9/ Embryology

Maturation of the germ cells and fertilisation

During normal cell division or mitosis, the nuclear chromatin is arranged into a number of short thread-like structures called chromosomes. The essential factors involved in the process of transmission of hereditary characteristics are located on the chromosomes. There are 46 chromosomes arranged in pairs in the nucleus of every cell. The 22 pairs are called autosomes, involved in the transmission of ordinary hereditary characteristic and the 23rd pair is concerned with the determination of sex.

The sex chromosomes differ in the two sexes. In the female, the sex chromosome consists of a pair of identically large X chromosomes whereas in the male the pair consists of X chromosomes and Y chromosomes. During mitotic division each chromosome splits lengthwise one-half passing to each daughter cell. The nucleus of the cell will contain the same number of chromosomes as the parent cell.

Union of two germ cells, each of which contain 46 chromosomes, would produce a zygote containing 92 chromosomes. Hence during maturation of both the male and female germ cell, the number of nuclear chromosome must be reduced to half. This reduction in the number of chromosomes is the result of a meiotic division, in which chromosomes come together as in mitosis, exchange their components and again separate. One complete chromosome from each pair passes through half daughter cell, whilst the other number passes to the second daughter cell. As, a result, each daughter cell possess half the number of chromosomes of the parent cell (haploid).

A primary spermatocyte contains 44 autosomes and a pair of sex chromosomes. The matured spermatozoa contain either 22 plus X or 22 plus Y chromosomes. In the female the chromosomal component of the secondary zygote is 22+X. If a spermatozoön carrying X chromosomes fertilises the ovum with X chromosome the resulting zygote will contain (22+X) plus (22+X) chromosomes and the sex will be female. On the other hand, a spermatozoön containing 22+Y chromosomes will give rise to a zygote, with (22+Y) plus (22+X) chromosomes and the sex will be male.

The result of fertilisation is the evolution of a new individual which is known as zygote. The results of fertilisation mainly are—

(*i*) restoration of full number of chromosomes (46),

(*ii*) determination of the sex of the zygote,

(*iii*) initiation of series of mitotic division known as cleavage division.

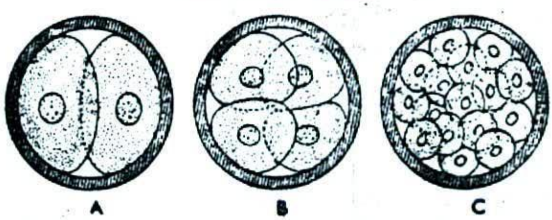

FIG. 9.1. It shows the development of zygote from 2-cell stage to the late morula stage. A=2-cell stage at about 30 hours after fertilisation; B=4-cell stage at about 40 hours; C=12-16-cell stage at about 72 hours and the late morula stage at about 96 hours.

The zygote moves down the Fallopian tube and when the 12–16–cell stage is reached, it is called morula. The morula (FIG. 9.1). consists of a group of centrally located cell, the inner cell mass and a peripheral layer of cells known as the outer cell mass. The morula reaches the uterine cavity at about 12–16 cell stage between the third and fourth day after fertilisation.

BLASTOCELE AND BLASTOCYST

The fluid from the uterine cavity passes into intercellular spaces of the inner cell mass, and forms a cavity known as blastocele (FIG. 9.2). With the disappearance of the zona pellucida, the zygote is known as the blastocysts. Inner cell mass is now described as embryoblast and the outer cell mass is known as trophoblast (FIG. 9.2).

The cells of the embryoblast give rise to ectodermal, entodermal and mesodermal germ layers—the three basic layers of the embryo proper. The trophoblast also secretes a gonadotrophic hormone, which prevents degeneration of the corpus luteum, which becomes the corpus luteum of pregnancy.

Secretion of a large amount of progesterone produced by the corpus luteum of pregnancy prepares the uterine mucosa to receive the blastocyst. The attachment between the blastocyst and the uterine mucosa occurs about 5 to 6 days after ovulation.

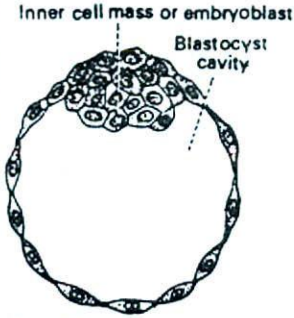

FIG. 9.2. A section through a human blastocyst recovered from the uterine cavity at about 108 hours after fertilisation (diagrammatic).

About the 8th day of development, the trophoblast forms a solid disc with an inner layer called cytotrophoblast and an outer layer called syncytiotrophoblast (FIG. 9.3).

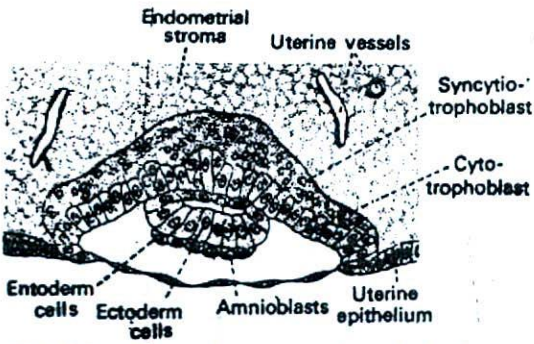

FIG. 9.3. Schematic representation of the human blastocyst partially implanted in the endometrial stroma at about 7–8 days after fertilisation.

BILAMINAR GERM DISC

The cells of the embryoblast also differentiate into two distinct layers: (*i*) the entodermal germ layer, and (*ii*) the ectodermal germ layer, which is in contact with the cytotrophoblast. The embryo thus reaches a stage of bilaminar germ disc.

