Development of the Kidney

Upper Urinary System Development:

- Origin: Intraembryonic intermediate mesoderm.

- Position: After embryo folding, it lies behind the intraembryonic coelom on either side of the descending aorta.

- Stages of Development:

1. Pronephros
2. Mesonephros
3. Metanephros

Pronephros

- Origin: Intermediate mesoderm of the cervical region at the 4th week.

- Structure:

- Segmented into 7 cell clusters called nephrotomes.
- Nephrotomes elongate and form pronephros tubules.
- Tubule ends:
  - Medial end: Receives a capillary plexus from the adjacent aorta, forming an internal glomerulus.
  - Lateral end: Grows caudally and connects with successive tubules to form the pronephric duct, which opens into the cloaca.

- Fate:

- Pronephric tubules degenerate.
- Pronephric duct transforms into the mesonephric duct, serving the second kidney.

Mesonephros

- Origin: Intermediate mesoderm of thoracic and upper lumbar regions.

- Development:

- Segmented into about 70 clusters, forming S-shaped mesonephric tubules.

- Tubule ends:

- Medial end: Invaginated by a capillary plexus, forming a primitive glomerulus surrounded by Bowman's capsule, creating a renal corpuscle.

- Lateral end: Joins the mesonephric (Wolffian) duct.

- Fate:

- Mesonephros degenerates and is replaced by the metanephros (permanent kidney).

- Parts persist to form urogenital structures, differing in males and females.

Metanephros

- Site: Sacral region at the 5th month of development.

- Development: From two mesodermal structures:

- Ureteric Bud: Arises as a diverticulum from the lower mesonephric duct near the cloaca, forming the collecting system of urine (ureter, renal pelvis, calyces, and collecting tubules).

- Metanephric Cap: Induced by the ureteric bud, forming nephrons (Bowman's capsule, proximal convoluted tubule, Loop of Henle, distal convoluted tubule).

- Postnatal Changes:

- Shape: Fetal kidney is lobulated; lobulation disappears in early infancy.

- Position and Blood Supply: Moves from the pelvis to the abdomen, changing blood supply from the median sacral artery to the common iliac artery, then to the abdominal aorta.

- Direction: Initially anterior hilum rotates medially 90 degrees.

Congenital Anomalies

1. Renal Agenesis: Absence of one or both kidneys due to ureteric bud failure.

2. Congenital Polycystic Kidney: Cysts in collecting ducts.

3. Ectopic Kidney: Fails to ascend, remaining in the pelvis.

4. Horseshoe Kidney: Fusion at lower poles, ascent prevented by inferior mesenteric artery.

5. Accessory Renal Artery: Additional artery to kidney pole.

6. Bifid Ureter: Bifurcation of the ureteric bud, leading to a double renal pelvis.

7. Double Ureter: Premature division of the ureteric bud, resulting in duplicated ureter and renal pelvis.

Development of the Urinary Bladder

Development of the Cloaca

- **Origin:** Dilated endoderm-lined terminal part of the hindgut.

- **Structure:**

  - Ventrally continuous with the allantois.

  - Sides receive mesonephric ducts.

  - Caudally closed by the cloacal membrane.

- Urorectal Septum: Mesodermal septum (its remnant gives perineal body + rectovesicle fascia (Denonvilliers' fascia)) **and it divides the cloaca into two parts**:

  - Primitive Urogenital Sinus: Ventral, continuous with the allantois, and receiving mesonephric ducts.

  - **Anorectal Canal:** Dorsal, continuous with the hindgut, forming the rectum and upper anal canal.

- **Membrane Division:**

  - **Urogenital Membrane**: Closes the caudal end of the urogenital sinus.

  - **Anal Membrane:** Closes the caudal end of the anorectal canal.

Urogenital Sinus Subdivisions

1. **Cranial (Vesico-Urethral Canal):** Continuous with allantois, forming the bladder.

2. **Caudal (Definitive Urogenital Sinus):** Divided into pelvic and phallic parts.

   - **Pelvic Part:** Forms the lower urinary and reproductive structures.

   - **Phallic Part:** Contributes to external genitalia.

Allantois and Urachus

- **Allantois:** Forms the urachus, a fibrous cord connecting to the bladder apex, becoming the median umbilical ligament post-birth.

- **Mesonephric Ducts**: Absorbed into the bladder wall, forming the trigone.

Congenital Anomalies

1. **Ectopia Vesicae:** Mucosa of the bladder exposed due to anterior abdominal wall defect, often with epispadias.

