Acrosomal enzymes aid sperm penetration

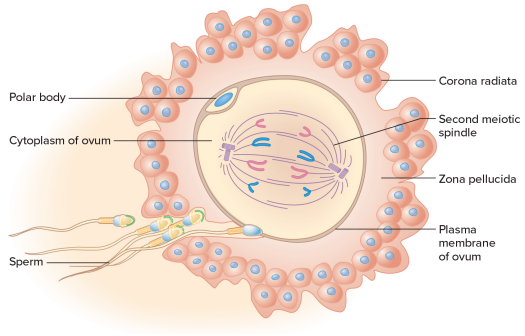
Chemical and electrical changes in the oocyte surface block entry of more sperm

Two genetic packages meet and merge, forming a **zygote**

38

## Fertilization 2




Access the text alternative for slide images.

39

## Cleavage

A day after fertilization, the zygote divides by mitosis, beginning a period of frequent cell division called **cleavage**

- Resulting early cells are called **blastomeres**

Developing embryo becomes a solid ball of 16+ cells called a **morula**

The ball of cells hollows out, and its center fills wit fluid, creating a **blastocyst**

40

## Blastocyst

Some of the blastocyst cells form a clump on the inside lining called the **inner cell mass**.

- Develops into the embryo.

Outermost blastocyst cells form the **trophoblast**

- Secrete the hormone human chorionic gonadotropin (hCG) that prevents menstruation.
  - A sign of pregnancy

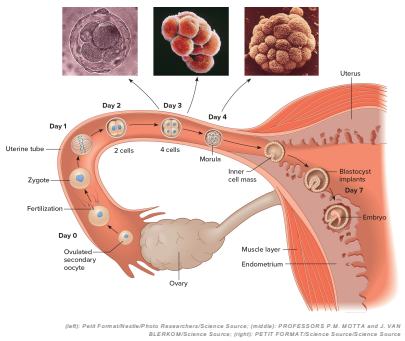
**Implantation** in the uterus occurs around day 7.

- Takes about a week

41

## From Ovulation to Implantation




(left): Petit Format/Nestle/Photo Researchers/Science Source; (middle): PROFESSORS P.M. MOTTA and J. VAN BLERKOM/Science Source; (right): PETIT FORMAT/Science Source/Science Source

Access the text alternative for slide images.

42

## Embryo Formation

The **primary germ layers** form in the second week after fertilization:

- **Ectoderm** (outermost layer)
- **Mesoderm** (middle layer)
- **Endoderm** (innermost layer)

This three-layered structure is the **gastrula**

Cells in each layer begin to form specific organs controlled by genes called homeotic

**Epigenetic** effects oversee differentiation as cells in each germ layer develop into organs.

 43

43

## Supportive Structures

Structures that support and protect the embryo include:

Chorionic villi

- Yolk sac
- Allantois
- Umbilical cord
- Amniotic sac

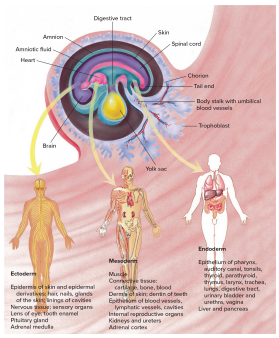
By 10 weeks the **placenta** is fully formed from the chorionic villi

- It continues to secrete hormones that maintain pregnancy and sends nutrients to the fetus

 44

44

## The Primordial Embryo




Access the text alternative for slide images.

 45

45

## Stages of Early Prenatal Development

| Stage | Time Period | Principal Events |
|---|---|---|
| Fertilized ovum | 12 to 24 hours following ovulation | Oocyte fertilized; zygote has 23 pairs of chromosomes and is genetically distinct |
| Cleavage | 30 hours to third day | Mitosis increases cell number |
| Morula | Third to fourth day | Solid ball of cells |
| Blastocyst | Fifth day through second week | Hollowed fluid-filled ball forms trophoblast (outside) and inner cell mass, which implants and flattens to form embryonic disc |
| Gastrula | End of second week | Primary germ layers form |

 46

46

## Multiple Births

Twins & other multiples arise early in development

**Dizygotic twins** (**DZ**; Fraternal)

- Two sperm fertilize two oocytes
- Same genetic relationship as any two siblings

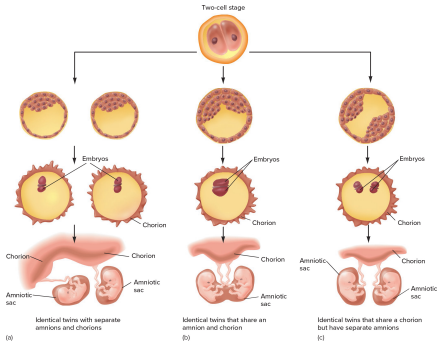
**Monozygotic twins** (**MZ**; Identical)

- Arise from a single fertilized ovum
- Three types of MZ twins can form, depending upon when the fertilized ovum or very early embryo splits
- Exposed to slightly different uterine environments

 47

47

## Types of Identical Twins




Access the text alternative for slide images.