AMNIOTIC CAVITY

With further development, small intercellular spaces appear between the cytotrophoblast and ectodermal germ layer. These spaces coalesce to form the amniotic cavity (FIG. 9.4). The cells from the inner surface of the cytotrophoblast form a thin membrane known as Heuser's membrane (FIG. 9.4). This membrane becomes continuous with the margins of the entoderm and together they form a lining of the exocoelomic cavity or a primitive yolk sac (FIG. 9.4). The cavity of the amnion increases in size at the expense of the exocoelomic cavity which is gradually obliterated.

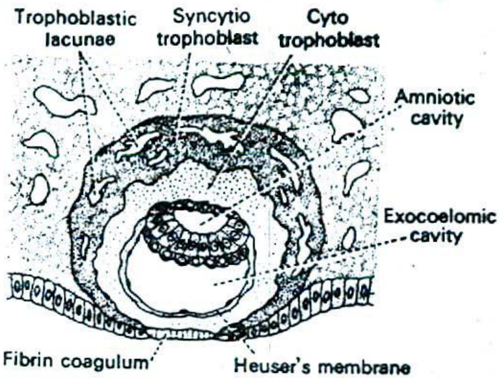

FIG. 9.4. It shows a human blastocyst at about 9 days old (diagrammatic).

PLACENTA

The cells of the trophoblast penetrate deep into the endometrium and give rise to future placenta. Towards the end of the second week, the cells of the syncytiotrophoblast penetrate deeper into the endometrium and begin to erode the endothelial lining of the maternal sinusoids. The syncytiotrophoblast thus becomes continuous with the remaining endothelial cell of the vessels and maternal blood enters the lacunar system establishing the basis of the future uteroplacental circulation (Fig. 9.5).

EXTRAEMBRYONIC MESODERM

On the inner surface of the cytotrophoblast, cells continue to delaminate forming a thin layer known as extraembryonic mesoderm. The

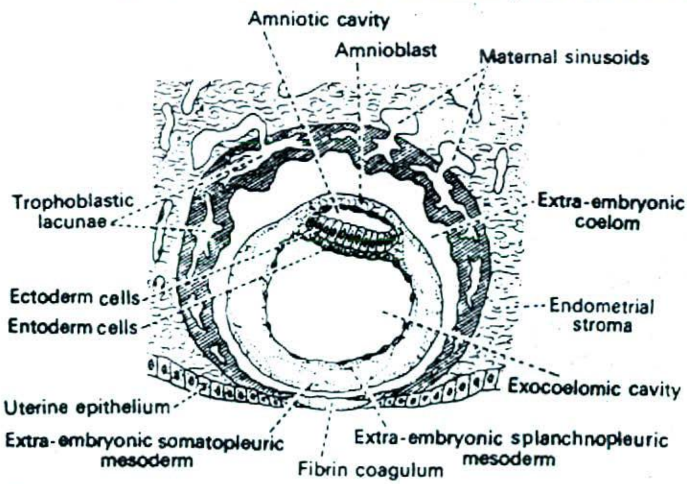

FIG. 9.5. Diagrammatic representation of a human blastocyst of about 11-12 days old after fertilisation.

extraembryonic mesoderm lining the cytotrophoblast and the amnion is called extraembryonic somatopleuric mesoderm (FIG. 9.5). The extraembryonic mesoderm covering the yolk sac is known as extraembryonic splanchnopleuric mesoderm. In between the extraembryonic somatic mesoderm and the extraembryonic splanchnopleuric mesoderm, lies the cavity of the extraembryonic coelom (FIG. 9 5).

The somatopleuric and splanchnopleuric mesoderm are both continuous—anteriorly with the mesoderm which lies immediately behind the anterior embryonic rim, i.e., the mesoderm of the future transverse septum. The transverse septum is therefore continuous with both the body wall (derived from the somatopleure) and the gut wall (formed from the splanchnopleure).

The entodermal germ layer continues to proliferate and gradually lines a new cavity known as the secondary yolk sac. The secondary yolk sac is much smaller than the primitive yolk sac (FIGS. 9.6 & 9.10). The primitive yolk sac gradually disappears.

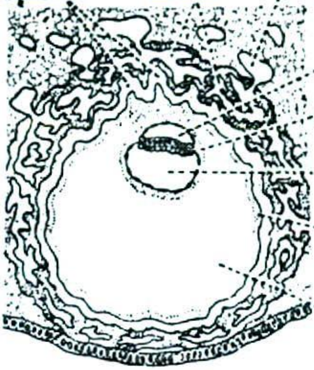

FIG. 9.6. Schematic representation of a human blastocyst of about 13–14 days old after fertilisation.

PRIMITIVE STREAK

Early in the third week the ectodermal cells in the caudal region of the germ disc proceed towards the middle line forming the primitive streak. At about the fifteenth day after fertilisation the primitive streak appears. It forms a keel-like thickening on the underside of the embryonic ectoderm where it is in contact with the entoderm. The position of the streak is excentric of the circular embryonic disc, and it is here that the future hinder end of the embryo will develop. The primitive streak elongates anteriorly, and its anterior extremity becomes thickened as Hensen's node (*vide* FIG. 9.10). Proliferation of the ectodermal cells of the node leads to a cord of cells, the notochordal or head process, growing forwards in the midline between the ectoderm and entoderm. There is a concurrent alteration in shape of the embryonic disc, which becomes oval with its long axis lying in an anteroposterior direction.

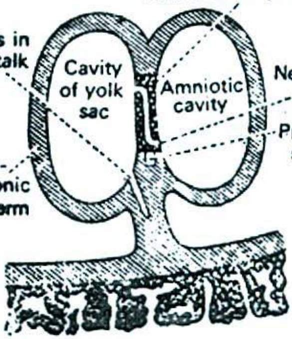

FIG. 9.7. Diagrammatic representation of a section of an embryo showing the neurenteric canal.

INTRAEMBRYONIC MESODERM

The head process continues to lengthen and soon outgrows the primitive streak itself. The ectodermal cells of both these structures produce cells which come to lie alongside (i.e., lateral to) the streak and its head process, forming a third layer, the intraembryonic mesoderm, which is situated between the ectoderm and entoderm. The ectodermal cells move to invaginate in the region of the primitive streak (FIG. 9.8). From there the cells migrate between the ectodermal and entodermal germ layers. The newly formed intermediate cell layer is known as the mesodermal germ layer forming the trilaminar germ disc (FIG. 9.9).

