Paparella: Volume I: Basic Sciences and Related Principles

Section 1: Embryology and Anatomy

Part 2: Head and Neck

Chapter 3: Embryology and Anatomy of the Head, Neck, Face, Palate, Nose, and Paranasal Sinuses

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Basic Embryology

Formation of the Foregut

The human embryo develops at the interface between two sacs, a dorsal amniotic sac and a ventral yolk sac. It consists, therefore, of a dorsal plate of ectoderm and ventral plate of endoderm. The ectoderm is thickened caudally to form a linear mass of cells, the primitive streak, which recedes caudally as growth in length of the embryonic disc occurs, and in so doing leaves behind a linear rod of cells subjacent to the midline ectoderm; this is the head process and is later converted into the notochord. Under the influence of the head process, the overlying midline ectoderm is induced to thicken first into a neural plate and later into a neural groove, from which the CNS is formed by a process of fusion. The intraembryonic mesoderm spreads out from the primitive streak and the head process to all parts of the embryonic disc except in two areas: the buccopharyngeal area anteriorly and the cloacal membrane posteriorly. In these two sites the ectoderm and endoderm remain in firm contact and later break down to permit continuity between the amniotic sac and the yolk sac at the mouth and at the anus, respectively. Anterior to the buccopharyngeal area, the mesoderm spreads across the midline, forming the primitive diaphragm or septum transversum in which the pericardium, the heart, and the associated great vessels are formed. Caudal to the cloacal membrane, the mesoderm is continuous with the mesoderm investing the amnion dorsally and the yolk sac ventrally on the one hand, and on the other hand with the body stalk through which vascular connections between the embryo and the placental structures are developed; the latter is subsequently converted into the umbilical cord.

The next important step in the development of the embryo by which its definitive internal and external form is established is the formation of the head and tail folds. The ectodermal surface of the embryo and the rapidly elongating neural tube grow more rapidly than does the yolk sac, with the result that the embryo as a whole begins to arch dorsally into the amniotic sac around an arbitrary axis marked anteriorly by the attachment of the amnion to the septum transversum and posteriorly by the attachment of the amnion to the cloacal membrane and body stalk. In this manner, the anterior and posterior ends of the embryonic disc begin to overhang the yolk sac, forming the head and tail folds, and at the same time the upper part of the yolk sac is incorporated bodily into the C-shaped embryonic body to form the gut cavity. The septum transversum containing the heart and pericardium is likewise carried caudally under the overhanging head of the embryo into its definitive position in relation to the diaphragm; the cloacal membrane and body stalk are carried cranially under the tail of the embryo.

Progressive closure of the connection (vitello-intestinal isthmus) between the intraembryonic part of the yolk sac (gut) and the extraembryonic part then takes place and the connection is ultimately obliterated. The peripheral part of the yolk sac takes no further part in development but becomes atrophic. Connections may persist between the yolk sac and the gut, in which case they form varieties of the so-called Meckel's diverticulum, usually found in the small intestine about 1 m proximal to the ileocecal valve. That part of the yolk sac incorporated anteriorly into the head fold forms the foregut; it ends caudally at an arbitrary point dorsal to the septum transversum and immediately caudal to the liver outgrowth or hepatic diverticulum (Fig. 1B). The hindgut is formed from that portion of the yolk sac incorporated caudally into the tail fold. The intermediate portion of the intraembryonic yolk sac forms the midgut. We are concerned in this chapter exclusively with the further development of the foregut. Its salient relationships are illustrated in detail in Figure 2.

The foregut is related dorsally to the central nervous system caudal to about the level of the hindbrain. The notochord lies between the roof of the foregut and the nervous system in a bed of mesoderm and has important relationships anteriorly, where it ends immediately caudal to the dorsal attachment of the buccopharyngeal membrane. Rathke's pouch, the primordium of the anterior pituitary, lies immediately anterior to the buccopharyngeal membrane, arising as an upgrowth of the dorsal ectoderm of the mouth or stomodeum. Thus, the notochord in the adult may be considered to terminate anteriorly in the body of the basisphenoid immediately posterior to the sella turcica. Here, tumors of the notochord (chordomas) may be found in relation to the base of the skull and the roof of the pharynx. Here, also, tumors of the anterior pituitary (craniopharyngiomas) or benign rests and adenomas of the pituitary may be found.

The foregut is related ventrally to the roof of the pericardium and more caudally to the septum transversum (Fig. 2). Two outgrowths of the foregut into these mesodermal beds dorsal to the foregut are observed: the laryngotracheal groove (primordium of the tracheal and pulmonary diverticula) and the hepatic diverticulum (primordium of the liver and gallbladder). Laterally, the foregut is limited by a thick wall of mesoderm in which the branchial or pharyngeal arches are developed. These arches are five in number and superficially resemble the gill arches of a fish (see Fig. 4A). The arches are separated by external grooves, also reminiscent of the gill slits of fishes. The external grooves do not, however, communicate at any stage with the cavity of the foregut as in fish. The external branchial or pharyngeal arches correspond on the inside of the foregut to a set of internal arches also separated by internal pharyngeal grooves (see Fig. 15). A transverse section of the foregut at the level of the primitive pharynx is shown in Figure 3. The section passes through a pharyngeal arch on the right side and through an external and internal groove on the left side. The plate of apposed ectoderm and endoderm in the depth of the internal and external grooves is the closing membrane. A typical branchial or pharyngeal arch artery and nerve are shown on the right of the figure.

Further Development of the Foregut and the Evolution of the Pharyngeal (Branchial) Arches

The primitive foregut is converted by subsequent elongation and growth into the pharynx, esophagus, stomach, and proximal part of the small intestine as far caudally as the origin of the bile duct. All these parts of the foregut are surrounded by mesoderm and are also related ventrally either to the mesoderm in the roof of the pericardium or of the septum transversum. The pulmonary outgrowths arise from the ventral wall of the caudal pharynx (hypopharynx).

The pharyngeal arches, as stated previously, are five in number and are counted cranial to caudal, beginning with the first or mandibular arch immediately caudal to the mouth or stomodeum. The fifth arch does not appear on the surface but lies buried around the site of origin of the laryngotracheal outgrowth. It is conventionally called the sixth arch for reasons of evolution and comparative anatomy, which cannot be discussed here. The arches are thus described as follows: first (mandibular) arch, second (hyoid) arch, third arch, fourth arch, and sixth arch. Since the arches consist of mesoderm, they are capable of differentiating into a variety of tissues, i.e., connective tissue, cartilage, bone, blood vessels, and muscle. Nerves from the overlying ectodermal nervous system grow into the arches but are not differentiated from them.

Skeletal Derivatives of the Pharyngeal Arches

Cartilaginous bars are differentiated in each of the pharyngeal arches. The fate of each of the arch cartilages is as follows:

First (Mandibular) Arch. The cartilage of this arch is known as Meckel's cartilage. It extends dorsally to make contact with another cartilaginous mass surrounding the otocyst or primordium of the inner ear, the otic capsule. It extends ventrally to fuse with the opposite cartilage in the floor of the pharynx. Meckel's cartilage becomes enveloped by membrane bone, which forms the body of mandible and disappears without trace from the level of the lingula to the mental tubercles. Dorsal to the lingula, Meckel's cartilage becomes converted into the sphenomandibular ligament (Meckel's ligament), the anterior ligament and process of the malleus, the malleus and the incus.

Second (Hyoid) Arch. The cartilage of this arch, much slenderer than that of the first, is like it in that it also reaches the otic capsule dorsally and meets its fellow in the midline ventrally. It becomes converted into the upper part of the body of the hyoid bone, the lesser cornu of the hyoid bone, the stylohyoid ligament, the styloid process, and possibly the stapes. There is evidence in lower forms that the stapedial homologue develops not from the second arch but independently from the otic capsule.

Third Arch. This cartilage meets with the opposite arch in the floor of the pharynx but falls short of the otic capsule dorsally. It is converted into the lower part of the body and the greater cornu of the hyoid bone.

Fourth Arch. This arch cartilage is also limited to the ventral mesoderm of the pharynx and becomes converted into the thyroid cartilage and associated ligamentous structures.

Sixth Arch. This cartilage is small in extent and is transformed into the cricoid cartilage, the arytenoid cartilages, and the small accessory cartilages of the larynx.

Thus, the phylogenetically ancient suspensory and respiratory cartilages of the pharynx undergo a remarkable evolution in mammals in which their identity is maintained but their function is entirely altered. The skeletal structures of the cranial vault, the face, and the jaws are formed by phylogenetically new bone, called dermal bone since it is formed "in membrane", i.e., in mesoderm surrounding the brain, the eyes, the nose, and the face. The old branchial cartilages become superseded in this supportive function and either disappear or are transformed into new structures of peculiar importance and function in terrestrial mammals. Thus, the meckelian and hyoid cartilages become transformed into the ossicles of the middle ear. The rest of the hyoid cartilage and the third arch cartilage take on important functions in relation to the hyoid suspensory apparatus and swallowing. The fourth and sixth cartilages form the supporting and functional cartilages of the larynx.

Nerves of the Pharyngeal Arches

The arches become penetrated at an early stage by nerve fibers of the cranial nerves, which establish functional connections with the muscles and other structures within the arches, including the overlying skin.

First Arch. The nerve of the first arch is the trigeminal or fifth cranial nerve. The proper nerve of the arch is its third or mandibular division. The first and second divisions of the nerve do not enter the arch but pass in front of the eye and mouth, respectively, as the ophthalmic and maxillary nerves. The ganglion of the fifth nerve is large (gasserian ganglion). The motor branches of the nerve are distributed only through the mandibular division. The muscles innervated by this division, and so developmentally derived from the first arch mesoderm, are the muscles of mastication (masseter, temporalis, medial and lateral pterygoids), the anterior belly of the digastric and mylohyoid, the tensor tympani, and the tensor veli palatini.

