EMBRYOLOGY

SEM IV

V 1.0 2024-25

K HARISH BABU

PS GOVT COLLEGE PENUKONDA

SEMESTER-IV
COURSE 9: EMBRYOLOGY

LEARNING OBJECTIVES

- The objective of this course is to provide a comprehensive understanding of the concepts of early animal development.
- Students taking this course must develop a critical appreciation of methodologies specifically used to study the process of embryonic development in animals.
- In this course different concepts of animal development will be elaborated
- Students will be made familiar with different approaches that have been used to study embryology.
- Topics that will be discussed are organogenesis and regeneration.

LEARNING OUTCOMES:

The overall course outcome is that the student shall develop deeper understanding of concepts of embryology. This course will provide students with a deep knowledge in embryology by the completion of the course the graduate shall able to –

- Understand the historical perspective and concepts of embryology
- Acquire knowledge on gametogenesis, fertilization and cleavage patterns
- Understand the fate of germinal layers and extraembryonic membranes
- Explain the process of regeneration in certain animals
- Examine the process of organogenesis

UNIT-I:
1.1 Historical perspective and basic concepts: Phases of development
1.2 Cell-Cell interaction, Pattern formation, Differentiation and growth
1.3 Differential gene expression,
1.4 Cytoplasmic determinants and asymmetric cell division

UNIT-II:
2.1 Gametogenesis, Spermatogenesis, Oogenesis;
2.2 Types of eggs, Egg membranes; Fertilization (External and Internal)
2.3 Planes and patterns of cleavage; Types of Blastulae; Fate maps
2.4 Early development of frog and chick up to gastrulation

UNIT-III:
3.1 Fate of Germ Layers
3.2 Extra-embryonic membranes
3.3 Placenta (Structure, types and functions of placenta)
3.4 Amniocentesis

UNIT-IV:

4.1 Metamorphosis: Changes, hormonal regulations in amphibians
4.2 Regeneration: Modes of regeneration, epimorphosis, morphallaxis and compensatory regeneration (in Turbellarians)
4.3 Ageing: Concepts and Theories
4.4 Teratogenic agents and their effects on embryonic development

UNIT-V:

5.1 Organogenesis of Central Nervous system
5.2 Organogenesis of Eye, Ear
5.3 Organogenesis of Skin
5.3 Organogenesis of Circulatory system
(* Organogenesis in Human need to be explained)

Co-curricular activities (Suggested)

- Preparation of models of different types of eggs in animals
- Chart on frog embryonic development, fate map of frog blastula, cleavage etc.
- Chart on the organogenesis
- RBPT on the Placenta
- Model of extra embryonic membrane
- Laboratory observation of chick embryonic development

REFERENCES BOOKS:

- Developmental Biology by Balinksy
- Developmental Biology by Gerard Karp
- Chordate embryology by Varma and Agarwal
- Embryology by V.B. Rastogi
- Austen CR and Short RV. 1980. Reproduction in Mammals. Cambridge UniversityPress.
- Gilbert SF. 2006. Developmental Biology, 8th Edition. Sinauer Associates Inc.,Publishers, Sunderland, USA.
- Longo FJ. 1987. Fertilization. Chapman & Hall, London.
- Rastogi VB and Jayaraj MS. 1989. Developmental Biology. KedaraNath Ram NathPublishers, Meerut, Uttar Pradesh.
- Schatten H and Schatten G. 1989. Molecular Biology of Fertilization. AcademicPress, New York.

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SEMESTER-IV COURSE 9: EMBRYOLOGY PRACTICAL

LEARNING OBJECTIVES

- The objective of this course is to provide a comprehensive practical knowledge on the embryology
- Must develop a critical understanding of the early embryological events
- Acquire knowledge on the developmental stages of chick
- Understand the histology of placenta

SYLLABUS:

1. Study of whole mounts and sections of developmental stages of frog through permanent slides: Cleavage stages, blastula, gastrula, neurula, tail-bud stage, tadpole (external and internal gill stages)

2. Study of whole mounts of developmental stages of chick through permanent slides: Primitive streak (13 and 18 hours), 21, 24, 28, 33, 36, 48, 72, and 96 hours of incubation (Hamilton and Hamburger stages)

3. Study of different sections of placenta (photomicrograph/ slides)

4. Project report on chick embryo development

RFERENCE WEB LINKS:

- https://praxilabs.com/en/3d-simulations/cultivation-and-preparation-of-the-virus-in-chick-embryovirtual-lab
- https://vlab.amrita.edu/
- https://www.vlab.co.in/
- https://www.youtube.com/watch?v=p_tx88He8Pk
- https://core.ac.uk/download/143957972.pdf
- https://egyankosh.ac.in/bitstream/123456789/57549/1/Exercise%207%20Chick%20Embryo.pdf
- http://www.macollege.in/app/webroot/uploads/department_materials/doc_501.pdf
- http://www.zoologyresources.com/uploadfiles/books/dc64b77d8769325515d17c945e461b45.pdf

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1.1. Embryology:: Historical perspective and basic concepts: Phases of development

i. Historical Perspective of Embryology

Embryology, the study of embryo development, has evolved significantly over centuries, shaped by observations, experiments, and technological advancements.

1. Ancient and Classical Periods:

Aristotle (384–322 BC): Often considered the founder of embryology, Aristotle proposed that the embryo developed from a homogenous mass through a series of progressive changes. His work "Generation of Animals" was foundational, though limited by the observational tools of his time.

Galen (130–200 AD): A Roman physician who furthered the understanding of fetal development and described the development of the heart and blood vessels.

2. Renaissance and Enlightenment:

William Harvey (1578–1657): Known for his work on blood circulation, Harvey also studied chick embryos, coining the phrase "ex ovo omnia" (everything comes from an egg).

Marcello Malpighi (1628–1694): Used early microscopes to describe chick embryo development, detailing structures like the neural groove and somites.

3. 19th Century:

Karl Ernst von Baer (1792–1876): Formulated the laws of embryology, known as Baer's laws, which describe the general features of a large group of animals appearing earlier in development than the specialized features of a smaller group. He also discovered the mammalian egg.

Hermann Fol (1845–1892): Observed the penetration of a spermatozoon into an ovum, providing insights into fertilization.

4. 20th Century to Present:

Hans Spemann (1869–1941): Awarded the Nobel Prize for his discovery of embryonic induction, highlighting how certain cells influence the fate of others.

Modern Genetics and Molecular Biology: The advent of genetic and molecular tools has revolutionized embryology. Techniques like gene editing (CRISPR), live imaging, and omics technologies have provided deeper insights into developmental processes.

ii. Basic Concepts: Phases of Development

Embryonic development is typically divided into several phases, each characterized by specific processes and milestones:

1. Fertilization:

* The union of sperm and egg to form a zygote.

* Restores diploidy, combines genetic material from both parents, and activates the egg to begin development.

1. **Cleavage**:
    - Rapid mitotic divisions of the zygote without growth, producing smaller cells called blastomeres.
    - Leads to the formation of a multicellular structure called the blastula (or blastocyst in mammals).
2. **Gastrulation**:
    - A process that reorganizes the blastula into a three-layered structure (gastrula) with ectoderm, mesoderm, and endoderm.
    - Establishes the basic body plan and primary germ layers.
3. **Neurulation**:
    - Formation of the neural tube from the ectoderm, which will develop into the central nervous system (brain and spinal cord).
    - Involves the folding and closure of the neural plate.
4. **Organogenesis**:
    - The development of organs and tissues from the three germ layers.
    - Complex interactions and signaling pathways guide the differentiation and morphogenesis of specific organs.
5. **Growth and Differentiation**:
    - Cells proliferate, differentiate, and grow to form the functional tissues and organs.
    - Involves precise regulation of gene expression, cellular interactions, and morphogenetic movements.
6. **Fetal Development** (in mammals):
    - Post-organogenesis, the embryo is termed a fetus.
    - Focuses on growth, maturation of systems, and preparation for independent life.

Integration of Processes

- **Cell-Cell Interaction**: Essential for communication and coordination during development. Signaling pathways (e.g., Notch, Wnt, BMP) and cell adhesion molecules play critical roles.
- **Pattern Formation**: Establishes the spatial organization of tissues and organs through mechanisms like morphogen gradients and segmentation.
- **Differentiation**: Cells acquire specialized functions through gene regulation and epigenetic modifications.

- **Growth**: Involves balanced cell proliferation and apoptosis, influenced by intrinsic genetic programs and extrinsic factors.

Embryology bridges multiple disciplines, from anatomy and genetics to molecular biology, providing a comprehensive understanding of how complex organisms develop from a single cell.

1.2. Cell-Cell interaction, Pattern formation, Differentiation and growth

Embryology is the branch of biology that studies the formation, early growth, and development of living organisms. It encompasses a wide range of processes, including cell-cell interactions, pattern formation, differentiation, and growth. Here's an overview of these key concepts:

i. Cell-Cell Interaction

1. **Induction**: Cells influence the development of neighboring cells through signaling molecules. This process is crucial for establishing the basic body plan and organ development.
2. **Cell Adhesion**: Cells communicate and interact with each other via adhesion molecules like cadherins and integrins. These molecules help maintain tissue structure and transmit signals for growth and differentiation.
3. **Juxtacrine Signaling**: Direct contact between neighboring cells allows them to exchange signals through membrane-bound molecules, influencing each other's fate and function.

ii. Pattern Formation

1. **Morphogen Gradients**: Gradients of signaling molecules (morphogens) provide positional information to cells, leading to the spatial organization of tissues and organs. Examples include the gradients of Sonic hedgehog (Shh) and Bone Morphogenetic Proteins (BMPs).
2. **Segmentation**: The body plan is divided into repetitive segments, such as somites in vertebrates. Hox genes play a critical role in specifying the identity of these segments.
3. **Axis Formation**: Establishment of body axes (anterior-posterior, dorsal-ventral, left-right) is a fundamental step in development. Proteins like Nodal and Wnt are key players in axis formation.

iii. Differentiation

1. **Gene Expression Regulation**: Cells differentiate into various types by selectively expressing different sets of genes. Transcription factors like Oct4, Sox2, and Nanog are crucial for maintaining pluripotency, while others like MyoD promote muscle differentiation.

2. **Epigenetic Modifications**: DNA methylation and histone modifications alter chromatin structure and gene accessibility, influencing cell fate decisions without changing the underlying DNA sequence.
3. **Cell Lineage Commitment**: As development progresses, cells become progressively restricted in their potential, committing to specific lineages (e.g., ectoderm, mesoderm, endoderm).

iv. Growth

1. **Proliferation**: Controlled cell division increases cell numbers. Factors like growth factors (e.g., EGF, FGF) and cell cycle regulators (e.g., cyclins, CDKs) are essential for proliferation.
2. **Apoptosis**: Programmed cell death removes unnecessary or damaged cells, sculpting tissues and organs and maintaining homeostasis.
3. **Size Regulation**: Growth is regulated by a balance between cell proliferation and apoptosis. Organ size is controlled by intrinsic genetic programs and extrinsic factors like nutrient availability and hormonal signals.

Integration of Processes

These processes are highly interconnected. For example, cell-cell interactions can influence differentiation and growth, and pattern formation relies on precise regulation of gene expression and cellular behavior. Understanding these processes provides insight into normal development and congenital abnormalities, and informs regenerative medicine and stem cell research.