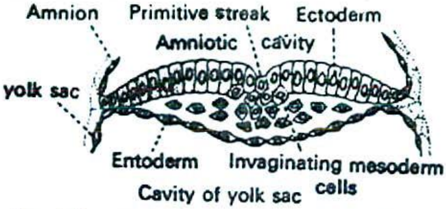

FIG. 9.8. It shows the invagination of the mesodermal cells sectioned through the region of the primitive streak.

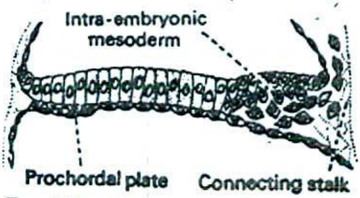

FIG. 9.9. Diagrammatic representation of cephalocaudal section of an embryo just lateral to the primitive streak showing migration of intraembryonic mesodermal cells into the extraembryonic mesoderm of the connecting stalk.

PROCHORDAL PLATE

In the bilaminar germ disc stage, the entodermal disc shows a slight thickening in the cephalic region, which is known as the prochordal plate. The mesodermal cells migrate into the cephalic direction of each side of the middle line and ultimately they meet in the most cephalic part of the germ disc in front of the prochordal plate. The middle line extending between the primitive streak and the prochordal plate, is not occupied by the intraembryonic mesoderm but by the notochordal process. In the central part of the Hensen's node there is a depression, which is known as primitive pit, extending from the node of Hensen to prochordal plate. A middle line structure appears which is known as notochord. The notochord contains a central canal which is the forward extension of the primitive pit. The lumen of the notochordal process is connected to the yolk sac cavity. The yolk sac cavity has an open connection with the amniotic cavity in the region of the Hensen's node. This temporary canal (neurenteric canal) (FIGS. 9.7 & 9.10) connects the yolk sac and the amniotic cavities. The notochordal plates folds along the longitudinal axis thereby forming a solid chord known as the definitive notochord. Meanwhile, dorsal to the notochord, the primordium of the central nervous system is formed by a midline thickening of the ectoderm. This thickening, the neural plate, extends from the tip of Hensen's node to the anterior extremity of the embryonic disc. The margins of this plate become raised to form the neural folds. With further growth the neural folds meet, near their anterior extremities in the first instance, and fuse progressively both cranially and caudally from that point. In this way a hollow neural tube is formed.

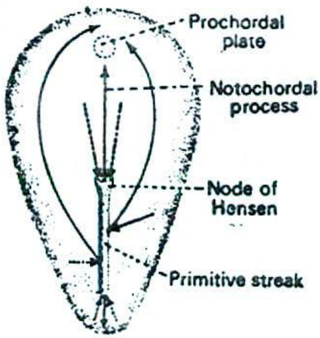

FIG. 9.10. Diagrammatic representation of the dorsal aspect of the germ disc after fertilisation.

It loses its connection with the overlying ectoderm and comes to lie free between the ectoderm above and the notochord below. Even before its complete separation from the ectoderm, the neural tube shows three dilatations cranial to the level of the fourth somite, indicating the presence of the three primary brain vesicles. The neural tube remains open for a while at both extremities, the anterior and posterior neuropores.

Whilst the neural tube is separating from the ectoderm, there appear, in the angle between them on either side, longitudinal chains of ectodermal cells called the **neural crests.** These cell columns will break up later into isolated masses to become the dorsal root ganglia of the spinal nerves and the sensory ganglia of the cranial nerves. The neural crest also gives rise to the peripheral part of the sympathetic nervous system. There remains an area immediately anterior to the head process which never receives any intraembryonic mesoderm; it is here that the ectoderm and entoderm remain in intimate contact as the future buccopharyngeal membrane. The mass of mesoderm immediately anterior to the buccopharyngeal membrane is the area where the heart will form, the cardiogenic protocardiac area. In front of the protocardiac area is a further mesodermal mass, the transverse septum, which lies between the protocardiac area and the anterior embryonic rim. Behind the primitive streak (between it and the posterior embryonic rim) there is another area where no mesoderm is laid down between the ectoderm and entoderm which here form the future cloacal membrane.

The entodermal germ layer in the mean time establishes contact with the ectoderm in the region immediately behind the primitive streak and, a bilaminar membrane—the cloacal membrane is formed (Fig. 9.11). Prochordal plate in the cephalic part of the embryonic disc gives rise to the buccopharyngeal membrane. With the formation of the cloacal membrane the posterior wall of the yolk sac gives rise to a small diverticulum which extends into the connecting stalk. This diverticulum is known as allantoenteric diverticulum or 'allantois' (Fig. 9.11).

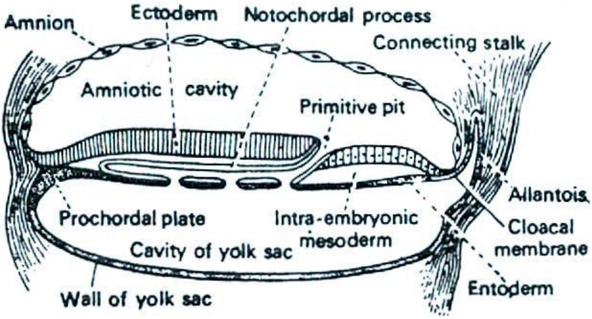

Fig. 9.11. It shows the notochordal process extending from primitive pit to prochordal plate and fused with the entoderm.