Second Arch. The nerve of this arch is the facial or seventh cranial nerve. Its ganglion (geniculate) is small and lies in relation to the otic capsule. A small branch of the facial nerve, the chorda tympani, passes into the first arch and joins the mandibular branch of the first nerve. It is called a "pretrematic nerve" (in front of the gill slit) since it passes into the arch next anterior to its proper arch; it is described in connection with the development of the middle ear. The muscles innervated by the facial nerve, and so of second arch origin, are the platysma and the muscles of facial expression - the stylohyoid, the posterior belly of the digastric, and the stapedius.

Third Arch. The third arch nerve is the glossopharyngeal or ninth cranial nerve. It has two small sensory ganglia. It also has a small "pretrematic" branch, the lesser (superficial) petrosal nerve, which will be described in connection with the middle ear. The muscles supplied by the ninth nerve are the stylopharyngeus and the upper (superior and middle) constrictor muscles of the pharynx.

Fourth Arch. The nerve of the fourth arch is the superior laryngeal branch of the vagus (tenth cranial nerve). This nerve has a sensory component (internal branch), supplying the mucosa of the laryngopharynx and larynx as far down as the true vocal cords, and a motor branch (external branch), which supplies the cricothyroid muscle.

Sixth Arch. The nerve of the last arch is the inferior (recurrent) laryngeal branch of the vagus nerve. It supplies all the intrinsic muscles of the larynx, the inferior constrictor muscle (wholly or in part), and the upper fibers of the esophagus as well as the mucous membrane of the larynx below the vocal cords and that of the lower pharynx and upper esophagus.

The position of the pharyngeal arch nerves in the adult is fixed in relationship with the skeletal derivatives of the arch cartilages. Thus, the mandibular branch, with its two terminal divisions (lingual and inferior alveolar or dental), lies internal to the sphenomandibular ligament within the pterygoid region. The facial nerve (of the second arch) lies immediately lateral to the base of the styloid process after emerging from the stylomastoid foramen. The glossopharyngeal nerve (of the third arch) lies deep and posterior to the stylopharyngeus muscle and then enters the tongue in the angle between the stylohyoid ligament and the greater cornu of the hyoid bone. The internal branch of the superior laryngeal nerve (of the fourth arch) lies ion the thyrohyoid membrane in the interval between the greater cornu of the hyoid bone and the upper margin of the thyroid cartilage. The inferior or recurrent laryngeal nerve (of the sixth arch) lies in the groove between the esophagus and the trachea and enters the larynx posterior to the cricothyroid joint under cover of the thyroid cartilage. The reason for the devious course of this nerve will be explained later in this chapter.

Arterial Derivatives of the Pharyngeal Arches

Five arteries are developed within the mesoderm of the arches. The vessels arise by the confluence of small vascular islands within the mesoderm (angioblastic islands) and are formed one after the other in cranial to caudal sequence. All five vessels are probably not found at any one stage, since the first and second arterial arches degenerate before the third and subsequent arteries are formed. The arteries arise from the ventral aorta in the roof of the pericardium and pass dorsally through the arch to unite with the dorsal aorta on either side. The dorsal aortae pass cranially to supply the rapidly developing forebrain and midbrain. They unite at a level caudal to the arch field to form a single dorsal aorta from which the arteries of the foregut (celiac axis), to the midgut (superior mesenteric), and to the hindgut (inferior mesenteric) arise in sequence. Small intersegmental arteries are given off from the dorsal aortae along the length of the embryo, passing between the segmental mesodermal blocks (somites), which later take part in the formation of the vertebrae; they supply the spinal cord and postvertebral skin and musculature. The arrangement of the pharyngeal arch (branchial aortic) arteries is strikingly similar to that in a primitive vertebrate such as the dogfish.

The flow of blood in the pharyngeal arch arteries is dorsally from the heart into the dorsal aortae. The fused dorsal aortae give rise caudally to two umbilical arteries through which the deoxygenated blood is carried to the placenta. It is returned as oxygenated blood to the heart by the umbilical veins.

Note that in every instance but one the pharyngeal arch nerves come to lie *anterior* to their respective arch arteries. The exception is the nerve of the sixth arch (inferior or recurrent laryngeal), which lies *posterior* to its respective arch artery. This exceptional circumstance has important consequences in relation to the adult course of this nerve.

The first and second arteries become atrophic and disappear probably before the third and more caudally placed arch arteries are fully formed. The dorsal segment of the second arch artery persists for a time during fetal life as the "stapedial artery", passing through the crura of the stapes, which are ossified around the vessel. This artery may rarely persist in the adult and may cause bleeding during operations on the middle ear and during mobilization of the stapes. In some animals, the vessel persists normally and takes part in the blood supply of the intracranial structures. The third arch artery becomes the proximal part of the internal carotid artery. The dorsal aorta cranial to the third arch artery forms the remaining part of the internal carotid artery, including its intracranial portion. The external carotid artery develops late as a small offshot of the ventral part of the third arch artery and passes cranially to supply the face and jaws. The short segment of the third arch artery proximal to the origin of the external carotid artery elongates and becomes the common carotid artery. Note that the trigeminal, facial, and glossopharyngeal nerves pass into their respective arch structures *lateral* to the dorsal aorta, and so lateral to the internal carotid artery; these cranial nerves are found in this relationship to the great vessels in the adult.

The fourth arch artery is transformed into the arch of the aorta. The dorsal aorta connecting this vessel to the third arch artery disappears. The left subclavian artery is developed from a persisting seventh intersegmental artery arising from the dorsal aorta and passing into the primordium of the forelimb. The vertebral artery is formed as a longitudinal anastomotic connection between the seventh intersegmental artery (subclavian) caudally and the individual intersegmental arteries cranial to this. That portion of the vertebral artery curving posteriorly and medially around the lateral mass of the atlas to enter the foramen magnum lateral to the medulla oblongata represents a persisting first or perhaps second intersegmental artery. Note that the internal branch of the superior laryngeal nerve (fourth arch nerve) also descends lateral to the internal carotid artery and enters the larynx through the thyrohyoid membrane.

The sixth arch artery on the left forms a large and important vessel in fetal life. Soon after the appearance of the lung diverticulum from the floor of the pharynx, a small pulmonary artery is given off from the caudal face of the sixth arch artery. Distal to this point, the sixth arch artery persists in fetal life as the ductus arteriosus. This important shunt provides a "bypass" for the deoxygenated blood from the right ventricle, returning it quickly to the placenta without passing through the lungs, which are not functional. The flow of blood in this vessel is reversed at birth following inflation of the lungs and expansion of the pulmonary vascular bed. The ductus arteriosus remains open during the postnatal period of adjustment to fluctuating right and left ventricular pressures and then undergoes an endarteritis, which obliterates its lumen. In about 1 per cent of newborns, the ductus remains patent as late as the end of the first year. In abnormal cases, it may remain widely patent in the adult, giving a characteristic "machinery murmur" on auscultation. Right ventricular decompensation and congestive heart failure supervene in later adult life unless the vessel is closed surgically.

Note that the inferior or recurrent laryngeal nerve (nerve of the sixth arch) is found caudal to its proper artery. Since the sixth arch artery persists as the ductus arteriosus, the recurrent laryngeal nerve curves around this vessel on its caudal or inferior surface before assuming its final position in the groove between the esophagus and the trachea. Its final entry into the larynx is through the cricothyroid interval, that is, between the derivatives of the fourth and sixth arch cartilages. The ductus arteriosus becomes converted in the adult into the ligamentum arteriosum, which connects the left pulmonary artery to the undersurface of the aortic arch. The recurrent laryngeal nerve is properly described as curving around the ligamentum arteriosum rather than around the arch of the aorta.

On the right side the first and second arch arteries disappear, as on the left side, with the possible exception of the persisting "stapedial artery". The third arch artery is converted into the internal carotid artery. The right fourth arch artery forms the proximal segment of the subclavian artery up to its point of union with the dorsal aorta. Beyond this point, the right subclavian artery is developed from the seventh intersegmental artery, which passes into the limb bud. Thus, on the left side, the subclavian artery is formed only from the seventh intersegmental artery; on the right side, it is formed from the fourth arch artery and also from the seventh intersegmental artery. The sixth arch artery gives off a small pulmonary artery, as on the left side. Dorsal to this point, however, the sixth arch artery disappears, so that there is no ductus arteriosus on this side. The effect of this on the position of the right recurrent laryngeal nerve is to cause it to curve around the next most cranial persisting arch vessel (the fourth), in this case the subclavian artery. The external carotid and vertebral arteries are developed as on the left side.

Note that the vessels arise from the ventral aorta *ventral* to the pharynx; they join dorsally on either side to form dorsal aortae, which fuse caudally *dorsal* to the esophagus. In a real sense, therefore, the persisting arch vessels (internal carotid, aorta, ductus arteriosus, right subclavian) embrace the lateral surfaces of the esophagus.

Nonrecurrence of the Right Inferior Laryngeal Nerve

This not infrequent anomaly is accidentally discovered during thyroidectomy and is *invariably* associated with a retroesophageal right subclavian artery. This anomalous vessel arises distally from the aorta beyond the attachment of the ligamentum arteriosum. The anomaly arises as a persistence of the right dorsal aorta distal to the origin of the seventh intersegmental artery (right subclavian). The sixth arch artery on this side disappears distal to the point of origin of the pulmonary artery. Thus, the recurrent laryngeal nerve on this side is now shifted cranially and curves anteriorly around the next most cranial persisting arch artery, in this case the right internal carotid artery. The nerve accordingly descends almost vertically in relation to the internal carotid artery and enters the larynx through the cricothyroid interval. A necessary corollary of this variation is the existence of a right subclavian artery, which arises from the dorsal artery beyond the left subclavian artery and passes to the right behind the esophagus. These two variations must coexist, and without the other is embryologically impossible. Aortograms in cases of nonrecurrence of the left inferior laryngeal nerve will always reveal a retroesophageal right subclavian artery. The latter may be symptomless or may cause dysphagia. The abnormal course of the left laryngeal nerve also predisposes it to possible damage during thyroidectomy.