1.3. Differential Gene Expression in Embryology

Differential gene expression is a fundamental process driving the development and function of all multicellular organisms. It underpins the transformation of a single fertilized egg into a complex organism with diverse cell types, tissues, and organs. This essay explores the mechanisms and significance of differential gene expression, emphasizing its critical role in development and cellular differentiation.

Mechanisms of Differential Gene Expression

Differential gene expression involves the selective activation and repression of genes in a cell-type-specific manner. This precise regulation ensures that different cells perform distinct functions, despite having the same genomic content. Several key mechanisms facilitate this regulation:

1. **Transcriptional Control**: Transcription factors bind to DNA regulatory sequences and either promote or inhibit gene transcription. This primary level of regulation ensures that genes are expressed in a cell type-specific manner.

2. **Epigenetic Modifications**: Chemical modifications, such as DNA methylation and histone acetylation, influence chromatin structure and gene accessibility. These modifications can switch genes on or off without altering the underlying DNA sequence.

3. **Post-transcriptional Regulation**: Processes like RNA splicing, editing, and stability control the abundance and diversity of mRNA transcripts. MicroRNAs (miRNAs) and other non-coding RNAs also play roles in post-transcriptional regulation by targeting mRNAs for degradation or blocking their translation.

4. **Translational and Post-translational Control**: After translation, proteins may undergo modifications, such as phosphorylation or glycosylation, which can alter their activity, stability, or localization. Translational control mechanisms regulate the synthesis of specific proteins in response to cellular demands.

Functional Significance

Differential gene expression is essential for the development, maintenance, and function of multicellular organisms:

1. **Development and Differentiation**: During embryonic development, differential gene expression drives the specialization of cells into distinct lineages and tissues. It ensures the precise spatial and temporal regulation of gene activity, leading to the formation of complex structures and organs.

2. **Cellular Homeostasis**: In adult organisms, differential gene expression maintains cellular identity and function. Cells continuously adjust their gene expression profiles in response to internal signals, environmental cues, and physiological changes to maintain homeostasis.

3. **Response to Environmental Stimuli**: Cells can alter their gene expression patterns in response to various stimuli, including stress, pathogens, and growth factors. This adaptive response allows organisms to survive and thrive in changing environments by activating specific gene expression programs.

1.4. Cytoplasmic Determinants and Asymmetric Cell Division in Embryology

Embryonic development is a marvelously orchestrated process where a single fertilized egg transforms into a complex multicellular organism. Two critical mechanisms driving this process are cytoplasmic determinants and asymmetric cell division. This essay delves into their roles, mechanisms, and significance in embryology.

i. Cytoplasmic Determinants

Cytoplasmic determinants are molecules asymmetrically distributed within the cytoplasm of a fertilized egg or zygote. These molecules include proteins, mRNA, and other signaling molecules inherited from the maternal gamete or synthesized soon after fertilization. During early embryonic development, the segregation of cytoplasmic determinants into daughter cells during cell division plays a pivotal role in establishing cell fate and differentiation.

1. **Localization**: Cytoplasmic determinants are often localized asymmetrically within the egg or zygote, typically through interactions with cellular structures such as the cytoskeleton or through membrane-associated cues.
2. **Cell Fate Specification**: Asymmetric distribution of cytoplasmic determinants leads to differential gene expression in daughter cells. This, in turn, determines their fate and developmental trajectory. For example, in Drosophila melanogaster, maternal mRNA molecules such as bicoid and nanos are localized to specific regions of the egg and play crucial roles in specifying anterior-posterior and germ cell fates, respectively.
3. **Gradient Formation**: Cytoplasmic determinants can establish concentration gradients within cells or tissues, providing spatial cues for pattern formation and morphogenesis during embryonic development. Morphogens, such as the Bicoid protein in Drosophila, act as cytoplasmic determinants and form concentration gradients that influence cell fate along the embryonic axis.

ii. Asymmetric Cell Division

Asymmetric cell division is a process whereby a single progenitor cell divides unequally, producing daughter cells with distinct fates or developmental potentials. This mechanism contributes significantly to the generation of cellular diversity during embryogenesis and tissue homeostasis in adult organisms.

1. **Polarization**: Asymmetric cell division involves the polarization of cellular components, such as organelles, cytoskeletal elements, and cell fate determinants. This polarization establishes spatial asymmetry within the dividing cell, ensuring the unequal distribution of cellular components into daughter cells.
2. **Cell Fate Determination**: Asymmetric segregation of cell fate determinants during division results in daughter cells with different developmental potentials. One daughter cell inherits a higher concentration of determinants, predisposing it to adopt a specific fate or lineage, while the other daughter cell receives fewer determinants and may differentiate into a different cell type.

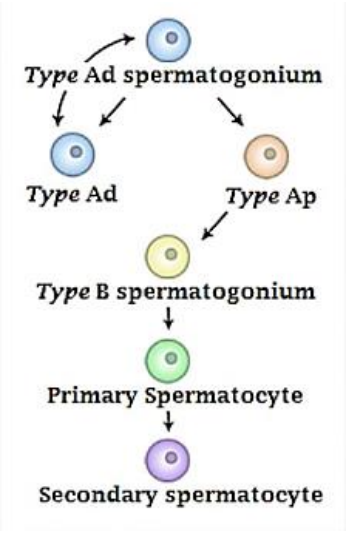
3. **Tissue Morphogenesis**: Asymmetric cell division contributes to tissue morphogenesis by generating cellular diversity and establishing tissue architecture. In epithelial tissues, for example, asymmetric divisions of stem cells generate both self-renewing stem cells and differentiated progeny, ensuring tissue homeostasis and repair.

Significance in Embryology

Cytoplasmic determinants and asymmetric cell division are essential mechanisms in embryonic development, orchestrating cell fate specification, tissue patterning, and organogenesis. By regulating the distribution of molecular cues and cellular components, these mechanisms ensure the precise spatial and temporal control of gene expression and cell differentiation. Understanding the roles of cytoplasmic determinants and asymmetric cell division provides insights into the fundamental principles of embryonic development and has implications for regenerative medicine, stem cell biology, and developmental disorders.

2.1.1. Spermatogenesis

Spermatogenesis is the process by which sperm cells (spermatozoa) are produced in the male testes. It is a highly organized and occurs in the seminiferous tubules of the testes and involves several stages.



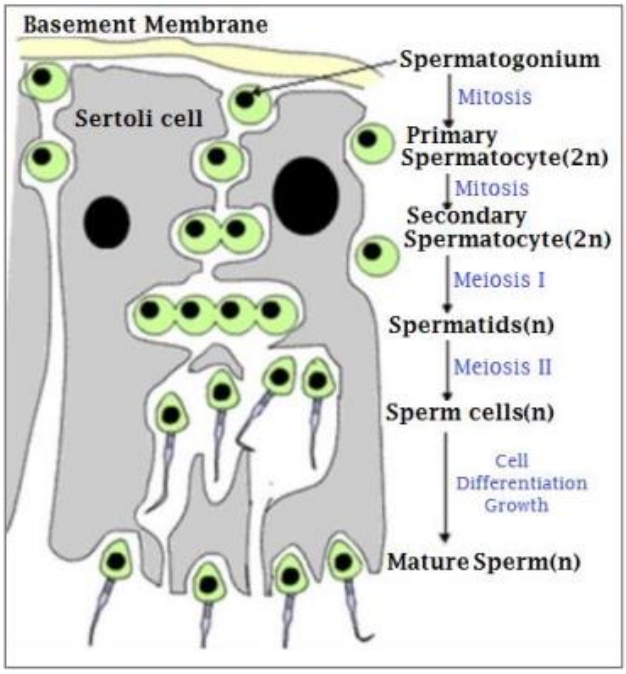
Stages of Spermatogenesis:

Stage 1: Spermatocytogenesis

i. Multiplication Phase: At maturity, the primordial germ cells divide by mitosis to produce a large number of spermatogonia. There are three types of spermatogonia: **Type A (dark)** which are reserve stem cells; **Type A (pale)** which are renewing stem cells; **Type B spermatogonia,** which are differentiating progenitors, and form spermatocytes. Type A spermatogonia is the stem cells which divide to form spermatogonia. Type B spermatogonia are the precursors of sperms.

ii. Growth Phase: Type B spermatogonia enter meiosis I to become primary spermatocytes. These cells are diploid (2n) and have double the amount of DNA.

iii. Maturation Phase: After completing meiosis I, primary spermatocytes produce two secondary spermatocytes, each haploid (n) but with duplicated chromosomes.



Stage 2: Spermatidogenesis

Secondary spermatocytes quickly undergo meiosis II to produce spermatids, which are haploid cells with a single set of chromosomes.

Stage 3: Spermiogenesis:

Spermatids undergo a series of morphological and structural changes to become mature spermatozoa. This includes:

*** Nuclear Condensation**: The chromatin becomes highly condensed and the nucleus shrinks.

*** Acrosome Formation**: The Golgi apparatus forms the acrosome, a cap-like structure containing enzymes crucial for penetrating the egg.

*** Flagellum Development**: The centrioles give rise to the flagellum, providing motility to the sperm.

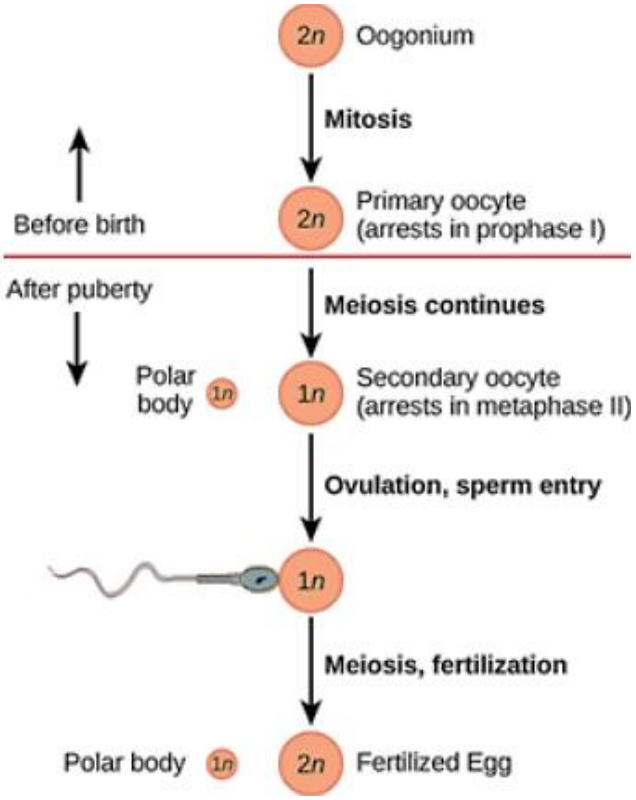
*** Cytoplasmic Reduction**: Excess cytoplasm is shed as residual bodies, which are phagocytosed by Sertoli cells.

*** Mitochondrial Sheath**: Mitochondria align in a spiral around the base of the flagellum to form the midpiece, supplying energy for motility.

The non-motile spermatozoa are transported to the epididymis in testicular fluid secreted by the Sertoli cells with the aid of peristaltic contraction. While in the epididymis, the spermatozoa gain motility and become capable of fertilization.