GERM LAYERS AND THEIR DERIVATIVES

Mesodermal germ layer

At the beginning, the mesoderm forms a thin sheet of cells on each side of the middle line of the developing embryo. Mesodermal cells in the cephalic part of the embryo, immediately lateral to the notochord proliferate and form a thickened mass of tissue known as paraxial mesoderm. More laterally, the mesoderm is known as the lateral plate. The tissue connecting the paraxial mesoderm and the lateral plate is known as intermediate mesoderm (Fig. 9.12).

The lateral plate mesoderm splits into two layers—a layer which is continuous with the extra-embryonic mesoderm and covering the amnion is known as somatic or parietal mesoderm. The other continues with the mesoderm covering the yolk sac and is known as splanchnic or visceral mesoderm. In between the somatic and visceral mesoderm, there is a newly formed cavity known as intraembryonic coelomic cavity (Fig. 9.12).

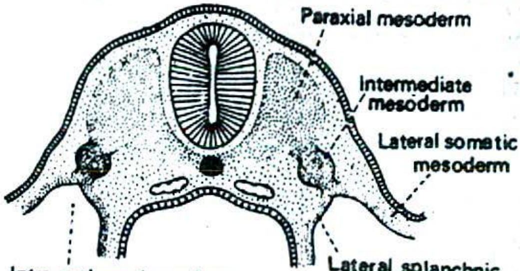

Fig. 9.12. Diagrammatic representation of the development of the mesodermal germ layer at about the end of third week after fertilisation.

Development of gastro-intestinal system

Oesophagus. Oesophagus develops from the cephalic part of the foregut which extends from the pharynx to the transverse septum. Elongation of oesophagus occurs with the descent of the heart.

Stomach. The stomach is developed from the foregut which is distal to the transverse septum. This portion of the foregut also gives rise to the proximal half of the duodenum. The foregut in this situation possess a dorsal mesentery and a ventral mesentery. The ventral mesentery attaches this part of the foregut to the transverse septum. There is 90° rotation of the stomach around its long axis. The dorsal mesentery becomes attached along its left border and the ventral mesentery along its right border of the developing stomach. The greater curvature of the stomach develops from the left border and the lesser curvature from the right border.

Duodenum. This part of the intestinal tract is formed by the terminal part of the foregut and the cephalic part of the midgut. The junction of the two parts is located opposite the origin of the hepatic and pancreatic buds. Thus, the duodenum is derived partly from the foregut and partly from the midgut and this explains its arterial supply as it receives contribution from both coeliac artery and the superior mesenteric artery.

Intestine. The intestine is formed by the small section of the caudal end of the foregut and from entire midgut and hindgut. The midgut has got only dorsal mesentery. The vitello-intestinal duct is attached to the antimesenteric border. The midgut with its attached dorsal mesentery rapidly elongates, so that midgut makes a loop ventrally. The vitello-intestinal duct is attached to the apex of the loop. The concave side of the apex receives the vitelline artery a branch from the dorsal aorta. This is the future superior mesenteric artery. While the cranial and the caudal ends of the primitive intestinal loop are fixed the remaining part continues to elongate rapidly. The abdominal cavity for the time being, is too small to accommodate all the intestinal loops. As a result, the loops enter the extra-embryonic coelom in the umbilical cord during the 6th week of development. The primitive intestinal loops start to rotate along the axis formed by the superior mesenteric artery. The rotation is counter clockwise and is through 270° to 360°. The elongation is most marked in the small intestine and consequently the jejunum and ileum form coiled loops. Large intestine, however, fails to participate in the coiling phenomena. As the mesonephric tubules disappear, the liver is reduced in its bulk and with the actual expansion of the abdominal cavity, the herniated intestinal loops return to the abdominal cavity during the 10th week of development. The proximal part of the jejunum is the first to re-enter and comes to be situated on the left side of the abdomen. Later returned loops gradually settle more and more to the right.

Jejunum and ileum. The midgut of the embryo gives rise to the continuous segment of the gut extending from the middle of the second part of the jejunum to a point at the junction of the proximal 2/3rd and distal 1/3rd of the transverse colon. The entire jejunum and the greater part of the ileum are developed from the proximal limb of the midgut. The ileum is developed from the caudal limb of the midgut which extends from the apex of the loop to the caecal rudiment.

Large intestine. The large gut is developed from the greater portion of the caudal limb of the midgut loop. The caecum, the appendix, the ascending colon and the proximal 2/3rd of the transverse colon are developed from the caudal limb of the midgut. The remaining portion of the large intestine, i.e., distal 1/3rd of the transverse colon, descending colon, pelvic colon and the rectum are developed from the hindgut.

Anal canal. The hindgut ends in a blind sac known as cloaca. On its ventral aspect, the entoderm of the cloaca is in direct contact with the ectoderm. These two layers from the cloacal membrane. The primitive streak lies dorsal to the cloaca. A coronally disposed mesodermal septum divides the cloaca into a dorsal component, the rectum, and the ventral component, the urogenital sinus. The urorectal septum finally reaches and fuses with the cloacal membrane during the 7th week. The cloacal membrane is divided into two parts:

1. The dorsal part forms the anal membrane which breaks down towards the end of the second month and thus the hindgut becomes continuous with the amniotic cavity.

The anal membrane lies in the floor of the surface depression, lined by ectoderm. This surface depression is known as the anal pit. The adult anal canal is derived from the ectodermally lined pit and from the terminal part of the endodermally lined hindgut.

2. Ventral membrane—which forms the hymen.

Development of important endocrine glands

Pituitary gland. Hypophysis cerebri is developed from two distinctly separate components. An outgrowth from the stomodeum immediately in front of the buccopharyngeal membrane is known as Rathake's pouch and is lined by ectoderm (FIG. 9.13).