In situs inversus, the thoracic and abdominal viscera are reversed in position, and in these instances there is a persistence of the right dorsal aorta rather than the left. The ductus arteriosus is then found on the right side. The inferior laryngeal nerve on the right turns around the abnormal ductus, and the nerve on the left side turns around the subclavian artery.

Evolution of the Great Veins of the Head and Neck and Thorax

Pattern of veins in the early human embryo at abut the fifth week of development is rather simple. A bilaterally symmetric system of venous channels, the cardinal system, empties into the caudal chamber of the heart or sinus venosus within the septum transversum. Anterior cardinal veins on either side drain caudally from the head region. Posterior cardinal veins from the caudal parts of the embryo join with the anterior cardinal veins to form a large venous channel on either side - the common cardinal veins or ducts of Cuvier that enter the lateral horns of the sinus venosus. Also emptying caudally into the sinus venosus are two bilaterally symmetric systems of veins, the umbilical (right and left) and the vitelline (right and left). The former are the placental veins, which convey oxygenated blood from the placenta to the heart; the latter are the veins of the yolk sac.

At later stage the pattern of veins is modified. The right anterior and common cardinal veins become enlarged, while the left common cardinal system is reduced. This relative preponderance of the right over the left cardinal system is associated with the development of a massive venous shunt between the anterior cardinal veins anterior to the trachea. This is the left innominate (left brachiocephalic) shunt, which becomes the adult vein of the same name. At the same time the posterior cardinal veins become reduced in size on both sides, and their former function of receiving the intersegmental venous drainage of the body wall is taken over by a new and more dorsally placed system of veins, the supracardinal or perisympathetic veins.

Complex changes also occur in the veins entering the sinus venosus from the body wall and yolk sac. The four veins (two umbilical and two vitelline), which formerly entered the sinus venosus, no longer do so; instead, a single vein, usually considered to be the terminal portion of the right vitelline vein, is the only one to enter the chamber at this level. This short vessel forms the terminal segment of the inferior vena cava. The development of this great vessel more caudally is of no concern in relation to this chapter. The right umbilical vein disappears and the left umbilical vein enlarges to become the single definitive placental vein.

The final disposition of the great vein is shown in Figure 12 C. The right anterior cardinal vein, as low as the right seventh intersegmental vein (subclavian), forms the right internal jugular vein. The right anterior cardinal vein caudal to the subclavian vein forms the right innominate (brachiocephalic) vein. The left anterior cardinal likewise forms the left internal jugular vein as low as the left seventh intersegmental vein (subclavian); these two veins fuse to form the left innominate (brachiocephalic) vein. The latter passes across the midline anterior to the trachea and unites with the right innominate vein to form the superior vena cava. The right posterior cardinal vein persists as the part of the azygos vein, which arches over the root of the right lung. The distal portion of the azygos vein, which receives the intersegmental drainage (intercostal) of the body wall, is developed from the supracardinal or perisympathetic plexus of veins (Fig. 12B). The right superior intercostal vein, a vessel of considerable radiologic importance, is also of supracardinal origin and drains into the azygos vein above the root of the lung. It is of interest that in rare cases the lung, in its growth into the thoracic wall, may encounter the azygos vein, and a portion of the upper lobe may be entrapped medial to this vessel, forming an azygos lobe (see Chapter 4). This condition is usually an incidental finding on radiologic study and is without symptoms. The right common cardinal vein forms the terminal segment of the superior vena cava, which passes into the pericardium and enters the right atrium.

On the left side, the common cardinal vein forms the coronary sinus. More cranially, the coronary sinus is continuous with the oblique vein of the left atrium (vein of Marshall) and still more cranially with a fibrous remnant homologous with the superior vena cava, the ligamentum venae cavae sinistrae. The latter is attached to the undersurface of the left innominate vein and represents a portion of the anterior cardinal vein. As on the right, the supracardinal system persists as the left superior intercostal vein and the hemiazygos system.

Anomalies of the great veins are common and are of importance to the practicing otolaryngologist. Persistence of the left superior vena cava may occur, in which case there is absence of the coronary sinus and of the left innominate vein. The anomalous vessel passes down the back of the left atrium to enter the right atrium at the normal site of the coronary sinus, which it replaces. It usually causes no symptoms but may present anatomic difficulties during open heart surgery. The pulmonary veins, which normally arise as endothelial outgrowths of the posterior wall of the left atrium, may also arise abnormally from the wall of such an anomalous left superior vena cava or from any other convenient systemic vein (eg left innominate, subclavian, inferior vena cava, azygos). These aberrant pulmonary veins are of importance in that they may represent a significant or total "left to right" shunt of pulmonary venous blood. Anomalies of the azygos and hemiazygos veins are legion and are usually important.

Development of the Pharyngeal Pouch System

A striking feature of the development of the pharynx is the origin of the principal endocrine glands of the head and neck (thyroid, parathyroid) and of the large lymphatic organs such as the tonsil and thymus in relation to endodermal diverticula. It must be presumed that in the early evolution of these glandular structures in vertebrates, they developed as endodermal diverticula of the foregut. It will be recalled that the lumen of the primitive pharynx conforms to the external and internal configuration of the mesodermal pharyngeal arches. Thus, the pharynx is relatively narrow from side to side at the level of arches and is extended laterally in the form of recesses or pouches in the grooves between the arches.

The pharynx is seen to be wide anteriorly in relation to the arches and pouches, and to narrow posteriorly (hypopharynx) at the level of the pulmonary outgrowth. There are four pouches, which are numbered from cranial to caudal. A rudimentary sixth pouch is an appendage of the fourth pouch and has no independent communication with the pharyngeal lumen. The third arch artery (internal carotid) passes dorsally between the second and third pouches, the fourth arch artery between the third and fourth pouches, and the sixth arch artery between the fourth pouch and its (sixth) appendage on the one hand and the wall of the hypopharynx on the other. The thyroid is shown arising as a midline diverticulum of the floor of the pharynx and so is not a pouch derivative.

In later stage of their development, the pouches become separated from the wall of the pharynx, and their connections with the pharyngeal lumen become drawn out into elongated pharyngobranchial ducts. The first and second pouches merge to form the tubotympanic recess, from which the middle ear and eustachian tube are differentiated. The ventral component (wing) of the second pouch does not take part in the formation of the tubotympanic recess but forms an isolated pocket around which lymphatic cells later congregate, forming the palatine tonsil. The ventral remnant of the second pouch is represented in the adult by the intratonsillar fossa.

The third, fourth, and sixth pouches give rise to important glandular structures by a process of epithelial (endodermal) proliferation and differentiation. The dorsal wing of the third pouch gives rise to parathyroid III, so called because of its origin. The dorsal wing of the fourth pouch gives rise to parathyroid IV. The ventral wing of the third pouch proliferates to form the thymus. The thymus becomes greatly elongated and extends into the superior and anterior mediastinum of the thorax. In this later growth and caudal displacement, the parathyroid associated with it (parathyroid III) is also displaced caudally. Thus, the parathyroid derived from the third pouch becomes the inferior parathyroid of the adult, though it is developmentally the more cranial of the two parathyroids. Parathyroid IV remains at a more cranial level and is the superior parathyroid of the adult. Rarely, a rudimentary thymus may develop from the ventral wing of the fourth pouch, forming an accessory thymus in relation to the superior parathyroid.

The sixth pouch, observed previously as an appendage of the fourth pouch, gives rise to the ultimobranchial body. This conspicuous spherical body differentiates into glandular tissue that resembles fetal thyroid tissue. Its subsequent fate is unknown. In the pig, it is conspicuous at birth and resembles embryonic thyroid tissue.

It is now known that the ultimobranchial body gives rise to the interfollicular cells of the adult thyroid, which secrete thyrocalcitonin.

Development of the Cervical Sinus

Closely bound up with the development of the pharyngeal pouches, which are of endodermal origin, is that of the cervical sinus (cervical sinus of His), which is derived from the ectoderm. At first, the external pharyngeal arches from the first to the fourth are visible; the sixth is buried beneath the surface. At a slightly later stage there is a relative caudal growth and enlargement of the first and second arches in such a way that the third and fourth arches become submerged in a shallow ectodermal pit, the cervical sinus. The depth of this pit is further enhanced by the appearance of a V-shaped swelling caudal to the arch field, the epipericardial ridge. The V lies on its side with the point facing caudally and the arms of the V embracing the caudal arches anteriorly. The epipericardial ridge is raised up by the proliferation of the underlying mesoderm, in which the musculature caudal to the arch field is differentiated (sternomastoid-trapezius complex), the infrahyoid muscles, and the muscles of the floor of the mouth and tongue. Contained within this mesodermal ridge are the spinal branch of the accessory (eleventh) and the hypoglossal (twelfth) cranial nerves. These nerves are not properly cranial nerves but belong to the cranial group of spinal nerves that are presumed to have been incorporated into the skull in the process of the evolution of mammals. The caudal growth of the second or hyoid arch, which is innervated by the seventh cranial nerve, resembles the growth of the so-called operculum in the bony fishes, which overhangs and partially occludes the underlying gill slits. Thus, the earlier stage resembles the cartilaginous fish or "sharklike" stage of human ontogenesis; the later stage resembles the bony fish stage.