2.1.2. Oogenesis: The Process of Egg Cell Formation

Oogenesis is the process by which female gametes, or ova (egg cells), are produced in the ovaries. It is a complex and prolonged process that begins before birth, continues with cyclical changes throughout a woman's reproductive life, and concludes at menopause. Oogenesis can be divided into several stages:



i. Stages of Oogenesis

1. Prenatal Development:

Oogonia Formation: During fetal development, primordial germ cells migrate to the developing ovaries and differentiate into oogonia. These oogonia undergo rapid mitotic divisions to increase their number.

Primary Oocyte Formation: Oogonia enter the first meiotic division but arrest in prophase I, becoming primary oocytes. Each primary oocyte is surrounded by a layer of granulosa cells, forming a primordial follicle.

2. Growth and Maturation:

Primordial Follicle to Primary Follicle: After birth, primordial follicles can begin to grow and mature. The granulosa cells surrounding the primary oocyte proliferate and secrete a glycoprotein layer called the zona pellucida, forming a primary follicle.

Secondary Follicle Formation: As the primary follicle grows, it becomes a secondary follicle. The granulosa cells multiply, and theca cells form around the follicle. Fluid-filled spaces, called antral spaces, develop among granulosa cells.

Graafian Follicle (Mature Follicle): The secondary follicle continues to grow, and an antrum (fluid-filled cavity) forms, leading to the development of a mature Graafian follicle. This follicle contains the primary oocyte arrested in prophase I until it receives the signal to resume meiosis.

3. Ovulation and Completion of Meiosis I:

Hormonal Trigger: Each menstrual cycle, under the influence of luteinizing hormone (LH), one dominant Graafian follicle completes the first meiotic division. This division results in a secondary oocyte and a smaller first polar body, both haploid (n).

Secondary Oocyte: The secondary oocyte begins the second meiotic division but arrests in metaphase II. This arrest will continue until fertilization.

4. Fertilization and Completion of Meiosis II:

Fertilization: If a sperm penetrates the secondary oocyte, meiosis II is completed, producing an ovum and a second polar body.

Formation of Zygote: The haploid nuclei of the sperm and ovum fuse to form a diploid zygote (2n), marking the beginning of a new organism.

2.2.1. Types of Eggs

Eggs (ova) can vary widely among different species in terms of their size, structure, and the amount of yolk they contain. These variations are adaptations to the specific reproductive strategies and developmental needs of the species.

A. Based on Yolk Content

1. Microlecithal Eggs: Contain a very small amount of yolk. Ex. Amphioxus (a primitive chordate), most mammals.

2. Mesolecithal Eggs: Contain a moderate amount of yolk, usually concentrated at one pole. Ex**.** Amphibians, some fish.

3. Macrolecithal (or Megalecithal) Eggs: Contain a large amount of yolk. Ex. Birds, reptiles, and some fish.

B. Based on Distribution of Yolk

1. Isolecithal Eggs: Yolk is evenly distributed throughout the egg. Ex. Most invertebrates, mammals.

2. Telolecithal Eggs: Yolk is concentrated at one end of the egg (vegetal pole), with the other end (animal pole) being relatively yolk-free. Ex. Birds, reptiles, amphibians.

3. Centrolecithal Eggs: Yolk is concentrated in the center of the egg. Ex. Most arthropods (e.g., insects).

4. Homolecithal Eggs: Yolk is uniformly distributed, Ex. Eggs of annelids, molluscs, echinoderms and protochordates.

C. On the Basis of Shell

i. Cleidoic egg: These eggs contain a thick and hard outermost shell. Cleidoic egg is a terrestrial adaptation. Ex. Birds & Reptiles, Prototheria mammal and insects.

ii. Non-cleidoic egg: Egg membranes are soft in these eggs Ex. All viviparous animals and in oviparous animals which lays eggs in water.

D. Mosaic and Regulative Eggs

i. Mosaic or determinate Egg: ln certain eggs, in which the future developmental potentialities are predetermined in the form of a mosaic, is called mosaic or determinate egg. Ex. annelids, Molluscs and ascidians.

ii. Regulative or indeterminate Egg: The type of egg in which the future developmental potentialities are not predetermined is known as regulative or indeterminate egg.

2.2.2. Egg Membranes

Eggs are surrounded by membranes that provide protection and support during development. These membranes can be primary, secondary, or tertiary.

1. Primary Membranes:

*** Vitelline Membrane**:

Directly surrounds the plasma membrane of the egg. It is a glycoprotein layer critical for species-specific sperm recognition and fertilization.

*** Zona Pellucida**:

In mammals, the vitelline membrane is called the zona pellucida, which plays a crucial role in sperm binding and preventing polyspermy.

2. Secondary Membranes:

*** Chorion**:

Formed by follicle cells surrounding the oocyte in some species, providing an additional protective layer.

*** Egg Shell**:

Insects and reptiles have chorionic membranes that harden to form a protective shell around the egg.

3. Tertiary Membranes:

*** Albumen (Egg White)**:

In birds and reptiles, albumen surrounds the yolk, providing additional nutrients and cushioning.

*** Shell Membranes**:

In birds, two shell membranes (inner and outer) lie beneath the calcified shell, offering further protection and aiding in gas exchange.

*** Calcified Shell**:

Provides structural protection and helps in the exchange of gases and moisture.

2.2.3. Fertilization

Fertilization is the process by which sperm and egg unite to form a zygote, initiating embryonic development. It can occur externally or internally, depending on the species.

External Fertilization

Description: Gametes are released into the external environment where fertilization occurs outside the body. **Examples**: Most aquatic animals, such as fish and amphibians.

Process:

- **Gamete Release**: Both eggs and sperm are released into the water.
- **Fertilization**: Sperm swim to find the eggs, and fertilization occurs in the water.
- **Advantages**: Large numbers of eggs and sperm can be released, increasing the chances of fertilization.
- **Disadvantages**: High predation risk, and environmental conditions can affect the success rate.

Internal Fertilization

Description: Sperm are deposited inside the female reproductive tract, where fertilization occurs internally. **Examples**: Most terrestrial animals, including mammals, birds, and reptiles.

Process:

- **Copulation**: Sperm are transferred to the female through copulation.
- **Sperm Storage**: In some species, females can store sperm for extended periods and use it to fertilize eggs over time.
- **Fertilization**: Sperm travel to the egg within the female reproductive tract, where fertilization takes place.
- **Advantages**: Protects gametes from environmental hazards and predators, leading to higher fertilization success.
- **Disadvantages**: Typically involves fewer offspring, as more parental investment is required per offspring.

Key Steps in Fertilization

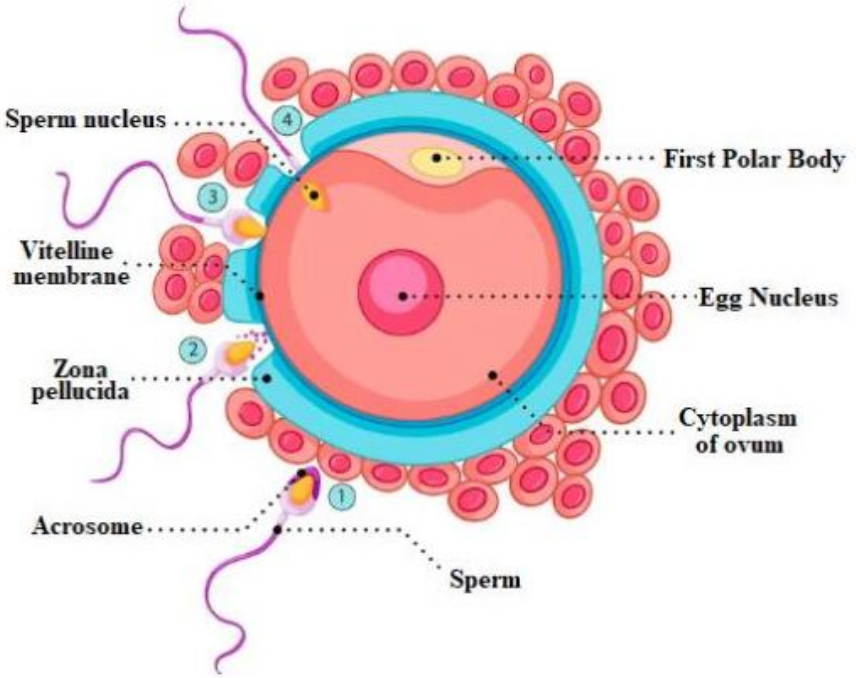
Stage i: Preparation of the Sperm:

Ejaculated sperm are not ready to fertilize an egg when they enter the vagina. In response to the dilution of semen in the vagina, they undergo several changes. The changes includes 1. Increase in intracellular Ca^{++} levels. 2. Activated Sperm motility and 3. Loss of Sperm cell surface antigens and the sperm more receptive to binding to the egg. All these changes collectively known as **capacitation**.

Stage ii: Sperm-Egg Binding:

In humans the process of sperm-egg binding is not so simple. The complicating factor is the thick zona pellucida, which keeps sperm from binding close to the egg plasma membrane. Binding of sperm to the zona pellucida is a receptor-ligand interaction with a high degree of

species specificity. As a result of irreversible binding of the sperm to the egg, the zona pellucida triggers the **acrosome reaction.**



The outer plasma membrane of the acrosome fuses at multiple sites with the plasma membrane leading to leakage of acrosomal enzymes from the sperm's head. As the acrosome reaction progresses, the sperm passes through the zona pellucida. By the time the sperm traverses the zona pellucida, the entire anterior surface of its head, down to the inner acrosomal membrane, is denuded.

Stage iii: Sperm-Egg Fusion

Once a sperm penetrates the zona pellucida, it binds to and fuses with the plasma membrane of the oocyte. Binding occurs at the posterior or post-acrosomal region of the sperm head. This binding or fusion due to attachment of sperm glycoprotein i.e., **fertilins** with the membrane proteins of the egg.

Once the sperm fuses with the egg, the beating of the tail stops immediately. The sperm instead, is drawn into the egg by elongation and fusion of the egg's microvilli. As a result, the sperm nucleus and other organelles are incorporated into the egg cytoplasm. The sperm nucleus undergoes a series of changes to form a male pronucleus. The male pronucleus migrate to the center of the cell, where it fuses with the female pronucleus and forms a diploid nucleus.

Stage IV: Activation - The Egg's Response

Prior to fertilization, the egg is in a quiescent state, arrested in metaphase of the second meiotic division. Upon binding of a sperm, the egg rapidly undergoes a number of metabolic and physical changes that collectively are called ***egg activation***. Prominent effects include a rise in the intracellular concentration of calcium, completion of the second meiotic division and the so-called cortical reaction.