The downward extension from the floor of the diencephalon forms the infundibulum. By the end of the second month, Rathake's pouch is in contact with the stomodeum and is closely applied to the infundibulum. The cells in the anterior wall of the Rathake's pouch proliferate to form the anterior lobe of the hypophysis. The anterior lobe of the hypophysis produces a small extension, pars tuberalis which surrounds the infundibulum stock. The posterior wall of the Rathake's pouch develops into the

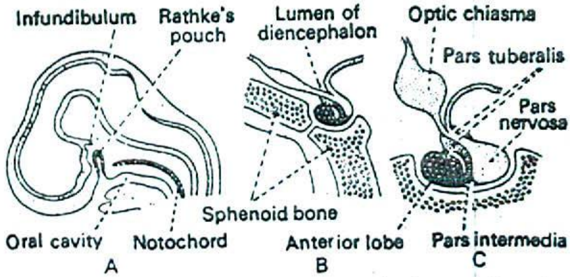

FIG 9.13. It shows the development of the hypophysis cerebri. A = sagittal section through the cephalic part of about a 6-week-old embryo. B = showing sagittal section through the developing hypophysis of about a 11-week-old embryo. C = representing sagittal section through the developing hypophysis of about a 16-week embryo.

pars intermedia. Rathake's pouch forms the anterior lobe of the hypophysis and infundibulum forms the posterior lobe of the gland.

Thyroid gland. On the floor of the primitive pharynx, behind and medial to the first arch, proliferation of extrapharyngeal mesoderm produces a median prominence, known as tuberculum impar.

A little caudal to the tuberculum impar, another swelling appears, flanked on either side by the ventral ends of the second, the third and the fourth arches (FIG. 9.14). This swelling is known as the hypobranchial eminence or copula of His.

In between the tuberculum impar and the hypobranchial eminence, an entodermal evagination, from the pharyngeal floor, grows down along the midline, in front of all the caudal arches, beginning with the second This midline solid entodermal cord of cells is the median thyroid diverticulum.

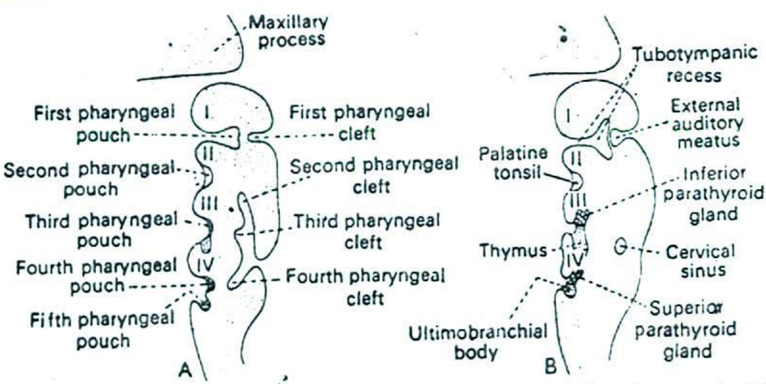

FIG. 9.14. Diagrammatic representation of the development of the pharyngeal clefts and pharyngeal pouches. A = early in the fifth weeks, before the formation of the cervical sinus. B = showing the temporary formation of the cervical sinus from the remnants of the second, third and fourth pharyngeal clefts. I, II, III and IV denote first, second, third, and fourth pharyngeal arches. Fifth pharyngeal pouch is atypical and often considered as part of the fourth pouch.

The median thyroid diverticulum at its caudal end, divides into two, each half giving rise to one of the two lobes of the thyroid gland.

In adult anatomy, a depression between the anterior two-thirds and the posterior third of the tongue marks the site of commencement of the median thyroid diverticulum. This depression is known as the foramen caecum.

Contribution of the fourth pharyngeal pouch towards the development of an adult thyroid is doubtful.

Adrenal gland. The adrenal gland consists of cortex and medulla. The cortex and medulla have different origins. The adrenal gland is formed by two components: (*i*) the mesodermal portion which develops into the cortex of the gland, and (*ii*) the ectodermal portion which forms the medulla of the gland.

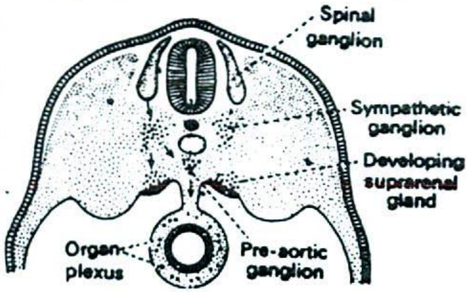

FIG. 9.15. Diagrammatic representation of the developing sympathetic ganglion

During the 5th week of development, mesothelial cells situated between the root of the mesentery and the developing gonad begin to penetrate the underlying mesoderm. These cells form large acidophylic masses which form the foetal or the primitive cortex of the suprarenal gland (FIG. 9.16 A). The definitive or the permanent cortex is derived from the coelomic endothelium in the same situation about a week after the formation of the foetal cortex. The cells of the permanent cortex are smaller than the cells of the foetal cortex. After birth, the foetal cortex undergoes rapid regression except for its outermost layer which forms the basophalic part of the postnatal cortex.

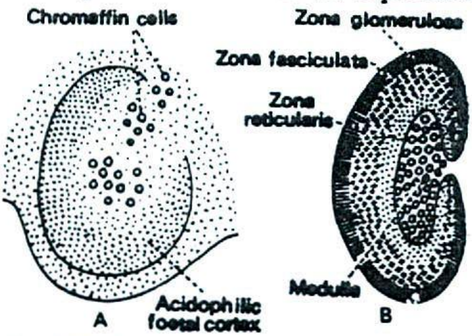

FIG. 9.16. Schematic representation of the development of the suprarenal gland. A = showing the penetration of chromaffin (sympathetic) cells into the foetal cortex. B = representing a late stage of development.

The medulla of the suprarenal gland is derived from the sympathetic nervous system. During the 6th or 7th week, cells originating from the sympathetic system invade the medial aspect of the cortex (FIG. 9.15). These cells will ultimately give rises to the medulla of the adult suprarenal gland (FIG. 9.16 B). These cells stain brown with chromic salts and hence are called chromaffin cells. These cells do not form the nerve processes.