The approximate area of the cervical sinus is in the angle between the limbs of the epipericardial ridge. The upper and caudal limb of the V is represented by the trapezius and sternomastoid muscles. The inferior limb of the V is represented by the infrahyoid muscles, the muscles of the floor of the mouth, and the intrinsic muscles of the tongue. The arch field, represented in the adult by the mandibular structures, the hyoid bone, and the thyroid and cricoid cartilages, is contained within the angle made by the two muscular limbs of the epipericardial ridge. The arching course of the hypoglossal nerve lateral to the internal and external carotid results from the differentiation of the epipericardial ridge caudal to the arch field; the nerve subsequently migrates cranially until it is arrested by the lower sternomastoid branch of the occipital artery. The loop of the ansa hypoglossi, containing fibers of the first, second, and third cervical nerves, is also determined by the ridge. The patterns of fibers from the platysma muscle, innervated by the facial nerve, which overlie the arch field and sweep down onto the anterior part of the upper thorax, result from the growth and migration of second arch mesoderm lateral to the arch field. It is evident from a consideration of the above developmental facts that any persisting connection between the surface and the cervical sinus, or between the latter and the deeper endodermal pouches of the pharynx, must lie deep to the platysma muscle and also must lie anterior to the derivatives of the epipericardial ridge and the hypoglossal loop.

The cervical sinus is formed by the caudal extension of the second arch and the raising of the epipericardial ridge caudally. The effect of this process is to close off from the surface an ectodermally lined pit, in the floor of which are the third and fourth arches and the related closing membranes. The hypoglossal nerve and branches of the spinal accessory and upper cervical nerves are contained within the epipericardial ridge and so lie caudal to the arch field. The cervical sinus is eventually cut off from the surface by the closure of the external orifice; the sinus itself is obliterated and normally no trace of it remains.

Persistence of the Cervical Sinus

Lateral Cysts of the Neck. The cervical sinus may persist, clinically recognized as a lateral cyst of the neck. The cyst is of ectodermal origin and so is lined by epidermal epithelium, which, by desquamation, may produce a cholesteatoma. The cyst is also prone to repeated infection and to malignant change, giving rise to an epidermoid carcinoma. Its complete removal is, therefore, imperative. The cyst differs from the midline cysts of the neck (usually of thyroglossal cyst origin) in that it does not move on swallowing. Fistulous connections between the cyst and the surface may exist, in which case they may exude cholesterol-like material, pus, or infected material. The orifice lies at some point along the anterior surface of the MSCM, as would be expected from the manner of its development. The cyst itself lies deep to the platysma, since the latter is a second arch derivative. It also lies in close relationship to the carotid sheath.

Connections with the second endodermal pouch are the most common. Connections with the third pouch are probably rare but possible. Connections with the fourth pouch must be very rare, if they occur at all.

Connection of Cervical Sinus Cyst with Second Pouch. The tract ascends from the cyst along the carotid sheath until it reaches the hypoglossal nerve above the hyoid bone lateral to the internal and external carotid arteries and the loop of the lingual artery. Note that the hypoglossal nerve is tethered by the small but important lower sternomastoid branch of the occipital artery. This vessel, considered to be a persisting intersegmental artery, may be absent, in which case the hypoglossal nerve descends almost vertically from the base of the skull. The fistulous tract loops over the hypoglossal nerve since the nerve belongs to the epipericardial ridge and not the arches. It then pierces the pharyngeal wall at the level of the middle constrictor muscle and opens into the intratonsillar fossa, which is the remnant of the ventral wing of the second pharyngeal pouch. Note that the tract must necessarily pass anterior to the internal carotid artery (third arch artery) and so between the fork of the internal and external carotid arteries. It must also pass cranial to the third arch nerve, in this case the ninth (glossopharyngeal) nerve. Damage to this nerve must be avoided.

Connection of Cervical Sinus Cyst with Third Pouch. The course of the cyst and of the fistulous tract over the loop of the hypoglossal nerve is as in the previous case. However, the tract in this case passes posterior to the internal carotid artery (artery of the third arch). It then descends in close relation to the pharyngeal wall caudal to the glossopharyngeal nerve. It pierces the thyrohyoid membrane between the hyoid bone (third arch) and the thyroid cartilage (fourth arch) to enter the pharynx in the region of the pyriform sinus, generally held to be the approximate site of the third endodermal pouch. The tract pierces the thyrohyoid membrane cranial to the internal branch of the superior laryngeal nerve (nerve of the fourth arch).

Theoretic Connections Between the Cervical Sinus and the Fourth or Sixth Pouches. Connections between the cervical sinus and the caudal pouches are theoretically possible but are not described in the literature. The characteristic loop of the tract over the hypoglossal nerve could scarcely survive the extensive caudal displacement of the arteries of the fourth and sixth arches. However, remnants of the tract or of the endodermal pouches may possibly persist, in which case they would be found caudal to the fourth or sixth arch derivatives in the root of the neck or upper mediastinum. Cysts in relation to the subclavian artery, the arch of the aorta, or the pulmonary arteries could conceivably be of cervical sinus or endodermal pouch origin. In the former case, the lining of the cyst is ectodermal in origin and could be expected to give rise to epidermoid carcinoma. In the latter case, the cyst is lined by noncornified squamous epithelium of pharyngeal or esophageal type or a columnar epithelium of intestinal type. Resulting malignant change could, therefore, give rise to epidermoid carcinoma or adenocarcinoma. Some of the so-called dermoid cysts in the upper mediastinum could also be of cervical sinus origin.

Development of the Tongue

The tongue arises as a composite structure in the floor of the pharynx. Its covering epithelium is endodermal. It arises anteriorly as two symmetric swellings (lingual swellings) at the ventral ends of the two first pharyngeal arches. An unpaired swelling posterior to the lingual swellings is the tuberculum impar. Posterior to the tuberculum impar is an extensive linear swelling, the hypobranchial eminence, with which the ventral ends of the third and fourth arches merge. The thyroid gland arises as an outgrowth of the floor of the pharynx between the tuberculum impar and the hypobranchial eminence.

At a later stage, the lingual swellings are enlarged and soon fuse to form the anterior two thirds of the tongue. This part of the tongue, therefore, is bilateral in origin, a fact that accounts for the area of low vascularity in the midline of the tongue. The tuberculum impar is now small and becoming submerged by the piling up of the hypobranchial eminence posterior to it to form the posterior third of the tongue. At the same time, there is a general migration of the third arch mesoderm into the posterior third of the tongue, merging with the hypobranchial eminence. The hypobranchial eminence also develops a horizontal groove dividing it into an anterior compartment, which assists in the formation of the posterior third of the tongue, and a posterior compartment, which forms the epiglottis.

Thus, the adult tongue consists of several parts. The anterior two thirds is of first or mandibular arch origin, and so is supplied by the mandibular (lingual) branch of the trigeminal nerve. The posterior third is derived in part from the hypobranchial eminence and in part from third arch mesoderm, and so receive its sensory innervation from the superior laryngeal nerves (supplying the hypobranchial eminence anterior to the epiglottis) and from the glossopharyngeal nerve (third arch). Special sensation (taste) to the anterior two thirds of the tongue is mediated by the chorda tympani branch of the facial nerve. This nerve was previously observed within the first arch as the pretrematic branch of the facial nerve. Taste is carried to the posterior third through lingual branches of the glossopharyngeal and the internal branch of the superior laryngeal nerves.

The division between the anterior two thirds and posterior third of the adult tongue corresponds approximately with the V-shaped line of the circumvallate papillae. The palatine tonsil, as has been described, is formed by the aggregation of lymphoid tissue around the ventral wing of the second pouch (intratonsillar fossa). The site of the third pouch is probably high up in the floor of the pyriform sinus. The site of the fourth and sixth pouches is also unknown but may reasonably be expected to be in the lower part of the pyriform sinus caudal to the internal branch of the superior laryngeal nerve. The vallecula corresponds to the groove between the anterior (lingual) and posterior (epiglottal) parts of the hypobranchial eminence, and so has no relationship to any pharyngeal pouch.

The anterior and posterior pillars of the fauces corresponds approximately with the second and third internal arches, respectively, and the second pouch or intratonsillar fossa lies between them. The pharyngoepiglottic fold may correspond with the fourth arch. The aryepiglottic folds mark the site of evagination of the laryngotracheal diverticulum. Identification of these adult structures with the primitive arches has little validity, however, and serves little practical purpose.

Development of the Thyroid Gland - Thyroglossal Cysts

The thyroid gland develops as the earliest of the endocrine derivatives of the pharynx as a single midline evagination of the endoderm in the floor of the pharynx. The site of the thyroid outgrowth later lies between the tuberculum impar and the hypobranchial eminence. The thyroid diverticulum then grows caudally in a loose subpharyngeal plane of mesoderm and also proliferates at its tip into two lateral lobes. The thyroid lobes come early into anterior relationship with the third arch artery as it emerges from the ventral aorta and so is related intimately in the adult to the internal carotid artery. The connecting (thyroglossal) duct between the thyroid and the floor of the pharynx becomes attenuated and normally disappears. The pyramidal lobe indicates its former site of attachment to the thyroid gland.

Persistence of the thyroglossal duct may occur and may give rise to cystic masses at any point along its path, from the floor of the pharynx to the pyramidal lobe of the gland. When the tract persists throughout its length, its course is characteristic. The tract ascends form the pyramidal lobe, which lies, as a rule, to the left of the midline. It necessarily passes anterior to the pharyngeal arch derivatives and so ascends anterior to the thyroid cartilage and the body of the hyoid bone. It then pierces the floor of the mouth between the two mylohyoid muscles and penetrates the base of the tongue, finally opening into the foramen cecum. The foramen cecum represents the site of origin of the original thyroid diverticulum and lies at the junction of the anterior two thirds and the posterior third of the tongue.