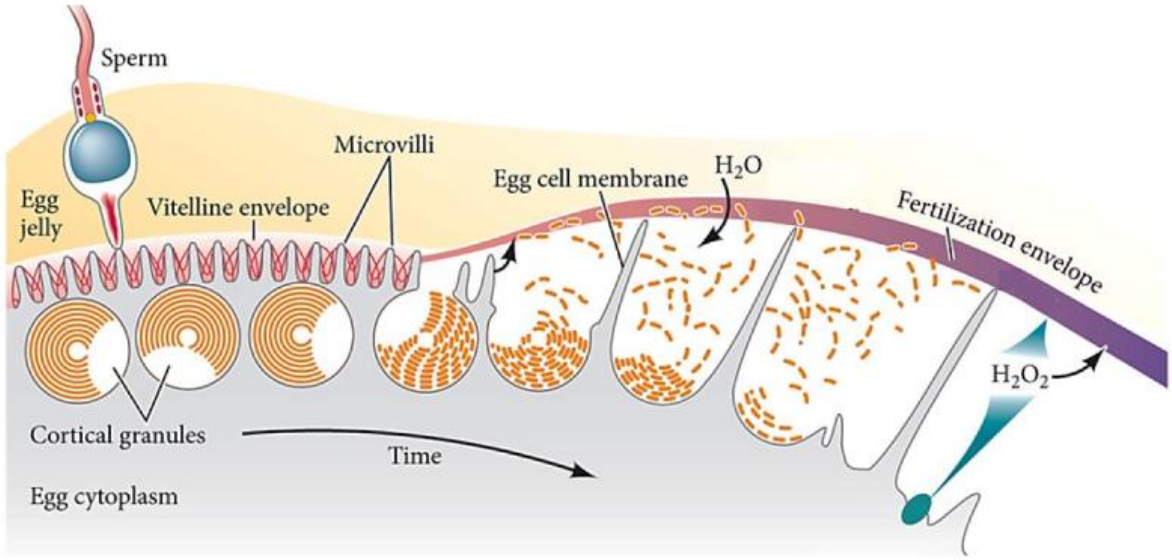


Fig F: Zona reaction

DEVELOPMENTAL BIOLOGY 11e, Figure 7.17 (Part 1)
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Cortical reaction: The cortical reaction refers to a massive exocytosis of cortical granules seen shortly after sperm-oocyte fusion. **Cortical granules** contain a mixture of enzymes, including several proteases, which diffuse into the zona pellucida following exocytosis from the egg. These proteases alter the structure of the zona pellucida, inducing what is known as the zona reaction. Components of cortical granules may also interact with the oocyte plasma membrane.

Zona Reaction: The zona reaction refers to an alteration in the structure of the zona pellucida includes its hardening and the destruction of sperm receptors. Activation of the egg also includes the initiation of development of the new zygote. Protein synthesis and other metabolic processes are upregulated to provide for the developing embryo.

Post-fertilization Events: Following fusion of the fertilizing sperm with the oocyte, the sperm head is incorporated into the egg cytoplasm. Chromatin from both the sperm and egg are soon encapsulated in a nuclear membrane, forming pronuclei. They migrate together, their membranes break down, and the two genomes condense into chromosomes, thereby reconstituting a diploid organism.

2.3. Planes and patterns of cleavage

Planes and patterns of cleavage refer to the orientation and manner in which cells divide during early embryonic development after fertilization. Cleavage is a series of rapid cell divisions that results in the formation of a multicellular embryo. The planes and patterns of cleavage play a crucial role in establishing the body plan and developmental fate of the embryo.

A. Planes of cleavage

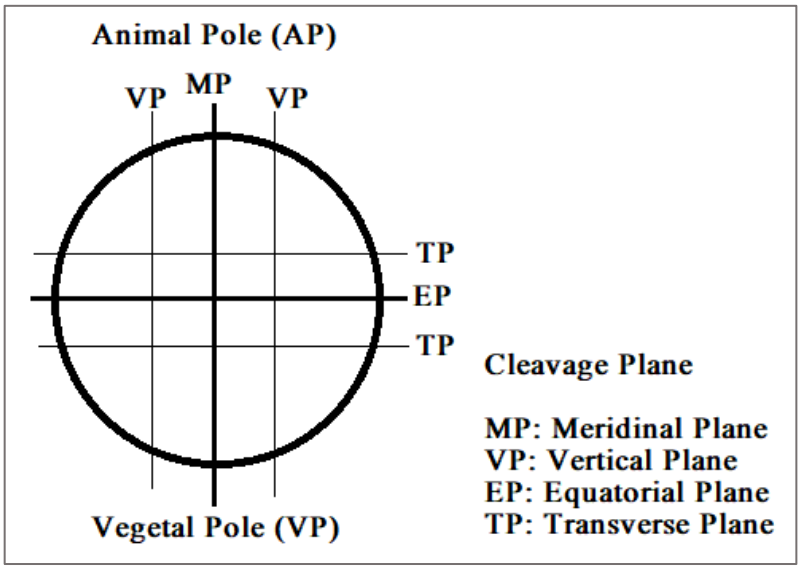
An egg can be divided from different planes during cleavage. Depending on the position of the cleavage furrow the planes of cleavage are named.

1. Meridional plane: The plane of cleavage lies on the animal vegetal axis. It bisects both the poles of the egg. Thus the egg is divided into two equal halves.

2. Vertical plane: The cleavage furrows may lie on either side of the meridional plane. The furrows pass from animal to vegetal pole. The cleaved cells may be unequal in size.

3. Equatorial plane: This cleavage plane bisects the egg at right angles to the main axis. It lies on the equatorial plane. It divides the egg into two halves.

4. Latitudinal plane: It is similar to the equatorial plane, but it lies on either side of the equator. It is also called as transverse or horizontal cleavage.



B. Patterns of cleavage

The development of multi-cellular organisms begins from a single-celled zygote, which undergoes rapid cell division to form the multicellular embryo. The rapid, multiple rounds of cell division are termed cleavage.

1. Based on the amount of Yolk

Cleavage can take place in two ways: *holoblastic* (total) cleavage or *meroblastic* (partial) cleavage. The type of cleavage depends on the amount of yolk in the eggs.

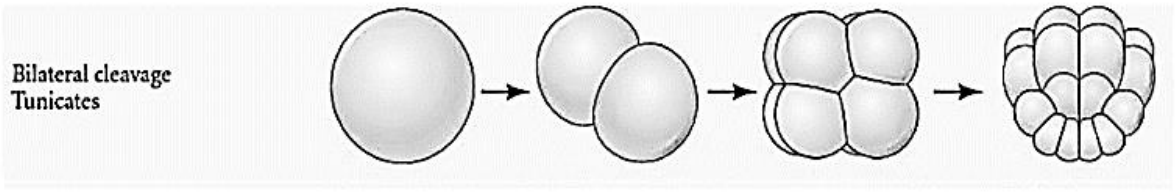
a. Holoblastic cleavage (total or entire cleavage):

This type of cleavage takes place in which the concentration of yolk is not very large (isolecithal cell) or in mesolecithal eggs. The zygote completely divides into blastomeres at each cleavage and the number of blastomeres goes on increasing. In holoblastic eggs the first cleavage always occurs along the vegetal-animal axis of the egg, the second cleavage is

perpendicular to the first. From here the spatial arrangement of blastomeres can follow various patterns, due to different planes of cleavage, in various organisms.

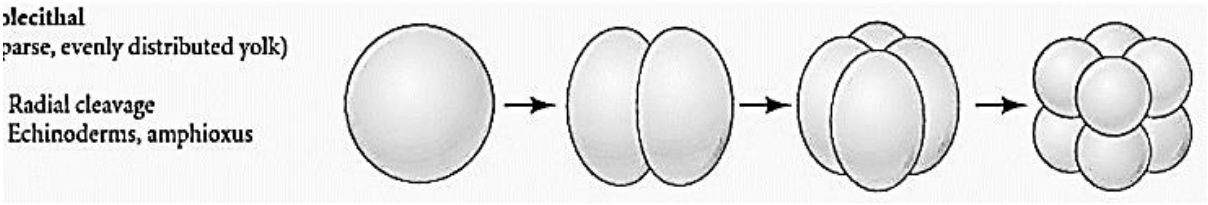
i. Bilateral Cleavage

The first cleavage results in bisection of the zygote into left and right halves. The following cleavage planes are centered on this axis and result in the two halves being mirror images of one another. In bilateral holoblastic cleavage, the divisions of the blastomeres are complete and separate; compared with bilateral meroblastic cleavage, in which the blastomeres stay partially connected.



ii. Radial Cleavage

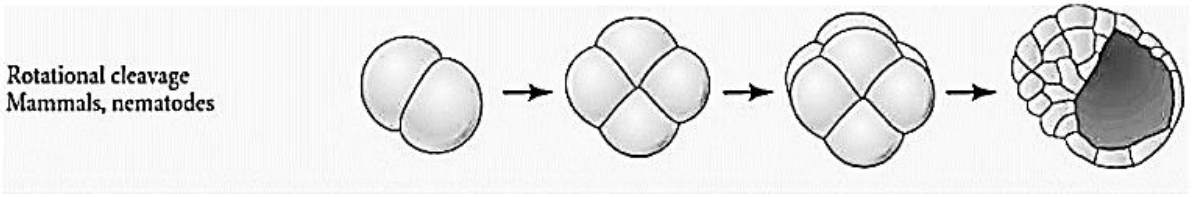
Radial cleavage is characteristic of the deuterostomes, which include some vertebrates and echinoderms, in which the spindle axes are parallel or at right angles to the polar axis of the oocyte.



iii. Rotational Cleavage

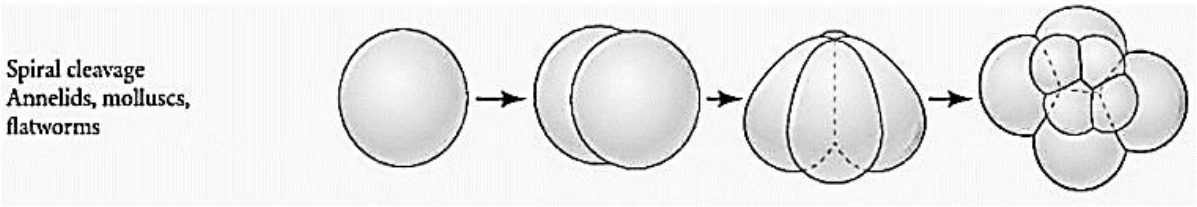
Mammals display rotational cleavage, and an isolecithal distribution of yolk (sparsely and evenly distributed). Because the cells have only a small amount of yolk, they require immediate implantation onto the uterine wall in order to receive nutrients.

Rotational cleavage involves a normal first division along the meridional axis, giving rise to two daughter cells. The way in which this cleavage differs is that one of the daughter cells divides meridionally, whilst the other divides equatorially.



iv. Spiral Cleavage

In spiral cleavage, the cleavage planes are oriented obliquely to the polar axis of the oocyte. At thethird cleavage the halves are oblique to the polar axis and typically produce an upper quartet of smaller cells that come to be set between the furrows of the lower quartet. All groups showing spiral cleavage are protostomia, such as annelids and mollusks.

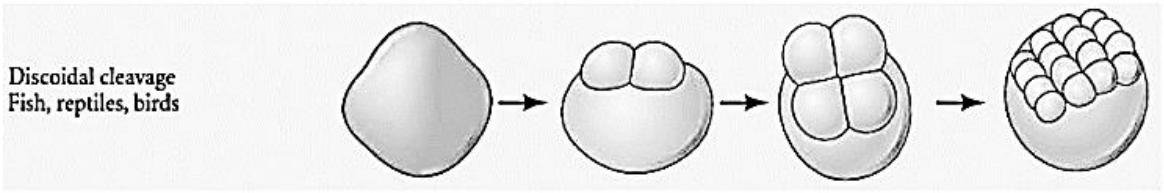


b. Meroblastic Cleavage (Partial cleavage)

In the presence of a large amount of yolk in the fertilized egg cell, the cell can undergo partial, or meroblastic, cleavage. The cleavage furrows are restricted to the active cytoplasm found either in the animal pole (macrolecithal egg) or superficially surrounding the egg (centrolecithal egg). Meroblastic cleavage may be of two types.