 48

48

**Conjoined Twins**

Access the text alternative for slide images.


Courtesy Brittany, Abby and Patty Hensel


49

**The Embryo Develops 1**

**Organogenesis** is the transformation of the simple three germ layers into distinct organs

During week 3, a band called the primitive streak appears along the back of the embryo

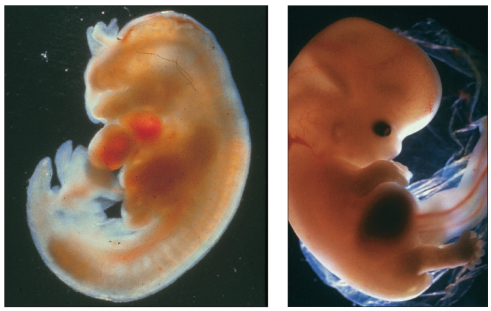
Followed by the connective tissue progenitor cells, notochord, **neural tube**, heart, central nervous system, arms, legs and other organ rudiments

By week 8, all the organs that will be present in the newborn have begun to develop




50

**The Embryo Develops 2**





(a): Petit Format/Nestle/Science Source; (b): Petit Format/Science Source


51

**The Fetus Grows 1**

During the fetal period, body proportions approach those of a newborn

Bone replaces softer cartilage

Nerve and muscle functions become coordinated

Anatomical differences between the sexes appear at week 6

- After the *SRY* gene is expressed in males.

By week 12, sucks thumb, kicks, makes fists and faces, and has the beginnings of teeth

By the fourth month, the fetus has hair, eyebrows, lashes, nipples, and nails




52

**The Fetus Grows 2**

Vocal cords will be formed by 18 weeks.

- But the fetus makes no sound because it doesn't breathe air.

By the end of the second trimester, the woman feels distinct kicks and jabs and may detect fetal hiccup.

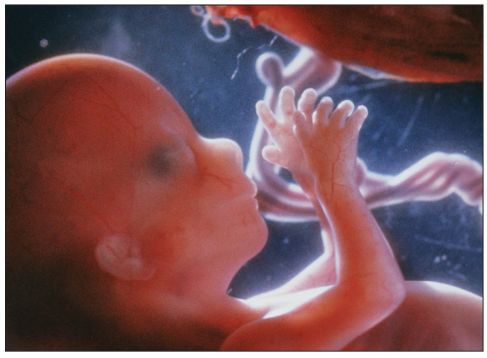
In the final trimester, fetal brain cells link into networks as organs elaborate and grow, and fat fills out the skin.

The digestive and respiratory systems mature last.




53

**16-Week Fetus**




Nestle/Petit Format/Science Source


54

**Birth Defects**

The time when genetic abnormalities, toxic substances, or viruses can alter a specific structure is called the **critical period**

About two-thirds of birth defects develop during the embryonic period

- More severe than those that arise during the fetal period

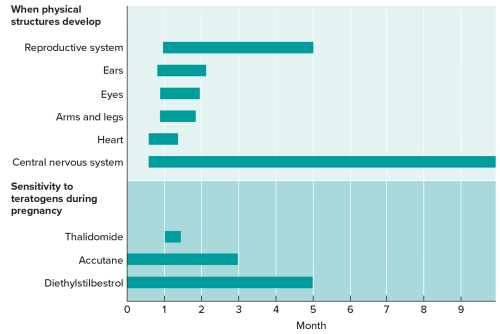
Some birth defects are caused by a mutation that acts at a specific point in prenatal development.

- Phocomelia is a suppression of limb development

 55

55

**Critical Periods of Development**




Access the text alternative for slide images.