The relationship of the thyroglossal tract to the body of the hyoid is important. Note that the attachment of the thyrohyoid membrane is to the upper and posterior rim of the body of the hyoid bone. The thyroglossal tract ascends on the anterior surface of the membrane, then curves caudally in intimate apposition to the posterior surface of the hyoid. It then ascends once more anterior to the body of the hyoid bone, usually slightly to the left of the midline, and passes through the floor of the mouth. In removing the tract, it is essential to eliminate it throughout its length from the foramen cecum to the pyramidal lobe. In order to remove completely the hyoid portion of the tract, it is usual to remove the middle segment of the body of the hyoid bone with bone shears. Failure to remove all the tract may result in recurrence. Unlike the lateral cysts of the neck, which are of cervical sinus origin (ectodermal), the thyroglossal or midline cysts of the neck move on swallowing since they are firmly attached to the thyroid cartilage and hyoid bone. Since they are of endodermal origin, they may give rise to adenocarcinoma.

Relevant Conceptual Anatomy of the Head and Neck

The anatomy of the adult head and neck is built around the pharynx and its associated branchial derivatives, which together form a "median visceral column" attached above to the base of the skull. Flanking the pharyngeal arch field posteriorly and anteriorly is the V-shaped muscle mass, differentiated within the epi-pericardial ridge, containing the sternomastoid-trapezius complex and the infrahyoid and suprahyoid muscles and the muscles of the tongue. Lateral to the median visceral column is a fascial space or compartment, the laterovisceral space, which contains the vascular structures and the components of the pharyngeal arch nerves.

Anatomy of the Median Visceral Column

The pharynx is a musculomembranous tube supported by overlapping constrictor muscles of striped muscle and other muscles arising from the base of the skull and styloid process (Fig. 19).

The superior constrictor muscle of the pharynx arises by a continuous origin from the lower half of the medial pterygoid plate, the pterygoid hamulus, the pterygomandibular ligament, and the bone immediately adjacent to the attachment of the ligament to the mandible. Since the pterygomandibular ligament is oblique, extending from the pterygoid hamulus medially to the mandible laterally, those fibers of the superior constrictor taking origin from it are in the same oblique plane as the ligament (Fig. 20). Moreover, since the buccinator muscle arises from the anterior surface of the pterygomandibular ligament, this muscle and the superior constrictor must also be in the same plane. Thus, an anatomic structure that descends from the pterygoid region (infratemporal fossa) above the level of the pterygomandibular ligament is automatically carried into the soft tissues of the cheek, i.e., the buccal branch of the mandibular nerve. Likewise, any infectious process related to the upper fibers of the superior constrictor muscle tends to pass into the cheek.

The superior constrictor muscle has an arching, free, lower border below the level of the pterygomandibular ligament (see Fig. 19). Below this edge, the fibers of the muscle sweep forward into the tongue in the vertical plane of the pharyngeal wall. A triangular gap between the pterygomandibular and lingual fibers of the superior constrictor muscle and the lingual muscle constitutes the "gateway" to the tongue (Fig. 20). Through this space pass the styloglossus muscle, the lingual artery, lingual nerve, and the glossopharyngeal nerve.

The upper fibers of the superior constrictor muscle also have a free border. The fibers arising from the medial pterygoid plate are often described as constituting a sphincteric mechanism at the junction of the nasopharynx and oropharynx (nasopharyngeal or Passavant's sphincter). The arching upper fibers of the superior constrictor are attached to the midline pharyngeal tubercle (Fig. 21) of the basisphenoid.

The middle constrictor muscle of the pharynx arises from the lower part of the stylohyoid ligament, from the lesser cornu of the hyoid bone, and from the entire length of the greater cornu of the hyoid bone (Fig. 19). The muscle also has free upper and lower borders. Posteriorly, the muscle overlaps the superior constrictor and is also inserted by a pointed tendon into the pharyngeal tubercle.

The inferior constrictor muscle of the pharynx arises from the oblique line of the thyroid cartilage, from a fibrous arch over the cricothyroid muscle, and from the side of the cricoid cartilage. The muscle also has a free upper margin; its lower fibers merge with the circular fibers of the esophagus (see Fig. 19).

There are nonmuscular areas in the muscular wall of the pharynx: (1) between the base of the skull and the upper fibers of the superior constrictor (sinus of Morgagni), (2) between the superior constrictor and the middle constrictor muscles, and (3) between the middle and inferior constrictor muscles. The first area (sinus of Morgagni) is occupied by a "eustachian complex" containing the pharyngotympanic tube, the tensor veli palatini (tensor palati) muscle, and the levator palati muscle (see Fig. 19). The second area contains the lingual fibers of the superior constrictor muscle passing into the tongue, the stylohyoid ligament, the lingual artery and nerve, and the glossopharyngeal nerve. This area (see Fig. 19) lies opposite the palatine tonsil, so that the aforementioned structures form important lateral relationships of the tonsil. Here also the external maxillary (facial) artery may make a conspicuous high loop in immediate lateral relationship to the tonsil that it supplies. This vessel, as well as the internal carotid artery itself, may be injured during tonsillectomy. The third nonmuscular area between the middle and inferior constrictors lies close to the posterior margin of the thyrohyoid membrane (see Fig. 19). Here, it is crossed by the internal branch of the superior laryngeal nerve and is related deeply to the pyriform sinus. A less conspicuous nonmuscular area lies between the inferior constrictor and the upper circular fibers of the esophagus (see Fig. 19). The latter are exposed at this point, since the longitudinal fibers pass forward and insert by a pointed tendon into the back of the cricoid cartilage. This and, to a lesser extent, the second and third nonmuscular areas constitutes zones of relative weakness in the pharyngeal wall through which pulsion diverticula may develop.

The Styloid Muscles

The styloid process and the stylohyoid ligament are parts of the second or hyoid arch cartilage. The stylohyoid is the proper muscle of this arch and is accordingly supplied by the facial nerve. The facial nerve turns laterally around the base of the styloid process and then passes forward to enter the parotid gland. The two other muscles attached to the styloid process - the styloglossus, supplied by the hypoglossal nerve, and stylopharyngeus, supplied by the glossopharyngeal nerve - become secondarily attached to the bony process during the development of the pharyngeal region. These three muscles form part of the suspensory apparatus of the tongue, the hyoid bone, and the thyroid cartilage and assist in swallowing.

The stylohyoid is the most superficial of the three styloid muscles. It arises by a slender tendon near the tip of the process and inserts onto the hyoid bone lateral to the lesser cornu. Here, it splits to allow passage of the intermediate tendon of the digastric muscle; the tendon itself is anchored to the bone by a fascial sling containing a bursa. The styloglossus is intermediate in depth and arises from the anterior surface of the lower part of the styloid process and the upper part of the stylohyoid ligaments; it inserts into the side of the tongue after passing under the arching free margin of the pterygomandibular fibers of the superior constrictor. The muscle pulls the tongue posteriorly during the first phase of swallowing. The stylopharyngeus is the deepest of the styloid muscles. It arises from the inner side of the base of the process, descends almost vertically, then passes deep to the upper fibers of the middle constrictor and is attached to the posterior margin of the thyroid cartilage. The glossopharyngeal nerve makes a characteristic turn around the muscle near its origin, passing to its lateral side. The muscle elevates the thyroid cartilage during the later phases of swallowing.

The "Eustachian Apparatus"

The pharyngotympanic (eustachian) tube is developmentally an outgrowth of the pharynx, and its cartilaginous component lies within the upper part of the pharyngeal wall. This part of the tube lies in the petrosphenoidal fissure and so is obliquely placed. The cartilaginous tube is continuous with the bony portion in the petrosphenoidal angle and (at its pharyngeal end) rests on a small spine on the posterior margin of the medial pterygoid plate. The tensor veli palatini muscle arises immediately lateral to the cartilaginous tube from the edge of the greater wing of the sphenoid adjoining the petrosphenoidal fissure, and also from the lateral wall of the tube itself. The muscle is triangular and narrows into a slender tendon that winds around the lateral surface of the pterygoid hamulus, which serves as a pulley for it. A bursa is found at this point. The tendon then pierces the pharyngeal wall and expands into the palatal aponeurosis within the soft palate. The aponeuroses of the two sides are fused in the midline so that simultaneous action of the two muscles tense and flattens the soft palate during swallowing. The tensor palati also opens the cartilaginous portion of the tube during swallowing as a result of its attachment to the lateral surface of the tube. It is supplied by the mandibular division of the fifth nerve through small branches arising near the foramen ovale. The levator palati arises medial to the cartilaginous tube from the inferior surface of the apex of the petrous temporal bone. It then descends almost vertically to be attached to the upper and posterior surface of the palatal aponeurosis. Its action is to raise the soft palate during swallowing. It is supplied by nerves of the pharyngeal plexus containing fibers of the cranial accessory (eleventh) nerve. The muscle also has some fibers of origin from the wall of the tube itself, and so assists in opening the tube.

The cartilaginous tube and its associated muscles form a functional group of structures conveniently grouped as the eustachian apparatus. Since they occupy the sinus of Morgagni between the upper fibers of the superior constrictor and the base of the skull, they are an integral part of the wall of the pharynx in this area.

Composition of the Pharyngeal Wall

From the top down, it comprises the eustachian apparatus: the superior, the middle, and the inferior constrictor muscles. The lateral surface of the pharyngeal wall is covered by a thin layer of connective tissue, the buccopharyngeal fascia. This fascia is carried into the cheek by the common attachment of the fibers of the superior constrictor and of the buccinator to the pterygomandibular ligament. Below this level it fades out in the floor of the mouth in relation to the styloglossus and the side of the tongue. The internal surface of the constrictor muscles is lined by a strong elastic fascial layer, the pharyngobasilar fascia. It is attached above to the skull medial to the eustachian apparatus; below, it merges with the muscularis mucosae of the esophagus. Internal to the pharyngobasilar fascia is the mucous membrane of the pharynx. Opposite the gap between the constrictors and between the last of these and the esophagus, as described previously, the pharyngeal wall consists only of the buccopharyngeal and pharyngobasilar fasciae and the underlying mucous membrane.