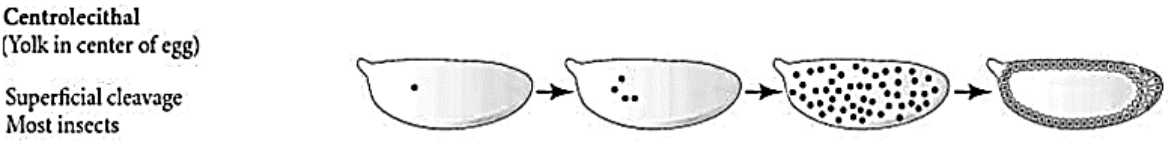
i. Discoidal Cleavage

Since the macrolecithal eggs contain plenty of yolk, the cytoplasm is restricted to the narrow region in the animal pole. Hence, cleavage furrows can be formed only in the disc-like animal pole region, called a blastodisc, on top of the yolk. Such a cleavage is called discoidal meroblastic cleavage. Discoidal cleavage is commonly found in birds, reptiles, and fish which have telolecithal egg cells (egg cells with the yolk concentrated at one end).



ii. Superficial Cleavage

In superficial cleavage, mitosis occurs but not cytokinesis, resulting in a polynuclear cell. With the yolk positioned in the center of the egg cell, the nuclei migrate to the periphery of the egg, and the plasma membrane grows inward, partitioning the nuclei into individual cells. Superficial cleavage occurs in arthropods which have centrolecithal egg cells (egg cells with the yolk located in the center of the cell). Ex. Insects



2. Cleavage Patterns based on plane of division

Early cleavage patterns vary widely between different groups of animals, based largely on the orientation of the division planes.

a. Radial Cleavage: occurs such that the resulting daughter cells are located exactly on top of one another. Radial cleavage is a characteristic of Deutrostomes, and results in indeterminant cells.

b. Spiral Cleavage: occurs such that the resulting daughter cells are not located exactly on top of one another; instead, they are located at a slight angle. Spiral cleavage is a characteristic of Protostomes, and results in determinant cells.

3. Determinate and Indeterminate Cleavage

Based on the potentiality of the blastomeres for the future development, the cleavage may be

a. Determinate: the developmental fate of each embryonic cell is established very early. Annelids, mollusks and ascidians which produce mosaic type of eggs exhibit determinate cleavage.

b. Indeterminate*:* The fates of blastomeres are not predetermined in the early embryonic period. Vertebrates and certain invertebrates such as echinoderms, which produce regulative type of eggs, exhibit indeterminate cleavage.

2.3.3. Types of Blastulae:

1. **Regular (Homogeneous) Blastula**:
    - **Description**: The blastocoel is centrally located, surrounded by a single layer of cells (blastoderm) that is relatively uniform in thickness.
    - **Examples**: Commonly found in organisms with holoblastic cleavage, such as amphibians like frogs and salamanders.
2. **Polar (Inverted) Blastula**:
    - **Description**: The blastocoel is displaced to one pole, resulting in an asymmetric distribution of cells.
    - **Examples**: Commonly found in organisms with spiral cleavage, such as certain marine invertebrates like mollusks and annelids.
3. **Discoidal Blastula**:
    - **Description**: The blastoderm is disc-shaped and sits atop a yolk mass, with the blastocoel reduced or absent.
    - **Examples**: Observed in organisms with meroblastic cleavage, such as birds and reptiles.

2.3.4. Fate Maps:

Fate maps are diagrams or models that illustrate the developmental fate of different regions of the embryo. They provide spatial information about how different regions of the embryo give rise to specific tissues and structures in the adult organism.

1. **Generation of Fate Maps**:
    - Fate maps are typically generated through experimental techniques such as lineage tracing, in which specific cells or regions of the embryo are labeled and tracked over time.
    - Other methods include transplantation experiments, in which cells from one region of the embryo are transplanted into another region to determine their fate.
2. **Applications of Fate Maps**:
    - Fate maps provide crucial insights into embryonic development, helping researchers understand the origins of different tissues and organs.
    - They are used to study gene expression patterns, cell signaling pathways, and the mechanisms underlying cell fate determination.
    - Fate maps are also valuable for comparative embryology, allowing researchers to compare developmental processes across different species.
3. **Examples of Fate Maps**:
    - In vertebrates, fate maps have been generated for organisms such as frogs, chicks, and mice, detailing the contributions of different regions of the embryo to various tissues and organs.
    - In invertebrates such as Drosophila, fate maps have been used to study the development of specific structures such as the nervous system and the segmentation of the body plan.

2.4.1. Early development of frog up to gastrulation

The early development of frogs, like other amphibians, involves a series of key stages from fertilization to gastrulation. Here's an overview of the early developmental events in frogs up to gastrulation:

1. Fertilization:

- Fertilization typically occurs externally in water, where the female releases eggs and the male releases sperm.
- Sperm swim to reach and fertilize the eggs, usually in shallow ponds or streams.

2. Cleavage:

- After fertilization, the zygote undergoes cleavage, a series of rapid cell divisions without significant growth.

- Initially, cleavage results in a single-cell zygote dividing into two cells, then four, eight, and so on, forming a multicellular embryo called a morula.

3. Blastula Formation:

- Cleavage continues, producing a blastula, which is a hollow ball of cells.
- During blastula formation, the blastocoel, a fluid-filled cavity, forms in the center of the embryo.
- The outer layer of cells, called the blastoderm, surrounds the blastocoel.

4. Gastrulation:

- Gastrulation is a crucial stage during which the three primary germ layers—ectoderm, mesoderm, and endoderm—are established.
- It involves complex cell movements and rearrangements that transform the blastula into a gastrula.

Key Events during Gastrulation in Frogs:

1. Invagination:

* The process begins with the invagination of cells at the dorsal lip of the blastopore, forming the dorsal blastopore lip.

* Invagination creates the archenteron, the primitive gut cavity, which eventually becomes the digestive tract.

2. Germ Layer Formation:

* As invagination progresses, cells ingress into the blastocoel, forming the mesoderm and endoderm layers.

* The ectoderm remains as the outermost layer.

* The mesoderm forms between the ectoderm and endoderm layers and gives rise to various structures, including muscles, bones, and circulatory system components.

* The endoderm forms the innermost layer and gives rise to the lining of the digestive tract and associated organs.

3. Convergence and Extension:

* Convergence and extension movements involve the rearrangement of cells to elongate and narrow the embryo.

* These movements contribute to the elongation of the body axis and the formation of structures such as the notochord.

4. Closure of the Blastopore:

* As gastrulation progresses, the blastopore narrows and eventually closes.

* The dorsal blastopore lip contributes to the formation of the anus, while the ventral lip contributes to the formation of the mouth.

2.4.2. Early development of chick up to gastrulation

The early development of a chick embryo, similar to other birds, is a fascinating process that begins with fertilization and progresses through several key stages, including cleavage, blastula formation, and gastrulation. Here's an overview of the early development of a chick embryo up to gastrulation:

1. Fertilization:

- Fertilization in birds occurs internally, with the male transferring sperm to the female's oviduct.
- Fertilization typically occurs in the upper region of the oviduct, where sperm fertilizes the ovum (unfertilized egg) released from the ovary.

2. Cleavage:

- After fertilization, the zygote undergoes cleavage, a series of rapid cell divisions without significant growth.
- Cleavage divides the single-cell zygote into a multicellular structure called a blastoderm.

3. Blastoderm Formation:

- The blastoderm is a disc-shaped structure consisting of a single layer of cells.
- It contains the future embryo and is situated on top of the yolk, which serves as a nutrient source for the developing embryo.
- The blastoderm is composed of the blastodisc, which consists of the area pellucida (clear area) and the area opaca (opaque area).

4. Blastula Formation:

- Cleavage continues, and the blastoderm undergoes further development to form a blastula.
- The blastula is a hollow ball of cells with a fluid-filled cavity called the blastocoel.
- The blastocoel forms within the area pellucida of the blastoderm.

5. Gastrulation:

- Gastrulation is a crucial stage during which the three primary germ layers—ectoderm, mesoderm, and endoderm—are established.
- It involves complex cell movements and rearrangements that transform the blastula into a gastrula.

Key Events during Gastrulation in Chick Embryos:

1. Primitive Streak Formation:

* The primitive streak forms along the midline of the blastoderm, extending from the posterior (caudal) end towards the anterior (cranial) end.

* Cells from the blastoderm migrate towards the primitive streak and ingress through it.

2. Germ Layer Formation:

* Cells ingressing through the primitive streak give rise to the three primary germ layers:

*** Ectoderm**: Forms the outermost layer and gives rise to the nervous system, epidermis, and other structures.

*** Mesoderm**: Forms between the ectoderm and endoderm layers and gives rise to muscles, bones, blood, and internal organs.

*** Endoderm**: Forms the innermost layer and gives rise to the lining of the digestive tract and associated organs.

3. Closure of the Blastopore:

* As gastrulation progresses, the primitive streak elongates, and its edges fuse, closing the blastopore.

* The closure of the blastopore marks the end of gastrulation and the beginning of organogenesis.

3.1. Fate of Germ Layers

During embryonic development, the three primary germ layers—ectoderm, mesoderm, and endoderm—give rise to different tissues and organs in the body through a process called organogenesis. Here's a summary of the fate of each germ layer:

1. Ectoderm:

- **Derivatives**:
    - **Epidermis**: The outermost layer of the skin.
    - **Nervous System**: The brain, spinal cord, and peripheral nerves.
    - **Sensory Organs**: The eyes, ears, and olfactory epithelium.
    - **Adrenal Medulla**: A part of the adrenal glands involved in the fight-or-flight response.
    - **Pigment Cells**: Melanocytes, which produce melanin for skin pigmentation.
    - **Tooth Enamel**: The outer layer of teeth.

2. Mesoderm:

- **Derivatives**:
    - **Skeletal System**: Bones, cartilage, and connective tissues.
    - **Muscular System**: Skeletal muscles, smooth muscles, and cardiac muscles.
    - **Circulatory System**: Blood vessels, heart, and lymphatic system.
    - **Excretory System**: Kidneys, ureters, and bladder.
    - **Reproductive System**: Gonads (testes and ovaries) and reproductive ducts.
    - **Dermis**: The inner layer of the skin.
    - **Spleen**: A lymphoid organ involved in immune function.
    - **Adrenal Cortex**: The outer layer of the adrenal glands involved in hormone production.

3. Endoderm:

- **Derivatives**:
    - **Digestive System**: Esophagus, stomach, intestines, liver, pancreas, and respiratory tract lining.
    - **Respiratory System**: Lungs and respiratory tract lining.
    - **Endocrine System**: Thyroid gland, parathyroid glands, thymus, and parts of the adrenal glands.
    - **Urinary Bladder**: Part of the excretory system.

- **Urethra**: Part of the urinary and reproductive systems.
- **Tonsils**: Lymphoid tissue in the throat.
- **Epithelial Lining**: The lining of various internal organs and structures.

Fate of Germ Layers in Gastrulation:

- During gastrulation, the three germ layers are established through complex cell movements and rearrangements.
- Ectoderm is primarily formed from cells located in the outer layer of the blastoderm.
- Mesoderm is derived from cells that ingress through the primitive streak during gastrulation.
- Endoderm is formed from cells that ingress through the primitive streak and migrate towards the future ventral side of the embryo.