Pancreas. The pancreas is developed from two primordia; a dorsal and a ventral pancreatic bud (FIG. 9.17 A). The dorsal pancreatic bud arises from the dorsal wall of the primitive duodenum. The ventral pancreatic bud arises from the hepatic diverticulum.

As the gut rotates and the common bile duct is bent to the right, the ventral pancreatic bud grows round the right side of the duodenum and soon merges with the dorsal bud. The adult pancreas is mainly derived from the dorsal pancreas which gives rise to most of the gland except the head. Most of the head of the pancreas arises from the ventral bud (FIG. 9.17 B).

The ventral duct persists as the main pancreatic duct (duct of Wirsung). The distal portion of the original dorsal duct persists and drains the tail of the pancreas by anastomosing with the ventral duct. The proximal part of the dorsal pancreatic duct is either obliterated or persists as a small channel as the accessory pancreatic duct of Santorini.

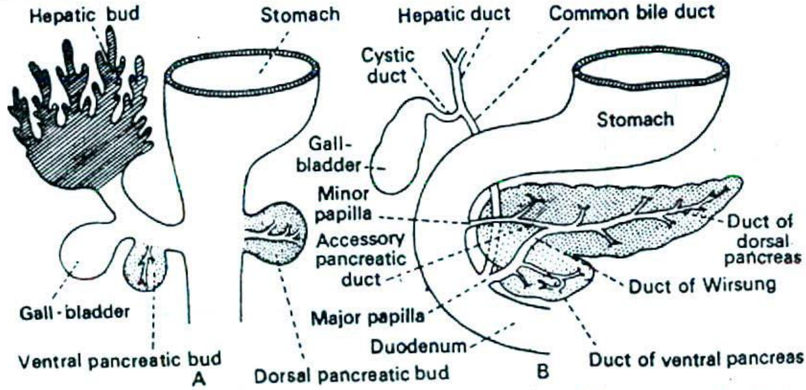

FIG. 9.17. Drawing showing the stages in the development of the pancreas. A = during 30 days of development. B = during 45 days of development.

Development of cardiovascular system

The entire development of heart is completed between the 21st and the 40th day of embryonic life within the span of twenty days. During this period, the embryo grows from 3 mm in length to approximately 15 mm (crown-rump length).

The first heart forming cells appear as irregular clumps and strands in the cephalic portion of the human embryo between the entoderm of the yolk sac and splanchnic mesoderm. When the embryo is 2–4 mm in length, the heart begins to pulsate. As the first somite appears these specialised clumps of cells from solid cords across the midline in front of the neural plate. As the embryo grows and the yolk sac folds off, the two cords of cells approach each other and acquire a lumen forming two endocardial tubes. The two endocardial tubes meet cranially, finally forming a single endocardial tube. The single tube gets invested with a layer of specialised cells called myoepicardial mantle. Between the myoepicardial mantle and endothelium of the primitive cardiac tube there is a layer of undifferentiated cells known as cardiac jelly.

The single cardiac tube lies in the pericardial cavity connected at two ends by dorsal and ventral mesocardium. The ventral mesocardium disappears first followed by the dorsal mesocardium.

The tissues dorsal to the single cardiac tube form the transverse sinus of the pericardial cavity.

The cardiac tube grows more rapidly than the pericardial cavity in which it lies. The two ends of the tube being fixed, the tube forms an U-shaped loop. The cephalic or the ascending loop of the tube forms bulbus cordis. The caudal or the descending loop gives rise to sinus venosus and the auricle.

Sinus venosus. The sinus venosus consists of: (*i*) transverse part—the median portion, (*ii*) right sinus horn, (*iii*) left sinus horn.

Each sinus horn receives (*a*) vitelline vein from the yolk sac, (*b*) umbilical vein from the placenta, (*c*) common cardinal vein from the embryo.

The left sinus horn rapidly disappears, the distal portion of the left sinus horn forming the oblique vein of Marshall of the left atrium. The proximal portion forms the coronary sinus. The definitive coronary sinus is finally situated in the right atrium being shifted by the development of the sino-atrial fold.

The right sinus horn increases rapidly in size, and is finally incorporated into the right atrium forming the sinus venarum—the smooth portion of the right atrium. The entry of the right sinus horn in the atrium is bounded on each side by right and left venous valves. Cranially and dorsally these valves fuse to form the septum spurium. The left venous valve is incorporated with i.. the atrial septum. The cranial portion of the right venous valve disappears. The caudal portion is divided into two parts: (*a*) the valve of the inferior vena cava or Eustachian valve, (*b*) the valve of the coronary sinus—Thebesian valve.

Interatrial septum. The division of the single atrial cavity into right and left begins at the 5 mm stage. A sickle-shaped septum grows down from the roof. This is known as the septum primum. The septum primum grows caudally and ventrally towards the endocardial cushion located at the commencement of the atrioventricular canal. The opening between the septum and the septum developing in the atrioventricular canal is known as ostium primum. The ostium primum is closed and the septum primum fuses with the partition formed in the atrioventricular canal. The upper part of the septum primum ruptures forming a new opening which is called ostium secundum.

Synchronously with these events another crescentic septum starts growing down from the roof of the atrium. This is known as the septum secundum. The free concave margin of the septum secundum overlies the ostium secundum which becomes the foramen ovale with septum secundum as the valve.

Atrioventricular valves. After fusion, the endocardial cushion divides the atrioventricular canal into right and left orifice. Each orifice is surrounded by localised proliferation of mesenchymal tissues. The tissue on the ventricular surface becomes hollowed out and form valves guarding the atrioventricular orifices.

Bulboventricular region and its partition. At the 5 mm stage a muscular ridge appears in the floor of bulboventricular region. This ridge forms the muscular part of the interventricular septum. The anterior limb passes towards the septum developing into the bulbus cordis. The posterior limb extends in the direction of the atrioventricular cushion.

The middle portion forms an upper concave border close to the primitive interventricular foramen.