The Lateropharyngeal and Lateroviesceral Spaces

The medial visceral column of structures, comprising the pharynx above and the esophagus and trachea below, is related throughout its length to a lateroviesceral space of great clinical importance. This space will be termed the "lateropharyngeal space" as low as the sixth cervical vertebra, where the pharynx joins the esophagus; below this level, it will be termed the "lateroviesceral space".

Lateropharyngeal Space

At the highest level, the lateropharyngeal space is the same as the pterygoid region (infratemporal fossa, deep parotid space). The attachment of the pharynx to the base of the skull in the region of the eustachian apparatus is oblique, as a result of the obliquity of the petrosphenoidal fissure and the tube that lies in it. Thus, the attachment of the pharynx, when both sides are visualized (see Fig. 21), is rhomboidal. The most lateral point of attachment on either side is the petrosphenoid angle, between the spine of the sphenoid and the petrous temporal bone. The obliquity of this attachment results in the formation of the lateral recess of the pharynx or fossa of Rosenmüller (Fig. 23). It is possible to palpate the entire inner surface of the cartilaginous portion of the eustachian tube in the wall of the lateral recess. Advantage is taken of the recess to cannulate the tube. The tip of the cannula is introduced into the recess posterior to the pharyngeal opening of the tube and gradually drawn forward; the tip then slides into the tube without difficulty. The lateropharyngeal space at the level of the lateral recess lies anterolaterally because of the obliquity of the pharyngeal wall at this level (Fig. 23). Immediate contents of the space are the two pterygoid muscles (medial and lateral), the mandibular branch of the trigeminal nerve emerging from the foramen ovale, and the internal maxillary artery, especially its middle meningeal branch, which enters the skull through the foramen spinosum.

The auriculotemporal nerve arises from the mandibular nerve immediately below the skull and encircles the middle meningeal artery, splitting into two branches that reunite beyond the artery. The nerve then passes laterally, posterior to and in close contact with the capsule of the temporomandibular joint. It then passes upward over the root of the zygoma and supplies the skin on the side of the head and the upper part of the auricle. It sends branches into the capsule of the temporomandibular joint and also into the bony auditory meatus to supply its mucosal lining and the external surface of the tympanic membrane. The latter branches enter the meatus through the squamotympanic fissure with branches of the posterior auricular artery. The nerve is an important source of referred pain from the teeth to the joint and the external ear.

The otic ganglion lies medial to the mandibular branch of the trigeminal nerve, between it and the tensor palati and close to the foramen ovale. Here, it receives the lesser superficial petrosal nerve (Fig. 23), a parasympathetic nerve arising from the glossopharyngeal nerve and conveying secretomotor fibers to the parotid gland via the auriculotemporal nerve. The chorda tympani nerve, described previously as the pretrematic branch of the facial nerve, emerges from the middle ear through the petrotympanic fissure (Fig. 23), grooves the spine of the sphenoid (groove of Lucas), and then descends lateral to the tensor palati muscle deep to the mandibular division of the fifth nerve. It joins the lingual branch of this nerve and carries secretomotor fibers to the submandibular and sublingual glands and taste fibers from the anterior two thirds of the tongue (see p. 72). Deep infections of the lateropharyngeal space at this level may arise from the maxillary molars and are very chronic, deep-seated, and painful.

Other important anatomic relationships of the lateral recess of the pharynx involve the great vessels (Fig. 23), the internal carotid artery, and the internal jugular vein. An aneurysm of the internal carotid artery at this point may bulge into the lateral recess of the pharynx and resemble a retropharyngeal or peritonsillar abscess. Pulsation of the swelling should be detected and may deter incision. The retropharyngeal space at this level lies between the constrictor muscle and its covering of buccopharyngeal fascia on the one hand and the atlas and axis vertebrae with their investing prevertebral muscles and prevertebral fascia on the other. This space, which contains no important structures except for lymph nodes, may also be the site of an abscess.

The lateropharyngeal space at a lower level (Fig. 24) shows important relationships to the parotid gland. For this reason it is referred to as the deep parotid space. Also evident at this level is a strong aponeurotic sheet extending from the pharyngeal wall to the styloid process and its muscles (Fig. 24).

A similar but less dense fascial sheet extends from the styloid process and its muscles to the mastoid process and posterior belly of the digastric muscle. These two fascial sheets constitute a strong "styloid diaphragm", which effectively separates the parotid space anteriorly from the space enclosing the great vessels posteriorly. Anterior to the styloid diaphragm (prestyloid region) are the two pterygoid muscles and the deep (pterygoid) process of the parotid gland. The deep process of the gland is continuous with the superficial lobe through a narrow isthmus of glandular tissue between the ramus of the mandible and the sternomastoid muscle; it fills all the available space in the prestyloid region. It also has an anterior extension that fills the angle between the medial and lateral pterygoids, and a deep or pharyngeal extension that reaches to the pharyngeal wall. Extension of the parotid into the vascular or retrostyloid space is prevented by the styloid diaphragm. Similarly, malignant extension of the gland is prevented by the styloid diaphragm and rarely involves the retrostyloid space and the great vessels.

Contained within the retrostyloid space are the internal carotid artery; the internal jugular vein; the seventh, ninth, tenth, eleventh, and twelfth cranial nerves; and the superior sympathetic ganglion of the cervical chain. The jugulodigastric gland lies lateral to the internal jugular vein and between it and the posterior belly of the digastric and receives afferent lymphatics from the pharynx and tonsil. It may become infected and be detected as a painful swelling below the mastoid, causing a diagnostic problem. The transverse process of the atlas projects laterally and may be palpated in the narrow gap between the ramus of the mandible and the tip of the mastoid process. It is overlaid by the posterior belly of the digastric muscles and is also crossed by the occipital artery and the spinal accessory nerve. The nerve may be irritated or caught up in an inflammatory process involving the jugulodigastric lymph node and give rise to considerable pain. The facial nerve (see Fig. 23) has only a brief course through the retrostyloid space after leaving the skull by the stylomastoid foramen. It pierces the lateral portion of the styloid diaphragm and enters the superficial portion of the parotid gland.

The lateropharyngeal space at the level of the body of the mandible is shown schematically in Figure 25. The styloid diaphragm is still present. In addition, however, there is a strong band of fascia, a thickening of the deep cervical fascia, the stylomandibular "ligament", extending from the styloid process to the angle of the mandible. It separates the superficial lobe of the parotid gland from the submandibular gland. The lateropharyngeal space (see Fig. 23) is continuous at this level with a fascial space occupied by the submandibular gland. The submandibular gland consists of two parts, a superficial and larger part, and a deep part. The two parts are continuous around the posterior free margin of the mylohyoid muscle (Fig. 25). The superficial part lies in the floor of the mouth inferior and lateral to the oral diaphragm (mylohyoid and anterior belly of the digastric). The deep part, from which Wharton's duct arises, lies in the forward extension of the lateropharyngeal space, which fades out anteriorly in relation to the side of the tongue. Here, the gland lies lateral to the styloglossus and hypoglossus muscles and is related superiorly to the mucous membrane in the floor of the mouth (paralingual sulcus). The lingual fibers of the superior constrictor also enter the submandibular space and the buccopharyngeal fascia investing it, then fade out in relation to the areolar tissue of the region (Fig. 25). The retrostyloid compartment at this level is limited anteriorly by the styloid diaphragm and contains the great vessels, the cranial nerve (IX to XII), the sympathetic chain, and the deep cervical lymph nodes. It is readily infected by lymphatics from the tonsil. The lateropharyngeal space becomes descriptively the laterovisceral space at the lower margin of the pharynx where it joins the esophagus. The styloid diaphragm disappears near the tip of the styloid process, merging anteriorly with the parotid fascia and the stylomandibular ligament, and inferiorly with the deep cervical fascia covering the anterior triangle of the neck.

Laterovisceral Space

The laterovisceral space lies lateral to a median visceral column made up of the esophagus and trachea (Fig. 26).

Integral with it, but separated from it by an independent, thin, fascial sheath, is the thyroid gland. The parathyroid glands may lie within the fascial sheath of the thyroid gland, embedded in its substance, or outside the sheath. The superior parathyroid is usually more distant in position than the inferior parathyroid. The infrahyoid, or "strap" muscles lie anterior to the median visceral column (Fig. 26). They are surrounded by a thin fascial sheath, independent of that enveloping the median visceral column, and continues laterally with the fascia of the omohyoid and sternomastoid muscles. This fascia is part of the enveloping deep fascia of the neck and is continued posteriorly across the posterior triangle, enclosing the trapezius and finally reaching the cervical spinous processes.

A layer of fascia covering the prevertebral muscles is the prevertebral fascia (Fig. 26). Between it and the fascia of the median visceral column is a potential space of considerable importance, the retroesophageal space, continuous above with the retropharyngeal space (Fig. 26). The prevertebral fascia extends laterally across the scalenus anterior muscle, which arises from the anterior tubercles of the transverse processes of the cervical vertebrae. The prevertebral fascia passes laterally in relation to the scalenus anterior (scalene fascia) and forms the anterior wall of the axillary sheath. Here, it meets with the deep cervical fascia covering the posterior triangle, forming a tubular fascial sheath around the trunks of the brachial plexus and, at a lower level, around the axillary artery and vein (Fig. 26).

The phrenic nerve, arising from the anterior rami of the third and fourth cervical nerves, lies deep to the scalene fascia on the anterior surface of the scalenus anterior, passing obliquely across the muscle from above down and from lateral to medial. It can be preserved intact in operations on the deep neck as long as this fascial layer is undamaged. The scalenus medius and the scalenus posterior muscles arise from the posterior tubercles of the cervical transverse process, and so lie posterior to the emerging roots of the brachial plexus (C5, C6, C7, C8, and T1).