3.2. Extra-embryonic membranes

Extra-embryonic membranes are crucial structures that support the developing embryo in various vertebrate species. These membranes do not form part of the body of the embryo itself but play vital roles in its nourishment, respiration, excretion, and protection. There are four primary extra-embryonic membranes: the yolk sac, amnion, chorion, and allantois.

i. Yolk Sac

The yolk sac is the first of the extra-embryonic membranes to form and is primarily involved in nutrient transfer to the developing embryo. In egg-laying vertebrates such as birds and reptiles, the yolk sac surrounds the yolk, a nutrient-rich substance that provides sustenance during early development. The walls of the yolk sac are highly vascularized, facilitating the transfer of nutrients from the yolk to the embryo.

In placental mammals, although the yolk sac is present, it is relatively small and does not contain a yolk. Instead, it plays a critical role in early blood cell formation and the development of the primordial germ cells. The yolk sac in mammals eventually becomes part of the umbilical cord structure, contributing to nutrient and waste exchange between the mother and the embryo.

ii. Amnion

The amnion is a thin but tough membrane that creates a protective amniotic cavity filled with amniotic fluid. This fluid-filled cavity serves several purposes: it cushions the embryo, provides a stable temperature environment, and allows for free movement, which is essential for muscular and skeletal development.

The presence of the amnion is a defining characteristic of amniotes (reptiles, birds, and mammals). In mammals, the amnion forms early in embryonic development and continues to expand, enveloping the embryo and forming a secure, buoyant environment that protects against mechanical shocks and prevents dehydration.

iii. Chorion

The chorion is the outermost membrane and plays a significant role in gas exchange. In reptiles and birds, the chorion often fuses with the allantois to form the chorioallantoic membrane, which is highly vascularized and facilitates the exchange of oxygen and carbon dioxide between the embryo and the external environment.

In mammals, the chorion contributes to the formation of the placenta, an essential organ for nutrient and gas exchange between the mother and the developing fetus. The chorionic villi, finger-like projections that extend into the uterine wall, increase the surface area for nutrient and waste exchange, making the placenta a highly efficient structure for supporting fetal development.

iv. Allantois

The allantois is involved in respiration and waste storage. In egg-laying vertebrates, the allantois expands significantly, becoming a large sac that stores nitrogenous wastes produced by the embryo. Additionally, it participates in respiration by facilitating gas exchange through its extensive vascular network.

In placental mammals, the allantois is much smaller but still crucial. It contributes to the formation of the umbilical cord and, like the chorion, plays a role in developing the placenta. The blood vessels of the allantois become the umbilical arteries and vein, which are integral to the circulatory connection between the embryo and the mother.

3.3. Placenta (Structure, types and functions of placenta)

Placenta can be defined as a temporary organ which is formed jointly by the extraembryonic membranes of the foetus and maternal tissues and by which the developing embryo or foetus of the viviparous mammals obtains its nourishment from the maternal uterine tissue. Balinsky (1981) gave a simplified definition of placenta. Placenta is a complex temporary organ composed of maternal and foetal tissues through which nutrients are supplied to developing embryo from its mother. The process involved in implantation of embryo to the uterine wall is called placentation.

Types of placenta:

Depending on different criteria placenta may be divided in following types –

1. Depending on the involvement of embryonic tissue:

a. Chorio-vitelline placenta (yolksac placenta): Highly vascular yolk sac fuses with the chorion. Ex. Marsupials, Didelphis, Macropus.

b. Chorio-allantoic placenta: Allantois with its blood vessels fuses with the chorion. Ex. All the Eutherian mammals.

2. Depending on the distribution of villi on chorion:

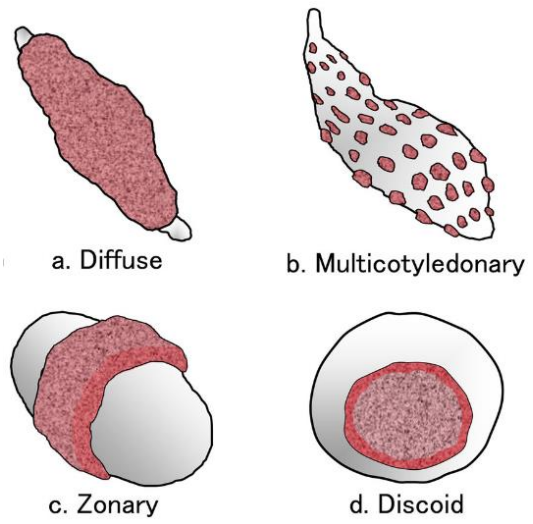
i. Diffuse Placenta: villi are uniformly distributed over the entire surface of the chorion. Ex. Pigs and horses.

ii. Cotyledonary Placenta: Villi distributed in isolated patches. Cows, sheep, and goats.

iii. Zonary Placenta: Chorionic villi form a band or zone around the fetal membranes. Ex. Dogs and cats.

iv. Discoid Placenta: It involves the formation of a single, disc-shaped placental structure. Ex. Insectivores, bat and rodents.

v. Metadiscoidal Placenta: Primates have a special type of discoidal placenta in which villi are at first scattered but later on become restricted to one or two discs. **Monodiscoidal placenta in** human. **Bidiscoidal placenta in** monkey and ape.



3. Based on the relationship of villi with the uterine wall:

According to the condition placenta are of two types:

a. Non deciduous placenta: In this placenta chorionic villi are loosely associated with the uterine endometrium. So that the villi can be withdrawn from the endometrium easily without any blood shedding. Ex. Pig, Cow, Goat etc.

b. Deciduous placenta: The placenta in which chorionic villi are deeply embedded in the uterine endometrium, so that during withdrawal of the villi profuse blood shedding of uterine wall takes place. Ex. All Primate mammals including man.

c. Contra deciduate placenta: Implantation or association is intimate but both fetal and maternal tissue are absorbed *in situ* by maternal leucocytes Ex. Parameles and Talpa (mole)

4. Based on the degree of involvement of foetal and maternal tissues:

Histological types of placenta:

The basic mature placenta has a total of six layers of tissue which separate the maternal and foetal blood. The six layers are made of three foetal extraembryonic membranes and three maternal layers. The three layers of foetal extraembryonic membranes are: 1.Chorionic epithelium 2.Connective tissue 3. Endothelium. The three potential maternal layers in a placenta are 1. Uterine Epithelium 2. Connective tissue outside blood vessel 3. Endothelium

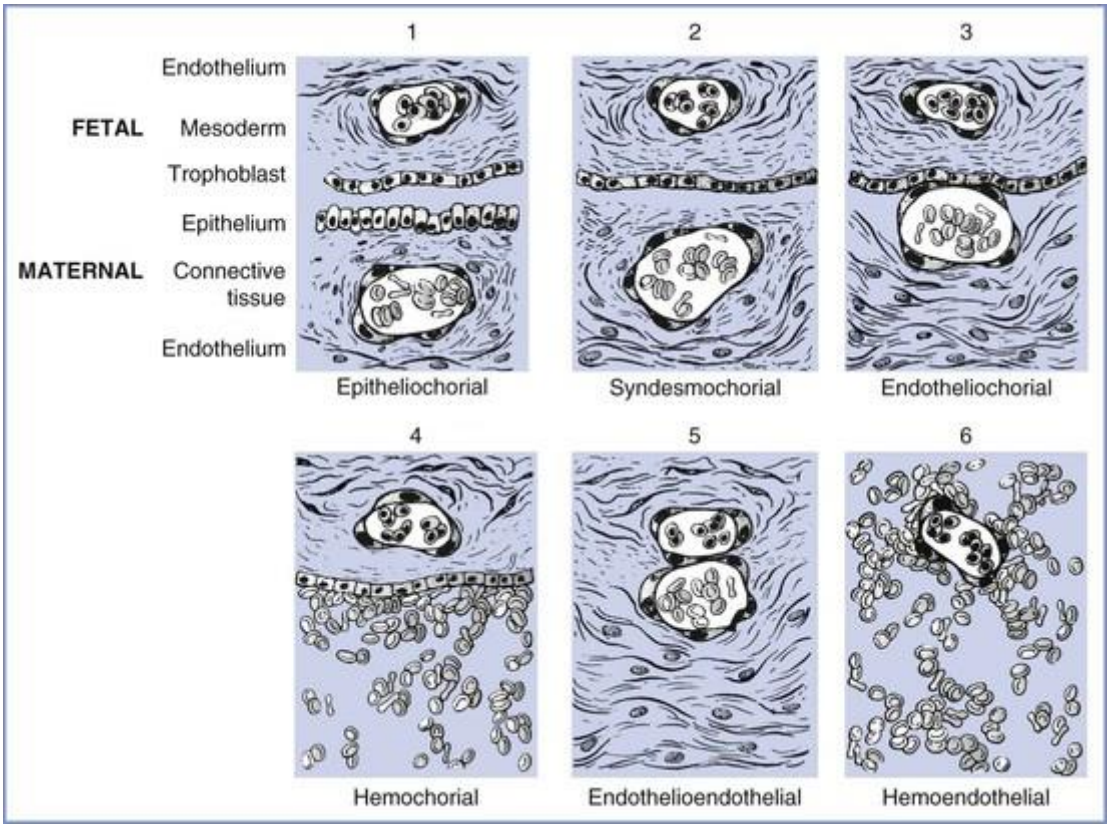
a. Epithelio-chorial placenta: This is a loose association of chorionic villi of the foetus with the epithelium of the uterus. Epithelium of the uterus folds to form pockets and within these pocket chorionic villi rests. So there are six barriers in between maternal and foetal blood. Ex. Pig, Horse, Marsupials etc.

b. Syndesmochorial placenta: The uterine epithelium disappears and the chorion of the foetus comes in direct contact with the connective tissue of the uterine wall of the mother. So there are five tissue barriers in between maternal and foetal blood. Ex. Sheeps, Giraffe, Deers etc.

c. Endothelio-chorial placenta: In this type of placenta the chorion of the foetus comes in direct contact with the endothelium of the uterine capillaries. There are four tissue layers in between the maternal and foetal blood. Ex. Dog, Cat, Fox etc.

d. Haemo-chorial placenta : In this type of placenta endothelium of uterine blood vessels is lost so the chorionic epithelium is bathed directly in maternal blood. There are only three barriers of tissue layers. Ex. Primates including Man, Insectivores (moles, shrews) and Chiropterans (bats).

e. Haemo-endothelial placenta: In this type of placenta chorionic epithelium and connective tissue of foetus are lost as a result the endothelium of the foetal blood vessel come direct in contact with maternal blood and be the only barrier between foetal and maternal blood. Ex. Rodents (mouse, rat, guinea pig, rabbit).



Functions of the Placenta:

The placenta is a highly-specialized organ that plays an essential role during pregnancy.

1. It is responsible for providing nutrition and oxygen to the fetus as well as removing waste material and carbon dioxide.

2. It is also responsible for creating a separation between the maternal and fetal circulation (known as placental barrier).

3. Besides that, the placenta protects the fetus from infections and other maternal disorders, while also helping in the development of the fetal immune system.

4. Additionally, this organ has an endocrine function as it secretes hormones (such as human chorionic gonadotropin) that affect the pregnancy, metabolism, fetal growth, and parturition.