During this period a pair of opposing ridges, the truncoconal ridges appear in the cephalic part of the truncus. These ridges take a spiral course. These two ridges ultimately fuse forming the aorticopulmonary septum. Due to the spiral disposition of the septum, the aorta and the pulmonary arteries are twisted round each other. In the distal area of the truncus the pulmonary artery is placed dorsally and to the left of the aorta. In the region of the conus, i.e., more proximally the pulmonary artery is ventral and to the right of the aorta.

By the end of the seventh week the interventricular foramen is closed by three components: (*i*) the left truncoconal ridge, (*ii*) the right truncoconal ridge, (*iii*) the posterior atrioventricular endocardial cushion.

It is in this trijunction, the basis of the foundation is laid of the membranous part of the definitive interventricular septum.

Arterial system

The first well-defined intraembryonic vessels to be formed are the right and left primitive aorta. They appear at 12 somite stage as continuation of the endocardiac tube. Both the primitive aorta are placed ventral to the foregut. They curve around the pharynx and continue caudally as the dorsal aortas.

Each dorsal aorta gives three sets of branches:

(*i*) Intersegmental arteries—to body wall.
(*ii*) Vitalline arteries—to the yolk sac.
(*iii*) Umbilical arteries—to the placenta.

Ventral portion of the two primitive aortas unite to form the aortic sac. The aortic sac gives paired branches to each of the developing pharyngeal arches. Six pairs of arteries from the aortic sac curve round the pharynx and join the primitive dorsal aortas on each side forming arches. All the six aortic arches are never present at the same time. The first pair of aortic arches disappear by the time the last or the sixth pair arises.

The aortic sac is partitioned in such a manner by the truncoconal septum that the aortic trunk continues into the third and fourth aortic arches while the pulmonary trunk opens into the sixth arches.

Vitelline arteries. Initially vitelline arteries are paired branches. Paired branches fuse, and run in the dorsal mesentery of the gut. In the adult these are represented by the coeliac, superior mesenteric and inferior mesenteric arteries.

Umbilical arteries. Initially they are paired ventral branches of the dorsal aorta and supply the placenta. During the second week, they loose their original origin and becomes connected with a dorsal branch of the aorta—the common iliac artery.

The proximal portion of the umbilical arteries are represented by the internal and superior vesical arteries. The distal portions of the umbilical arteries are represented by the lateral vesical ligaments.

Urogenital system

Urogenital system can be divided into the different parts—the urinary system and the genital system.

Embryologically and anatomically both the systems are closely related. Both develop from a common ridge formed by the cells of the intermediate mesoderm. The excretory ducts of both the system initially enter a common cavity called the cloaca.

In the males the primitive excretory duct, the mesonephric duct or the Wolffian duct functions temporarily as the urinary duct, later on becoming the definitive genital duct. In the females the primary excretory duct or the Wolffian duct regresses completely.

In the adult males, the urinary as well as the genital organs discharge their product outside through a common passage the urethra. The adult female is provided with two separate exists, the urethra and the vagina.

Urinary system

In the third week of development the intraembryonic mesoderm separates into three distinct parts: (*i*) The paraxial mesoderm—forming the somites. (*ii*) The lateral plate—which splits into the somatic and splanchnic layers enclosing the intraembryonic coelom. (*iii*) The intermediate mesoderm.

In the cervical segment, the intermediate mesoderm is segmented. In the thoracic region and further caudally it is an unsegmented mass of

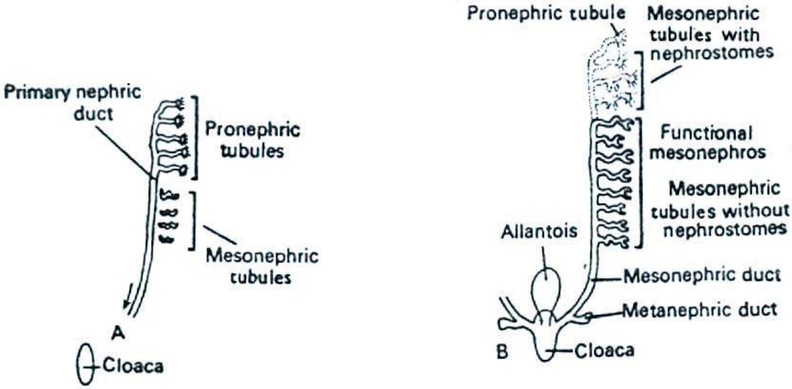

FIG. 9.18. Diagrammatic representation of the relation of the pronephric, mesonephric and metanephric system. In A a rudimentary pronephros consists of a group of tubules emptying, on either side (not shown), into the primary nephric ducts (=*pronephric ducts*). In B are shown approximately the conditions by the embryo towards the end of the 4th week.

cells, forming the nephrogenic cord. Excretory units of the urinary system arise from the nephrogenic cord. The collecting system arises from the duct of the nephrogenic cord, forming the mesonephric duct.

In the lower cervical and thoracic regions, the intermediate mesoderm forms nephrostomes. Each nephrostome acquires a lumen. Medially it opens into the intraembryonic coelom. Laterally, each nephrostome grows caudally and joins the succeeding one to form a longitudinal duct on each side of the embryo.

Three different, slightly overlapping kidney system are formed during the intrauterine life. These are (*a*) pronephros, (*b*) mesonephros, (*c*) metanephros (FIG. 9.18).

Pronephros. Pronephros consists of 6–7 rudimentary vestigeal tubules. These tubules are connected by a duct called pronephric duct. The pronephric tubules disappear by the end of the fourth week. The cranial portion of the pronephric duct also regresses. The caudal portion of the pronephric duct is taken over by the next generation of excretory primordia—the mesonephric tubules (FIG. 9.18 A). Henceforward the pronephric duct comes to be known as the mesonephric duct.