 56

56

**Teratogens**

Are chemical or other agents that cause birth defects

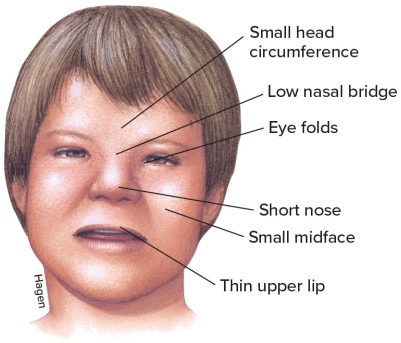
Examples:

- Cocaine
- Cigarettes
- Thalidomide
- Alcohol
  - Fetal alcohol syndrome
- Nutrients
  - Vitamins
- Viral infections
  - Zika virus; HIV; German measles (rubella)

 57

57

**Fetal Alcohol Syndrome**




Access the text alternative for slide images.

 58

58

**Maturation and Aging**

"Aging" means moving through the life cycle

Age 30 seems to be a turning point for decline.

- Some researchers estimate that, after this age, the human body becomes functionally less efficient by about 0.8 percent each year.

Many diseases that begin in adulthood, or are associated with aging, have genetic components.

- These diseases tend to be complex

 59

59

**Adult-Onset Inherited Disorders**

Genes may impact health throughout life.

Environmental factors can affect how certain genes can create risks that appear later.

- A powerful environmental influence is malnutrition.

Single-gene disorders that strike in childhood tend to be recessive.

Dominantly inherited conditions affect health in early to middle adulthood.

 60

60

**Syndromes That Resemble Accelerated Aging**

Genes control aging both passively (as structures break down) and actively (by initiating new activities).

Progeroid syndromes are single-gene disorders that speed aging-associated changes.

- The most severe progeroid syndromes are the progerias, which shorten life expectancy.

Most accelerated aging conditions are caused by the inability of cells to adequately repair DNA

 61

61

**Premature Aging Syndromes**

| Disease | Incidence | Average Life Expectancy |
|---|---|---|
| Ataxia telangiectasia | 1/60,000 | 19–25 |
| Cockayne Syndrome | 1/100,000 | 20 |
| Hutchinson-Gilford progeria syndrome | <1/1,000,000 | 13 |
| Rothmund- Thomson syndrome | <1/100,000 | Normal |
| Trichothiodystrophy | 1/1,000,000 | ? |
| Werner syndrome | <1/100,000 | 50 |

 62

62

**Hutchinson-Gilford Progeria Syndrome 1**

Is the most severe rapid aging condition.

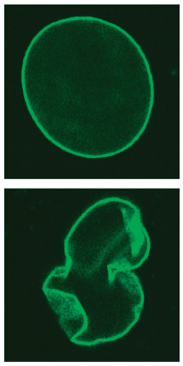
Normal cells growing in culture divide about 50 times before dying.

- Cells from Hutchinson-Gilford progeria syndrome patients die in culture after only 10 to 30 divisions.
- Caused by a mutation in the *LMNA* (lamin) gene
- A sticky form of lamin A, called progerin, triggers rapid programmed cell death (apoptosis)

 63

63

**Hutchinson-Gilford Progeria Syndrome 2**



 Source: Gordon P. Scaffidi P. L. T. Misteli/PLOS Biology Journal 64

64

**Is Longevity Inherited? 1**

Aging reflects genetic activity and a lifetime of environmental influences

Families and genetically isolated populations with many aged members have:

- Gene variants
- Shared environmental influences

Genome comparisons among centenarians to others are revealing genes that influence longevity

 65

65

**Is Longevity Inherited? 2**

Centenarians have inherited 2 types of gene variants— those that directly protect them and wild type alleles of genes that, when mutant, cause disease.

Genes can affect longevity control via:

- immune system functioning;
- insulin secretion and glucose metabolism;
- response to stress;
- the cell cycle;
- DNA repair;
- lipid (including cholesterol) metabolism;
- nutrient metabolism; and
- production of antioxidant enzymes.

 66

66

## Longevity Genes

| Gene | Protects Against | Population Studied |
|---|---|---|
| Apolipoprotein C3 (APOC-3) | Hypertension, diabetes | Ashkenazi Jews |
| | Cardiovascular disease | Amish |
| Bitter taste receptor (TAW2R16) | Poisoning, digestive problems | Calabria, Italy |
| Cholesteryl ester transfer protein (CETP) | Cardiovascular disease | Ashkenazi Jews |
| Forkhead box O3 (FOXO3) | Cancer, cardiovascular disease | Japanese-Americans |
| Growth hormone receptor (GHR) | Diabetes, cancer | Ecuador, Israel |
| Uncoupling proteins (UCP 2, 3, 4) | Oxidative damage, poor energy use | Calabria, Italy |




67

Because learning changes everything.®

www.mheducation.com



68