The laterovisceral space in the neck lies in the more or less triangular region (as seen in cross sections of the neck, Fig. 26), bounded medially by the median visceral column, anterolaterally by the sternomastoid and inferior belly of the omohyoid, and posteriorly by the prevertebral muscles and the scalenus anterior. It is traversed throughout its length from the thoracic inlet to the pharynx by the common carotid artery and the internal jugular vein. The loose areolar tissue within the laterovisceral space allows distention of these great vessels, as in extreme exertion. Added space is gained by the contraction of the omohyoid and its fascia. It is slightly condensed around the vessels forming the carotid sheath, which is exaggerated by formalin fixation and is much less real in life than in the dissecting room. Within the posterior wall of the sheath is the tenth cranial (vagus) nerve. In the anterior wall of the sheath is the ansa hypoglossi, a loop of nerve fibers made up of the descendens hypoglossi (containing fibers of C1) and the descendens cervicalis (containing fibers of C2 and C3). The ansa hypoglossi gives off branches to the infrahyoid muscles (sternohyoid, sternothyroid, omohyoid); its characteristic curving course reflects, as does that of the hypoglossal nerve, the development of the epipericardial ridge (p. 69) caudal to the arch field. There are also lymph nodes of the deep cervical chain within the areolar tissue of the laterovisceral space. They drain the floor of the mouth, the tonsillar area, the larynx, and lower pharynx as well as the median visceral column of structures below the level of the pharynx. The cervical sympathetic chain lies closely adherent to the prevertebral fascia in the posterior wall of the laterovisceral space (Fig. 26); it will be described in more detail later.

The extensions of the laterovisceral space and the retroesophageal space into the thorax are of great clinical importance (Fig. 26). The median visceral column is continued into the superior mediastinum and remains invested with a thin fascial sheath. The retroesophageal space also continues into the posterior mediastinum and comes to an end at the level of the diaphragm. Infections of this space, arising in the vertebral bodies or by lymphatic or direct extension from the pharynx, may thus extend into the posterior mediastinum throughout its length.

The laterovisceral space also continues into the upper thorax lateral to the median visceral column (Fig. 27). The space, filled with loose areolar tissue, here contains the roots of the great arteries arising from the arch of the aorta (left subclavian, left common carotid, innominate (brachiocephalic) arteries). The apex of the lung and its pleura occupy each side of the thoracic inlet and close off the laterovisceral space laterally. There are unimportant extensions into the a retropleural space in relation to the neck of the first rib and also in to the extrapleural space. The dome of the pleura is thickened superiorly by a tentlike extension of fascia stretching from the transverse process of the seventh cervical vertebra to the inner surface of the first rib (Sibson's fascia). Crossing the dome of the pleura at the thoracic inlet are the subclavian artery and vein. The sharp tendon of the scalenus anterior attached to the first rib at the scalene (Lisfranc's) tubercle separates the two vessels. The artery may be partially occluded by the tendon, especially when the neck is rotated. There may also be pressure on the lower trunk and cords of the brachial plexus, producing pain or paresthesia along the dermatomes of C8 and T1. These findings (scalenus anterior syndrome) are relieved by tenotomy of the scalenus anterior. A differential diagnosis must be made between it and the effects of a cervical rib. Branches of the subclavian artery and vein also arch across the dome of the pleura; the internal thoracic (mammary) vessels anteriorly, and costocervical trunk posteriorly. The latter divides at the level of the neck of the first rib (Fig. 27) into the superior intercostal artery and the deep cervical artery. It lies with the inferior ganglion of the cervical sympathetic chain in a retropleural fossa. The first thoracic nerve is closely related to this fossa. It emerges between the first and second thoracic vertebrae, passes laterally, first inferior to the neck of the first rib, and then superior to the shaft of the first rib, where it joins the eight cervical nerve.

The median visceral column of structures sinks deeper into the neck as it approaches the thoracic inlet. Thus, a space is opened up between it and the posterior surface of the manubrium sterni and the attachment of the infrahyoid ("strap") muscles to the sternum and first rib (Fig. 27). This pretracheal or retrosternal fascial space is occupied by loose areolar tissue and may permit infectious processes or tumors to expand widely before producing pressure symptoms on the trachea or great veins. In the fetus, the newborn, and the child up to about the age of puberty, the retrosternal space contains the upper part of the thymus gland, which may also produce pressure symptoms. The retrosternal space contains the upper part of the thymus gland, which may also produce pressure symptoms. The retrosternal space is entered during tracheostomy. In young children, the thymus with large superior thymic veins may be encountered. A large artery to the thyroid, the arteria thyroidea ima, may also be encountered anterior to the trachea. The innominate (brachiocephalic) artery may also lie in the retrosternal space behind the right sternoclavicular joint and may be injured. Techniques have been developed in recent years for performing biopsies of the hilar lymph nodes or of masses in this area by passing a needle into the mediastinum through the retrosternal space.

General Neuroanatomy of the Head and Neck

The neuroanatomy of the head and neck of importance to otolaryngologists includes (1) the nerve supply of the special sense organs (eye, ear, and nose), (2) the nerve supply of the extrinsic muscles of the eye (third, fourth, and sixth cranial), (3) the nerve supply of the pharyngeal or branchial arch derivatives (fifth, seventh, ninth, and superior and inferior laryngeal branches of the tenth), (4) the nerve supply of the supporting muscles of the head (trapezius, sternomastoid), the infrahyoid muscles, and the muscles of the tongue (eleventh, twelfth, upper cervical), and (5) the autonomic nerve supply of the smooth muscle and glandular tissue of the head and neck (sympathetic and parasympathetic).

Nerve Supply of the Special Sense Organs

The sense organs (eye, inner ear, and nose) are of ectodermal origin, as will be described later in this chapter, where the detailed innervation of these structures, insofar as it concerns the otolaryngologist, will also be described.

Nerve Supply of the Extrinsic Ocular Muscle

These muscles are of somitic origin, that is, they are derived from condensations of mesoderm lateral to the neural tube. They are striated and so are innervated by motor axons growing out from the ventral (basal) part of the neural tube. The nerves involved are the oculomotor or third nerve, which supplies the superior rectus, the medial rectus, the inferior rectus, and the inferior oblique muscles; the trochlear or fourth nerve, which supplies the superior oblique muscle; and the abducens or sixth nerve, which supplies the lateral rectus. They are of importance in that they may be irritated or paralyzed by infections or neoplastic processes invading the orbit. Irritative lesions cause spasm of the muscles supplied by the nerves. Paralysis of the nerves permits the eye to be pulled by unopposed antagonistic muscles into abnormal positions (strabismus), with double vision or inability to direct the gaze. Paralysis of the oculomotor nerve in all its branches results in a squint in which the eye is pulled laterally by the lateral rectus and also downward by the superior oblique. There is also mydriasis (dilated pupil) due to the paralysis of the sphincter pupillae, loss of accommodation due to paralysis of the ciliary muscle, and drooping of the eyelid (ptosis) from paralysis of the levator palpebrae superioris muscle. Paralysis of the sixth nerve results in double vision when attempts are made to gaze laterally. Such a lesion may be accompanied by deep orbital pain arising from an infectious process at the apex of the petrous temporal bone (Gradenigo's syndrome). Paralysis of the fourth nerve results in double vision when the gaze is directed downward and outward. Patients with this condition characteristically see double when going downstairs. Thrombosis of the cavernous sinus may also result in damage to these cranial nerves.

Nerve Supply of the Pharyngeal or Branchial Derivatives

These nerves have been studied in detail (pp. 62 to 63) and will be reviewed only briefly. The first arch derivatives are supplied by the trigeminal (fifth) nerve. The nerve supplies the forehead and face, the side of the head, and the lateral surface of the auricle and drum, the mucosa of the oral cavity, the teeth, and the mucosa of the nasal cavity. Motor fibers are distributed by the mandibular division to the muscles of mastication (masseter, temporalis, pterygoids) and the muscles of the floor of the mouth (anterior belly of the digastric, mylohyoid). The tensor veli palatini and the tensor tympani are also supplied by the facial or seventh nerve. It has no cutaneous supply. It supplies taste to the anterior two thirds of the tongue and to adjacent parts of the hard and soft palate. It distributes motor fibers to the stylohyoid, the posterior belly of the digastric, the platysma, the muscles of facial expression, and the stapedius muscle. Parasympathetic fibers are distributed to the lacrimal gland, the submandibular and sublingual glands, and to all the mucous and serous glands of the nose and palate (see later). The third arch derivatives are supplied by the glossopharyngeal or ninth nerve. The nerve has no cutaneous distribution. It supplies the posterior third of the tongue (taste and ordinary sensation), the adjoining vallecula, epiglottis and tonsillar area, and the nasopharynx in the region of the eustachian tube and the fossa of Rosenmüller. It also takes part in the pharyngeal plexus on the surface of the middle constrictor, and may share in the supply of this muscle and of the superior constrictor. The only muscle definitely known to be supplied by the glossopharyngeal nerve is the stylopharyngeus, which is involved in swallowing. The derivatives of the fourth arch are supplied by the superior laryngeal branch of the vagus nerve. It supplies by its internal branch the mucous membrane of the larynx above the level of the vocal cords and the adjoining areas of the pharynx, including the pyriform sinus and epiglottis. It supplies by its external branch the cricothyroid muscle, which is a tensor of the vocal cords. The sixth arch derivatives are supplied by the inferior or current laryngeal branch of the vagus nerve. It supplies the intrinsic muscles of the larynx and the mucous membrane of the larynx below the vocal cords, as well as the mucosa of the cervical and upper thoracic portion of the trachea and esophagus.