2. Urachal Anomalies:

- **Urachal Fistula:** Communication between bladder and umbilicus.
- **Urachal Cyst:** Fluid-filled mid-urachus dilation.
- **Urachal Sinus:** Blind dilation at the umbilical end.

Development of the Urethra

Male Urethra

1. Prostatic Urethra: Divided by seminal colliculus into:

- **Supracollicular Part**: From the vesico-urethral canal (endodermal), dorsal wall mesodermal.
- **Infracollicular Part:** From the pelvic urogenital sinus.

2. Membranous Urethra: From the pelvic urogenital sinus.

3. Penile (Spongy) Urethra: From the phallic urogenital sinus (fusion of urethral folds), terminal part from ectodermal ingrowths.

Female Urethra

- Development: Vesico-urethral canal (endodermal), dorsal wall mesodermal from mesonephric ducts.

Urogenital Sinus Derivatives

Male:

- Vesico-Urethral Part: Bladder (except trigone), supracollicular prostatic urethra (dorsal wall mesodermal).

- Pelvic Part: Infracollicular prostatic and membranous urethra.

- Phallic Part: Penile urethra (terminal part ectodermal).

Female:

- Vesico-Urethral Part: Bladder (except trigone), entire urethra (dorsal wall mesodermal).

- Pelvic and Phallic Parts: Lower vagina and vestibule.

Development of the Gonads

Gonadal Development Sources:

1. Proliferating coelomic epithelium: Mesodermal origin, located on the medial side of the mesonephros.

2. Adjacent mesenchyme: Mesodermal origin, dorsal to the coelomic epithelium.

3. Primordial germ cells: Endodermal origin, develop in the yolk sac wall and migrate along the dorsal mesentery to the developing gonad.

Indifferent Stage (Up to 6th or 7th Week):

- Coelomic epithelium proliferates to form a genital ridge.

- Primary sex cords invade the underlying mesenchyme.

- At this stage, the gonad cannot be distinguished as a testis or an ovary.

Development of the Testis

Key Factors:

- Testis Determining Factor (TDF): Gene on the Y-chromosome responsible for initiating testis development.

Coelomic Epithelium:

- Forms primary sex cords that elongate into testis cords (future seminiferous tubules).

- Testis cords lose contact with surface epithelium ventrally and form rete testis dorsally.

- Invaded by primitive germ cells.

Mesenchyme:

- Forms tunica albuginea and interstitial cells of Leydig.

- Leydig cells secrete testosterone, crucial for male differentiation.

Primitive Germ Cells:

- Differentiate into spermatogonia, maturing into spermatozoa at puberty.

Descent of the Testis:

- Internal Descent (4th-6th month): Testis descends to the iliac fossa.

- External Descent (7th-9th month): Testis traverses inguinal rings and canal to reach the scrotum.

Factors Aiding Descent:

1. Shortening of the gubernaculum.

2. Influence of hormones (androgens, gonadotropins).

3. Increased intra-abdominal pressure.

Congenital Anomalies and Causes:

1. Cryptorchidism:

- Cause: Failure of the testis to descend into the scrotum.

- Potential causes include hormonal imbalances, mechanical obstructions, or genetic factors.

2. Ectopic Testis:

- Cause: Abnormal position of the testis outside the normal pathway of descent.

- Often due to abnormal attachment or length of the gubernaculum.

3. Congenital Oblique Inguinal Hernia:

- Cause: Failure of the processus vaginalis to close, allowing abdominal contents to herniate into the inguinal canal.

4. Hydrocele:

- Cause: Accumulation of fluid in the scrotum or spermatic cord due to the persistent processus vaginalis.

Development of the Ovary

Key Factors:

- In absence of TDF, the undifferentiated gonad develops into an ovary.

Coelomic Epithelium:

- Forms medullary sex cords (medulla) and secondary (cortical) sex cords (cortex).

Mesenchyme:

- Forms ovarian stroma and thin tunica albuginea.

Primitive Germ Cells:

- Form primary oocytes, arrested in prophase of the first meiotic division until puberty.

Descent of the Ovary:

- 3rd Month: Ovary reaches the greater pelvis.

- After Birth: Ovary reaches the lesser pelvis.

Congenital Anomalies and Causes:

1. Ovarian Agenesis:

   - Cause: Complete absence of ovarian development.

   - Due to failure of the gonadal ridge to form or differentiate properly.

2. Congenital Inguinal Hernia:

   - Cause: Descent of the ovary into the inguinal canal due to failure of the processus vaginalis to obliterate.

Development of the Genital Ducts

Indifferent Stage (Up to 6th Week):

- Both males and females have mesonephric (Wolffian) and paramesonephric (Müllerian) ducts.