3.4. Amniocentesis

Amniocentesis is a prenatal diagnostic procedure used to obtain a sample of amniotic fluid from the amniotic sac surrounding the developing fetus in the uterus. This procedure is typically performed between the 15th and 20th weeks of pregnancy and can provide valuable information about the health and development of the fetus. Here's an overview of amniocentesis, including its purpose, procedure, risks, and uses:

i. Purpose of Amniocentesis:

1. Genetic Testing:

Amniocentesis can detect chromosomal abnormalities, such as Down syndrome (trisomy 21), Edwards syndrome (trisomy 18), and Patau syndrome (trisomy 13), as well as other genetic disorders.

2. Fetal Lung Maturity:

Amniocentesis can assess the maturity of fetal lungs by measuring the levels of surfactant proteins in the amniotic fluid. This information is important for determining the timing of delivery in cases where preterm birth is anticipated.

3. Infection Screening:

Amniocentesis can detect certain infections, such as fetal infections caused by viruses like cytomegalovirus (CMV) or toxoplasmosis.

4. Fetal Hemolytic Disease:

In cases where there is a risk of fetal hemolytic disease (e.g., Rh incompatibility), amniocentesis can assess the severity of fetal anemia by measuring levels of bilirubin in the amniotic fluid.

ii. Procedure:

1. Preparation:

Before the procedure, the mother's abdomen is cleaned and sterilized, and an ultrasound is used to locate the fetus and determine the best site for needle insertion.

2. Needle Insertion:

A thin, hollow needle is inserted through the abdominal wall and into the amniotic sac under ultrasound guidance. Local anesthesia may be used to minimize discomfort.

3. Sample Collection:

Once the needle is properly positioned, a small amount of amniotic fluid (typically around 20 milliliters) is withdrawn and collected in a syringe.

4. Post-Procedure:

After the sample is collected, the needle is removed, and the site of insertion is typically bandaged. The mother may be monitored for a short period to ensure there are no complications.

iii. Risks and Considerations:

1. Miscarriage:

While rare, there is a small risk of miscarriage associated with amniocentesis, estimated to be less than 1 in 200 to 1 in 400 procedures.

2. Infection:

There is a slight risk of infection, particularly if proper sterile techniques are not followed during the procedure.

3. Bleeding:

Some women may experience minor bleeding or spotting at the site of needle insertion.

4. Fetal Injury:

There is a very small risk of injury to the fetus, such as puncture of the umbilical cord or fetal skin, although this risk is minimized with careful ultrasound guidance.

4.1. Metamorphosis: Changes, hormonal regulations in amphibians

Metamorphosis is a fascinating biological process seen in many amphibians, particularly frogs and salamanders, where they undergo significant physiological and morphological changes as they transition from aquatic larvae to terrestrial adults. This transformation is orchestrated by complex hormonal regulations that govern the timing and coordination of various developmental events. Here's an overview of the changes and hormonal regulations involved in amphibian metamorphosis:

i. Changes during Metamorphosis:

1. **Body Form**:
    - Larvae typically have a tadpole-like body with a long tail, gills, and no limbs.
    - During metamorphosis, the body undergoes remodeling, including the loss of the tail and gills, and the development of limbs and lungs suitable for terrestrial life.
2. **Respiration**:
    - Larvae primarily respire through gills, which are adapted for aquatic life.
    - As metamorphosis progresses, lungs develop, allowing the frog or salamander to breathe air once it transitions to a terrestrial lifestyle.
3. **Digestive System**:
    - Larvae have a simple, herbivorous digestive system adapted for feeding on algae and detritus.
    - Adult frogs and salamanders have a more complex digestive system suited for carnivorous or omnivorous feeding habits.
4. **Skin**:
    - Larvae have smooth, permeable skin adapted for gas exchange in water.
    - Adult amphibians develop thicker, less permeable skin to prevent desiccation on land.
5. **Limbs**:
    - Larvae typically lack limbs, relying on lateral undulation for movement in water.
    - During metamorphosis, hindlimbs develop first, followed by forelimbs, enabling the amphibian to move effectively on land.

ii. Hormonal Regulations:

1. **Thyroid Hormones**:
    - Thyroid hormones, particularly triiodothyronine (T3) and thyroxine (T4), play a central role in regulating metamorphosis.
    - Increased levels of thyroid hormones trigger the onset of metamorphosis and coordinate the various developmental changes.
2. **Pituitary Hormones**:
    - Pituitary hormones, such as thyroid-stimulating hormone (TSH) and prolactin, stimulate the thyroid gland to produce thyroid hormones, thus indirectly influencing metamorphosis.
3. **Corticosteroids**:
    - Corticosteroids, such as cortisol, are involved in mediating stress responses and can affect metamorphosis.
    - In some amphibians, stress-induced release of corticosteroids can accelerate metamorphosis.
4. **Gonadal Hormones**:
    - Gonadal hormones, such as estrogens and androgens, may also influence metamorphosis, particularly in regulating secondary sexual characteristics in adult amphibians.

Environmental Factors:

- Environmental cues, such as temperature, photoperiod, and water availability, can also influence the timing and progression of metamorphosis.
- Adequate food availability and habitat suitability are essential for successful metamorphosis and the transition to terrestrial life.

4.2. Regeneration: Modes of regeneration, epimorphosis, morphallaxis and compensatory regeneration (in Turbellarians)

Regeneration is the remarkable ability of organisms to replace lost or damaged body parts. In Turbellarians, a group of flatworms that includes planarians, three main modes of regeneration are observed: epimorphosis, morphallaxis, and compensatory regeneration.

1. Epimorphosis:

Epimorphosis involves the regeneration of missing structures through the proliferation of undifferentiated cells called neoblasts.

Process:

- Following injury or amputation, neoblasts migrate to the wound site.
- Neoblasts proliferate and differentiate into various cell types, forming a blastema—a mass of undifferentiated cells.
- The blastema undergoes patterning and morphogenesis to regenerate the missing structures.

Example: If a planarian is bisected transversely, both the head and tail fragments can regenerate the missing parts, including the head and tail regions, through epimorphosis.

2. Morphallaxis:

Morphallaxis involves the rearrangement or remodeling of existing tissues to restore lost structures without significant cell proliferation or blastema formation.

Process:

- Following injury, surviving tissues undergo reorganization to replace lost structures.
- Existing cells change their shape, migrate, or differentiate to fill in the gaps and restore functional integrity.

Example: If a planarian is bisected longitudinally, the two halves can regenerate the missing structures by rearranging existing tissues through morphallaxis, without forming a blastema.

3. Compensatory Regeneration:

Compensatory regeneration involves the growth and remodeling of existing tissues to compensate for lost or damaged structures without significant alteration of body proportions.

Process:

- Following injury, existing tissues adjacent to the wound site proliferate and expand to replace the lost structures.
- Cell division and tissue remodeling occur in a localized manner to restore functional integrity.

Example: If a portion of a planarian's body is removed, the remaining tissues adjacent to the wound site proliferate and remodel to compensate for the lost tissue, restoring the overall body shape and size.

4. Importance of Neoblasts:

- Neoblasts are undifferentiated stem cells found in Turbellarians, particularly planarians, and play a central role in regeneration.
- They are capable of self-renewal and can differentiate into various cell types required for tissue repair and regeneration.
- Neoblasts are essential for the success of epimorphosis and provide a continuous source of cells for tissue turnover and repair throughout the life of the organism.

4.3. Ageing: Concepts and Theories

Ageing is a complex biological process characterized by the progressive decline in physiological function and increased vulnerability to disease, ultimately leading to death. While ageing is a natural and inevitable part of life, it is influenced by various genetic, environmental, and lifestyle factors. Several concepts and theories have been proposed to explain the mechanisms and underlying causes of ageing. Some key concepts and theories related to ageing:

1. Biological Age:

- Biological age refers to an individual's age as determined by physiological markers, rather than chronological age.
- Biological ageing can vary among individuals and is influenced by factors such as genetics, lifestyle, and environmental exposures.
- Biomarkers of biological age include telomere length, epigenetic modifications, cellular senescence, and the accumulation of age-related biomolecules (e.g., advanced glycation end products).

2. Senescence:

- Senescence refers to the gradual deterioration of biological function over time.
- Cellular senescence is a state of irreversible growth arrest that can be triggered by various stressors, including DNA damage, telomere shortening, and oxidative stress.
- Senescent cells can accumulate with age and contribute to age-related diseases and tissue dysfunction through the secretion of pro-inflammatory factors and other deleterious molecules (senescence-associated secretory phenotype, SASP).

3. Telomere Shortening:

- Telomeres are protective caps at the ends of chromosomes that shorten with each cell division due to the end replication problem.
- Telomere shortening is considered a hallmark of biological ageing, as it limits the proliferative capacity of cells and contributes to cellular senescence and genomic instability.
- Dysfunctional telomeres have been implicated in age-related diseases and conditions, including cancer, cardiovascular disease, and neurodegenerative disorders.

4. Oxidative Stress:

- Oxidative stress results from an imbalance between the production of reactive oxygen species (ROS) and the antioxidant defense mechanisms of the body.
- ROS can damage cellular components such as DNA, proteins, and lipids, leading to cellular dysfunction and ageing.
- Oxidative stress is implicated in the pathogenesis of various age-related diseases, including cardiovascular disease, neurodegenerative disorders, and cancer.

5. Mitochondrial Theory of Ageing:

- The mitochondrial theory of ageing proposes that age-related accumulation of mitochondrial dysfunction and oxidative damage contributes to cellular senescence and ageing.
- Mitochondria are major sources of ROS production, and mitochondrial dysfunction can lead to increased oxidative stress and cellular damage.
- Mitochondrial DNA (mtDNA) mutations and alterations in mitochondrial function are associated with age-related decline in tissue function and the development of age-related diseases.

6. Caloric Restriction and Longevity:

- Caloric restriction (reducing caloric intake without malnutrition) has been shown to extend lifespan and delay the onset of age-related diseases in various organisms, including rodents and non-human primates.
- Mechanisms underlying the anti-ageing effects of caloric restriction include improved metabolic efficiency, reduced oxidative stress, enhanced DNA repair, and activation of longevity pathways such as sirtuins and AMP-activated protein kinase (AMPK).

4.4. Teratogenic agents and their effects on embryonic development

Teratogenic agents are substances that can disrupt normal embryonic development and lead to the formation of structural or functional abnormalities in the developing embryo or fetus. These agents can include drugs, chemicals, infectious agents, environmental pollutants, and maternal factors. The effects of teratogenic agents on embryonic development can vary depending on factors such as the timing and duration of exposure, dose, and genetic susceptibility. Some common teratogenic agents and their effects on embryonic development:

1. Drugs and Medications:

- **Alcohol**: Prenatal exposure to alcohol can cause fetal alcohol spectrum disorders (FASDs), which can include facial abnormalities, growth deficiencies, central nervous system abnormalities, and intellectual disabilities.
- **Thalidomide**: Exposure to thalidomide during the first trimester of pregnancy can lead to limb deformities (phocomelia) and other birth defects.

- **Anticonvulsant drugs**: Some anticonvulsant medications, such as valproic acid and phenytoin, have been associated with an increased risk of neural tube defects and other congenital abnormalities.
- **Isotretinoin (Accutane)**: Isotretinoin, a medication used to treat severe acne, is known to cause severe birth defects, including craniofacial abnormalities, heart defects, and central nervous system abnormalities.