Mesonephros. During the regression of the pronephric tubules, the first tubules of the mesonephros begin to appear. These mesonephric tubules do not communicate with the intraembryonic coelom. These tubules lengthen rapidly and acquire an internal glomerulus at their medial extremity. At their opposite end the mesonephric tubules enter the pronephric duct, which becomes the mesonephric duct or the Wolffian duct (FIG. 9.18 B). The fate of the mesonephric duct or the Wolffian duct is different in the two sexes. In the males it forms the ductus deferens. In the females it disappears almost entirely.

Metanephros. During regression of the mesonephric tubules, the third generation of the urinary organ, the metanephros or the permanent kidney appears. The metanephros gives rise to the excretory system of the kidney. The collecting system of the kidney arises from a diverticulum from the caudal end of the mesonephric duct close to its entry into the cloaca. This diverticulum from the dorsomedial wall of the mesonephric duct, is known as the ureteric bud (FIG. 9.18). The ureteric bud grows dorsocranially and penetrates the metanephric mass. The metanephric blastoma forms a cap over the distal end of the ureteric bud.

The metanephros is initially situated in the lower lumbar and the sacral region. It shifts to more cranial position as the embryo grows. This so-called ascent of the kidney is caused by diminution of the body curvature as well as by the continued cranial growth of the ureteric bud. The metanephros starts functioning at the end of the pregnancy.

Bladder and Urethra. During the fourth to seventh week of development, the terminal part of the hindgut, the cloaca is partitioned by the downgrowth of the urorectal septum. The dorsal portion of the cloaca becomes the anorectal canal and the ventral portion of the cloaca becomes the primitive urogenital sinus. The urorectal septum by its downward growth fuses with the cloacal membrane. The cloacal membrane is thus divided into an anterior urogenital membrane and a posterior anal membrane.

Urogenital sinus. The mesonephric ducts enters the primitive urogenital sinus and divides it into an upper and a lower part. The upper part of the primitive urogenital sinus above the entrance of the mesonephric ducts forms vesicourethral canal. Below the level of the entrance of the mesonephric ducts, the primitive urogenital sinus becomes the definitive urogenital sinus. The termial parts of the mesonephric ducts, from where the ureteric bud arises, are gradually absorbed in the wall of the urogenital sinus. By this process of duct—absorption the ureters open into the part of the urogenital sinus which forms the base of the urinary bladder.

The development of the urogenital sinus differs in both the sexes.

Definitive urogenital sinus

Male	Female
(*a*) lower part of the prostatic urethra	(*a*) small portion of the urethra
(*b*) membranous urethra	(*b*) lower one-fifth of vagina
(*c*) penile urethra	(*c*) vestibule

Genital system

The sex of the embryo is determined at the time of the fertilisation. Definitive sex characters begins to develop by the seventh week of development (Fig. 9.19).

Gonadal ridge forms the earliest indication of definitive sex character. The gonadal ridges are formed by proliferation of the coelomic epithelium and thickening of the underlying mesoderm. These gonadal ridges are situated on each side of the mesonephros and the dorsal mesentery. Gonadal ridges are invaded by germ cells in the sixth week of development. Primordial germ cells appear in the third week in the wall of the yolk sac close to the allantois. The primitive germ cells are surrounded by primitive sex cords. Primitive sex cords are formed by the proliferation of the coelomic epithelial cells. At this stage the gonad is known as indifferent gonad, as sex differentiation is not yet possible. The indifferent gonads form the testis and ovary depending on the sex-identity of the embryo determined at the time of fertilisation.

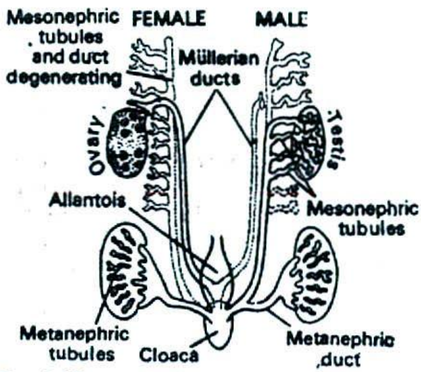

Fig. 9.19. It shows the conditions after sexual differentiation. Female left side and male right side of the drawing.

Genital ducts

In the sixth week of development, at the stage of indifferent gonads, there are two genital ducts: (*i*) Mesonephric or the Wolffian duct. (*ii*) Paramesonephric or the Müllerian duct—running parallel to the Wolffian duct and also entering the cloaca.

Depending upon the sex of the embryo, either the Wolffian duct or the Müllerian duct completes its development. If the embryo is male the Wolffian duct forms the main genital duct; if the embryo is female the Müllerian duct develops.

The Müllerian duct. This is formed by longitudinal invagination of the coelomic epithelium. The cranial end of the duct opens into the coelomic cavity. The caudal ends of the ducts join with each other. The common Müllerian duct opens into the cloaca. The two Müllerian ducts are initially divided by a septum. Later on the septum is absorbed and the combined portion of the Müllerian ducts forms the single uterovaginal canal.

The Müllerian duct can be divided into three parts:

(1) Cranial vertical portion with opens into the coelomic cavity (2) A horizontal part which crosses the Wolffian duct	Fallopian tube and its abdominal ostium.
(3) A caudal vertical part formed by the fusion of the two Müllerian ducts	Uterovaginal canal.

Though the female genital tract is formed mainly by the Müllerian ducts, remnants of the mesonephric system (tubules and duct) persist as vestigeal structures as (*i*) epoöphoron—remnants of the cranial mesonephric tubules, (*ii*) paroöphoron—remnants of the caudal mesonephric tubules.

The Wolffian duct. The development of the Wolffian duct has been described with the development of the urinary system. If the embryo is going to be a male the Wolffian duct persists and becomes the precursor of the adult male genital tract. If the embryo is going to be the female the Wolffian duct mostly disappears.

The Wolffian duct forms the vas deferens and the ejaculatory ducts.

In the male the Müllerian ducts completely disappears their remnants forming:

(*a*) Appendix of testes.
(*b*) Prostatic utricle.