Male Development:

- AMF (Antimüllerian Factor): Secreted by Sertoli cells, causing regression of the paramesonephric ducts.

- Mesonephric Ducts: Develop into the epididymis, vas deferens, seminal vesicles, and ejaculatory ducts.

Vestigial Structures in Males:

- Paramesonephric Ducts: Form appendix of the testis and prostatic utricle.

Female Development:

- In absence of AMF, paramesonephric ducts develop into the fallopian tubes, uterus, and upper 2/3 of the vagina.

- Vaginal Plate: Formed from the sinovaginal bulbs, contributes to the lower 1/3 of the vagina and the hymen.

Vestigial Structures in Females:

- Mesonephric Ducts: Form epoophoron, paroophoron, and Gartner's duct.

Congenital Anomalies and Causes:

1. Uterus Bicornis Unicollis/Bicollis:

- Cause: Incomplete fusion of the paramesonephric ducts.

- Results in a uterus with two horns (bicornuate) with either one cervix (unicollis) or two cervices (bicollis).

2. Uterus Unicornis:

- Cause: Complete failure of one paramesonephric duct to develop.

- Results in a uterus with a single horn.

3. Septate Uterus:

- Cause: Incomplete resorption of the septum between the two paramesonephric ducts.

- Leads to a uterus divided by a septum.

4. Vaginal Atresia:

- Cause: Failure of the vaginal plate to canalize.

- Results in a closed or absent vaginal canal.

5. Imperforate Hymen:

- Cause: Failure of the hymen to perforate during development.

- Leads to obstruction of the vaginal opening.

6. Congenital Rectovaginal Fistula:

- Cause: Abnormal connection between the rectum and vagina.

- Due to improper separation of the cloaca.

Development of External Genitalia

Indifferent Stage (4th-7th Week):

- Genital Tubercle: Forms phallus.

- Genital Folds: Form urethral folds.

- Genital Swellings: Form labio-scrotal swellings.

Male Development:

- Genital Tubercle: Elongates to form the penis and the corpora cavernosa.

- Genital Folds: Fuse to form the penile urethra and corpus spongiosum.

- Genital Swellings: Fuse to form the scrotum.

Congenital Anomalies and Causes:

1. Hypospadias:

- Cause: Incomplete fusion of the urethral folds.

- Results in the urethral opening on the ventral side of the penis.

2. Epispadias:

- Cause: Abnormal positioning of the genital tubercle.

- Results in the urethral opening on the dorsal side of the penis, often associated with bladder exstrophy.

Female Development:

- Genital Tubercle: Develops into the clitoris.

- Genital Folds: Form the labia minora.

- Genital Swellings: Form the labia majora.

- Vaginal Vestibule: Formed by shortening of the primitive urogenital sinus.

Congenital Anomalies and Causes:

1. Clitoral Hypertrophy:

- Cause: Exposure to excessive androgens.

- Results in an enlarged clitoris.

2. Labial Fusion:

- Cause: Fusion of the labia minora.

- Can be due to hormonal imbalances or genetic factors.

Gonadal Development:

- Originates from coelomic epithelium, mesenchyme, and primordial germ cells.

- Indifferent stage up to 6-7 weeks.

Testis Development:

- TDF initiates formation.

- Involves formation of testis cords and descent through the inguinal canal.

- Anomalies include cryptorchidism, ectopic testis, and hydrocele.

Ovary Development:

- Develops in the absence of TDF.

- Involves formation of primary and secondary sex cords.

- Anomalies include ovarian agenesis and congenital inguinal hernia.

Genital Duct Development:

- Both sexes initially have mesonephric and paramesonephric ducts.

- Male development influenced by AMF.

- Female development occurs in absence of AMF.

- Anomalies include uterus bicornis, uterus unicornis, and vaginal atresia.

External Genitalia Development:

- Indifferent stage leads to formation of genital tubercle, folds, and swellings.

- Male and female

differentiation results in distinct genital structures.

- Anomalies include hypospadias, epispadias, and clitoral hypertrophy.

Vestigial Structures in Males:

- Appendix of the Testis: Remnant of the paramesonephric duct.

- Prostatic Utricle: Remnant of the paramesonephric duct.

- Paradidymis: Remnant of the mesonephric duct.

- Appendix of the Epididymis: Remnant of the mesonephric duct.

Vestigial Structures in Females:

- Epoophoron: Remnant of the mesonephric duct.

- Paroophoron: Remnant of the mesonephric duct.

- Gartner's Duct: Remnant of the mesonephric duct.

- Hydatid of Morgagni: Remnant of the paramesonephric duct.