2. Environmental Chemicals and Pollutants:

- **Heavy Metals**: Exposure to heavy metals such as lead, mercury, and cadmium can interfere with normal embryonic development and cause a range of birth defects, including neurological abnormalities and developmental delays.
- **Pesticides**: Some pesticides and herbicides have been linked to an increased risk of birth defects, including neural tube defects and limb abnormalities.
- **Polycyclic aromatic hydrocarbons (PAHs)**: PAHs, which are found in tobacco smoke, air pollution, and certain occupational settings, have been associated with an increased risk of congenital heart defects and other birth defects.

3. Infectious Agents:

- **Rubella Virus**: Infection with the rubella virus during pregnancy can cause congenital rubella syndrome, which can include hearing loss, eye abnormalities, heart defects, and developmental delays.
- **Cytomegalovirus (CMV)**: Maternal infection with CMV during pregnancy can lead to congenital CMV infection, which can cause hearing loss, vision impairment, intellectual disabilities, and developmental delays in affected infants.
- **Toxoplasma gondii**: Infection with Toxoplasma gondii during pregnancy can lead to congenital toxoplasmosis, which can cause eye abnormalities, brain damage, and other birth defects.

4. Maternal Factors:

- **Maternal Malnutrition**: Inadequate maternal nutrition, including deficiencies in folic acid, vitamin A, and other essential nutrients, can increase the risk of neural tube defects, heart defects, and other birth defects.
- **Maternal Diabetes**: Poorly controlled maternal diabetes can increase the risk of congenital anomalies, including neural tube defects, heart defects, and macrosomia (large birth weight).
- **Maternal Smoking**: Maternal smoking during pregnancy has been associated with an increased risk of preterm birth, low birth weight, and certain birth defects, including cleft lip and palate and heart defects.

5.1. Organogenesis of Central Nervous system

Organogenesis of the central nervous system (CNS) is a complex process involving the formation and differentiation of neural tissue to give rise to the brain and spinal cord. This process begins early in embryonic development and proceeds through a series of highly coordinated events, including neural induction, neurulation, and regional patterning. The key stages and events involved in the organogenesis of the CNS:

1. Neural Induction:

- **Formation of the Neural Plate**: Neural induction occurs during gastrulation when signals from the notochord and underlying mesoderm induce the overlying ectoderm to differentiate into the neural plate, a specialized region of the embryonic ectoderm.
- **Specification of Neural Tissue**: Cells within the neural plate become committed to a neural fate through the action of signaling molecules such as bone morphogenetic proteins (BMPs) and fibroblast growth factors (FGFs).
- **Formation of the Neural Tube**: The neural plate folds inward along the midline to form the neural tube, a hollow structure that will give rise to the brain and spinal cord.

2. Neurulation:

- **Primary Neurulation**: Primary neurulation involves the closure of the neural tube from the anterior (rostral) to the posterior (caudal) end. The neural folds elevate and converge at the dorsal midline, ultimately fusing to form the neural tube. Failure of neural tube closure can lead to neural tube defects such as spina bifida and anencephaly.
- **Secondary Neurulation**: Secondary neurulation occurs in the caudal region of the embryo and involves the formation of the lower spinal cord and filum terminale from a solid cord of mesenchymal cells that undergo cavitation to form the central canal.

3. Regional Patterning:

- **Formation of Brain Vesicles**: Following neurulation, the anterior end of the neural tube expands and undergoes regional patterning to give rise to the three primary brain vesicles: the prosencephalon (forebrain), mesencephalon (midbrain), and rhombencephalon (hindbrain).
- **Further Division**: Each primary brain vesicle subsequently divides into secondary brain vesicles, which further differentiate into specific regions of the brain, including the telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon.

4. Cell Differentiation and Migration:

- **Neurogenesis**: Neurogenesis, the process of generating neurons from neural progenitor cells, occurs in discrete regions of the developing CNS. Differentiated neurons migrate to their appropriate locations within the brain and spinal cord.

- **Gliogenesis**: Gliogenesis involves the generation of glial cells, including astrocytes, oligodendrocytes, and microglia, which provide structural support and regulate neuronal function in the CNS.

5. Synaptogenesis and Circuit Formation:

- **Synaptogenesis**: Synaptogenesis involves the formation of synaptic connections between neurons, allowing for communication and information processing within the CNS.
- **Circuit Formation**: Neurons form complex neural circuits through the extension of axons and the formation of synapses with target cells. This process underlies the establishment of sensory, motor, and integrative circuits within the brain and spinal cord.

5.2. Organogenesis of Eye, Ear

The organogenesis of the eye and ear involves a series of intricate developmental processes that give rise to the complex structures responsible for vision and hearing, respectively. Here's an overview of the organogenesis of each:

5.2.1. Eye Organogenesis:

1. **Formation of Optic Vesicle**: During early embryonic development, the neural tube gives rise to the forebrain, which subsequently forms bilateral outpouchings called optic vesicles.
2. **Optic Cup Formation**: The distal portion of each optic vesicle invaginates to form a double-layered optic cup. The outer layer becomes the retinal pigment epithelium (RPE), while the inner layer gives rise to the neural retina.
3. **Lens Formation**: Nearby surface ectoderm thickens and invaginates to form the lens placode, which then detaches from the surface ectoderm and forms the lens vesicle. Cells within the lens vesicle differentiate into lens fibers, eventually forming the crystalline lens.
4. **Development of Retina and Optic Nerve**: The inner layer of the optic cup differentiates into the neural retina, consisting of various cell types such as photoreceptors, bipolar cells, and ganglion cells. Meanwhile, the optic nerve develops from axons of retinal ganglion cells that extend towards the brain.
5. **Vascularization and Maturation**: Blood vessels penetrate the developing eye to supply oxygen and nutrients. The eye undergoes further maturation, with the formation of distinct layers and structures necessary for vision.
6. **Cornea, Iris, and Ciliary Body Development**: Surface ectoderm gives rise to the cornea, while the iris and ciliary body develop from the neural crest cells surrounding the optic cup.

5.2.2. Ear Organogenesis:

1. **Formation of Otic Placode**: During early embryonic development, a thickening of ectoderm adjacent to the hindbrain forms the otic placode.
2. **Formation of Otocyst**: The otic placode invaginates to form a hollow structure called the otic vesicle or otocyst. The otic vesicle gives rise to various structures of the inner ear, including the cochlea, vestibular apparatus, and semicircular canals.
3. **Differentiation of Inner Ear Structures**: Within the otocyst, specialized regions develop into distinct components of the inner ear, such as the cochlear duct for hearing and the vestibular system for balance.
4. **Formation of Middle and External Ear**: Structures of the middle and external ear, including the ossicles (malleus, incus, and stapes), tympanic membrane, and external auditory canal, develop from mesoderm and ectoderm adjacent to the otic vesicle.
5. **Vascularization and Innervation**: Blood vessels penetrate the developing ear to provide nutrients, while nerves from the vestibulocochlear nerve (CN VIII) innervate the inner ear structures for sensory function.
6. **Maturation and Functional Development**: The inner ear undergoes further differentiation and maturation to enable hearing and balance functions after birth.

5.3. Organogenesis of Skin

Skin organogenesis refers to the process by which the skin, the largest organ of the human body, develops during embryonic development. It involves intricate interactions between various cell types and signaling molecules to form the complex structure of the skin, which serves as a protective barrier against external pathogens, regulates body temperature, and provides sensory information.

A brief overview of the key stages involved in the organogenesis of skin:

1. **Ectoderm Formation**: During early embryonic development, the outermost layer of cells, known as the ectoderm, forms. The ectoderm gives rise to various tissues, including the epidermis, hair follicles, sweat glands, and nerves of the skin.
2. **Epidermal Induction**: Around the sixth week of embryonic development, specialized signaling molecules, such as fibroblast growth factors (FGFs) and bone morphogenetic proteins (BMPs), induce the ectodermal cells to differentiate into the epidermis, which is the outermost layer of the skin.
3. **Dermal Development**: Concurrently, the mesoderm, another germ layer, gives rise to the dermis, the layer of skin beneath the epidermis. The dermis consists of connective tissue, blood vessels, nerves, and various specialized cells, including fibroblasts and immune cells.
4. **Formation of Skin Appendages**: As the epidermis and dermis develop, specialized structures such as hair follicles, sweat glands, sebaceous glands, and nails begin to form. These appendages play crucial roles in functions such as thermoregulation, sensation, and protection.
5. **Maturation and Differentiation**: Over the course of fetal development, the skin undergoes further maturation and differentiation. Epidermal cells undergo terminal differentiation, forming distinct layers such as the stratum basale, stratum spinosum, stratum granulosum, and stratum corneum. This process involves the expression of specific genes and the synthesis of structural proteins like keratins.
6. **Vascularization and Innervation**: Blood vessels and nerves penetrate the developing skin, providing oxygen and nutrients to the cells and establishing sensory connections for touch, temperature, and pain sensation.
7. **Birth and Postnatal Development**: After birth, the skin continues to develop and mature, undergoing processes such as growth, wound healing, and adaptation to environmental factors.

5.4. Organogenesis of Circulatory system

The organogenesis of the circulatory system, also known as cardiovascular development, is a complex process involving the formation and differentiation of various cell types and tissues to create the heart, blood vessels, and blood cells. This process occurs during embryonic development and is essential for sustaining life by providing oxygen and nutrients to tissues and removing waste products. Here's an overview of the key stages in the organogenesis of the circulatory system:

1. **Formation of Blood Islands**: Blood island formation is one of the earliest events in cardiovascular development. In the extraembryonic mesoderm, specialized cells called hemangioblasts differentiate into blood islands, which consist of blood cells and endothelial cells.
2. **Development of the Heart Tube**: The heart develops from mesodermal cells in the cardiogenic region of the embryo. Initially, two endocardial tubes form, which fuse to create a single primitive heart tube. The heart tube undergoes looping and segmentation to form the four-chambered heart.
3. **Formation of Heart Chambers and Septation**: As the heart tube elongates and loops, it begins to differentiate into distinct chambers: the atria and ventricles. Septation processes occur to separate the atria and ventricles, as well as the pulmonary and systemic circulations.
4. **Development of Heart Valves**: Endocardial cushions form within the heart tube and later undergo remodeling to give rise to heart valves, which ensure unidirectional blood flow through the heart.
5. **Differentiation of Blood Vessels**: Blood vessels, including arteries, veins, and capillaries, form from angioblasts and angiogenic cell clusters derived from mesoderm. Angioblasts aggregate to form primitive vascular plexuses, which then undergo remodeling and differentiation into mature blood vessels.
6. **Vascularization of Organs**: Blood vessels penetrate various tissues and organs to provide oxygen and nutrients. This process, known as vascularization or angiogenesis, is regulated by various signaling molecules and involves the sprouting, migration, and differentiation of endothelial cells.
7. **Formation of Blood Cells**: Blood cell formation, or hematopoiesis, occurs in several waves during embryonic development. Hematopoietic stem cells initially emerge in the yolk sac and later colonize the fetal liver, spleen, and bone marrow. These stem cells differentiate into various blood cell lineages, including erythrocytes (red blood cells), leukocytes (white blood cells), and platelets.
8. **Maturation and Functional Development**: The circulatory system undergoes further maturation and refinement during fetal development and after birth. Structural and functional changes occur to adapt to the increasing metabolic demands of the growing organism.