Nerve Supply of the Derivatives of the Epipericardial Ridge

There are only 10 cranial nerves in vertebrates below the birds and reptiles. In higher vertebrates there are 12, the additional nerves being the eleventh or accessory and the twelfth or hypoglossal nerves. These nerves are supposed to have been incorporated into the skull during evolution and represent upper cervical spinal nerves. These nerves enter the pharyngeal region within a V-shaped mesodermal bed or epipericardial ridge caudal to the arch area (p. 69). The sternomastoid, the trapezius, the infrahyoid, and the intrinsic muscles of the tongue are differentiated within this mesodermal mass. The nerves supplying these muscles are the accessory, the hypoglossal, and the upper three spinal nerves. The accessory nerve has a cranial and a spinal component. The cranial component is really a part of the vagus and is often included with it as the "vago-accessory complex". Its precise distribution is uncertain. It is considered to be responsible for the supply of the branchial musculature developed within the fourth and sixth arches, and so properly belongs with the branchial group of cranial nerves. It is distributed to the lower constrictor fibers of the pharynx, and the striated fibers of the upper and middle esophagus. The nerve may also be distributed to the lungs and great vessels, including the heart, these fibers being both sensory and motor.

The spinal accessory nerves arises from the lateral cells of the anterior gray matter in the upper four or five segments of the cervical spinal cord. It ascends immediately anterior to the denticulate ligament of the spinal cord within the subarachnoid space and enters the foramen magnum. It leaves the skull with the vagus and cranial root of the accessory, with which it is fused, through the jugular foramen and then parts company with the cranial root. It then passes laterally either to the outside (see Fig. 23) or the inside of the internal jugular vein, crosses laterally to the transverse process of the atlas vertebra deep to the posterior belly of the digastric, and enters the sternomastoid muscle just below the mastoid process. It supplies this muscle and then crosses the posterior triangle, where it is rather superficially situated within the deep cervical fascia. It is readily injured in this part of its course, especially when caught up in the inflammatory processes involving the deep cervical lymph nodes at this level. The nerve enters the trapezius about halfway down its anterior border and is reinforced by branches of the third and fourth cervical nerves, which form with it a "subtrapezial plexus".

The hypoglossal nerve enters the tongue immediately above the greater cornu of the hyoid bone (Fig. 16), deep to the mylohyoid and superficial to the hypoglossus. It supplies the intrinsic muscles of the tongue and also the styloglossus. The hypoglossal nerve carries fibers of the first cervical nerve that leave it near the tip of the greater cornu of the hyoid bone as the nerve to the thyrohyoid. Other fibers of the first cervical nerve leave the hypoglossal as the descendens hypoglossi; this joins the descends cervicalis, which contains fibers of the second and third cervical nerves, to form a loop on the anterior wall of the carotid sheath (ansa hypoglossi). From this loop, motor fibers are distributed to the two bellies of the omohyoid, the sternohyoid, and the sternothyroid.

Autonomic Nervous System of the Head and Neck

General Principles. The autonomic nervous system of the body is subdivided into two components: the thoracolumbar outflow comprising the sympathetic nerves, and the craniosacral outflow comprising the parasympathetic nerves. These nerves are concerned with the supply of smooth muscle and glandular tissue and are grouped together as general visceral efferent fibers (see Fig. 31).

Sympathetic Nerves

The thoracolumbar outflow arises in the intermediolateral column of small neurons within the spinal cord from the first thoracic to the second lumbar levels (Figs. 28 and 29).

A typical cross-section of a spinal cord segment (Fig. 28) illustrates the arrangement of the sympathetic outflow. Axons arise in the intermediolateral column, leave the spinal cord by the ventral (motor) root, and enter the spinal nerve. They leave the spinal nerve as a white ramus communicans, so called since it has a well-developed myelin sheath. Such a nerve fiber is preganglionic since it has not yet had a synapse. It enters one of the sympathetic ganglia lying ventrolateral to the vertebral column (paravertebral ganglia) and may take one of the following courses: (1) It may have an immediate synapse with a second order neuron within the ganglion and then return to the spinal nerve as a gray ramus communicans, so called because it lacks a well-developed myelin sheath. The gray ramus communicans is distributed with the spinal nerve to the blood vessels (vasomotor fibers), sweat glands (sudomotor fibers), and the piloerector muscles (pilomotor fibers). (2) It may ascend or descend in the sympathetic chain and have a synapse at any level with a second order neuron within a ganglion distant from its level of exit from the spinal cord. It may then leave the ganglion as a gray ramus communicans to enter a spinal nerve and be distributed as in (1). (3) The white ramus communicans may pass through a ganglion at any level without synapse and continue as an elongate splanchnic nerve to a distant collection of second order neurons within one or another of the visceral cavities, eg the cardiac and pulmonary plexuses in the thorax, the celiac and superior mesenteric plexuses in the abdomen, or the pelvic plexuses. Postganglionic fibers arise here and are distributed to the smooth muscle and glandular tissue of the viscera and to that of the blood vessels. (4) Second order neurons in the sympathetic ganglia may also pass directly into the visceral cavities to supply the viscera. Fibers that have not had a synapse, eg splanchnic nerves, are called preganglionic. Those which have had a synapse, eg gray ramus communicantes, are called postganglionic.

The chemical mediator released at the synaptic terminal of preganglionic sympathetic fiber is acetylcholine, and such fibers are termed cholinergic. The chemical mediator of postganglionic fibers to smooth muscle and piloerector muscles is epinephrine or norepinephrine, and such fibers are called adrenergic fibers. The postganglionic fibers to the sweat gland are cholinergic. Cholinergic fibers are blocked at the synapse by atropine and anticholinergic drugs, such as methantheline bromide (Banthine), propantheline bromide (Pro-Banthine) and methscopolamine bromide (Pamine). They are stimulated by cholinergic drugs, such as acetylcholine and pilocarpine. The drug physostigmine (Eserine) mimics the action of acetylcholine by inhibiting the enzyme cholinesterase, which normally hydrolyzes acetylcholine at the synapse. Pilocarpine is used to promote sweating. Postganglionic sympathetic fibers to the viscera are adrenergic, but the response of the smooth muscle depends on the type of receptors. Thus sympathetic stimulation of the bronchial and coronary musculature causes dilatation; stimulation of the smooth muscle of the vessels usually causes constriction. Postganglionic adrenergic fibers may be blocked by drugs such as Dibenamine. They are stimulated or mimicked by epinephrine or norepinephrine.

The spatial limits of the sympathetic preganglion outflow (thoracolumbar outflow) are determined by the location of the cells of the intermediolateral column, which is found only between the first thoracic and the second lumbar levels of the spinal cord (Fig. 29). Thus, white rami communicantes are found only between T1 and L2, whereas gray rami communicantes are found at all levels.

Afferent or sensory fibers also enter the spinal cord with the sympathetic system (Fig. 28). Sensory fibers arising in the viscera or great vessels ascend to the sympathetic ganglia along the splanchnic nerves. They enter the dorsal root (Fig. 28) with somatic sensory fibers, and their cell bodies lies within the dorsal root ganglion. Central processes of the cell body enter the cord and gray matter where they set up simple reflex arcs with motor neurons of the intermediolateral column (Fig. 28). Pain fibers from the heart, for example, ascend to the sympathetic chain of the neck via the cervical and upper thoracic splanchnic nerves. The pain is often referred to the somatic nerves arising from the cord at the same level as the incoming sympathetic fibers, in this case the cervical and upper thoracic nerves. The pain may accordingly be felt in the angle of the jaw (great auricular nerve), the shoulder, and along the inner side of the arm, forearm, and hand (dermatomes of C8 and T1).

The manner in which the head and neck are supplied by sympathetic nerves is illustrated in Figure 29. The cells of origin lie in the intermediolateral column of the upper two or three thoracic segments of the cord. Preganglionic fibers leave the cord via the ventral roots of the upper thoracic nerves. They then ascend within the upper thoracic and cervical chain and enter into synapse with second order neurons at any level up to the superior cervical ganglion at the base of the skull; this is the highest point at which a synapse takes place. Postganglionic fibers then leave the cervical chain: (1) gray rami communicantes, which join the nerves of the cervical plexus and are distributed to the blood vessels, sweat glands, and piloerector muscles of the neck and face; (2) reinforcing twigs to plexuses on the walls of the branches of the external carotid and vertebral arteries; and (3) the carotid plexus on the wall of the internal carotid artery. The plexuses on the vertebral and carotid arteries are distributed with their terminal branches to the face, the skull, and the contents of the cranial cavity, including the brain.

The postganglionic fibers along the internal carotid artery (carotid plexus) are of particular importance. They enter the skull with the artery and are distributed with the anterior and middle cerebral arteries and the ophthalmic artery. The ophthalmic plexus carries fibers (postganglionic) to the dilator pupillae, the smooth muscle in the floor of the orbit (Horner's muscle), the smooth muscle in the upper eyelid, and the blood vessels of the orbit and eye. Paralysis of the postganglionic fibers along the ophthalmic artery results in pupil constriction (miosis), drooping of the upper eyelid, and enophthalmos, in which the eye is sunken into the orbit. These ocular findings are part of Horner's syndrome (see later). Postganglionic fibers of the carotid plexus are also distributed to the sphenopalatine ganglion via the deep petrosal nerve and are distributed to the lacrimal and nasopalatine glands and to the blood vessels of the nose and palate.

There are three cervical sympathetic ganglia: inferior, middle, and superior. The inferior ganglion is often fused with the first thoracic ganglion, forming the stellate ganglion (Fig. 27).

It lies on the neck of the first rib in a retropleural fossa where it is closely related to the first thoracic nerve, the superior intercostal artery and vein, and the dome of the pleura. It is connected to the first thoracic nerve by white and gray rami communicantes, and to the eight cervical nerve by gray rami; some variation is observed, however. It is important to note that the inferior cervical sympathetic ganglion (or the stellate ganglion) is the highest point at which preganglionic fibers enter the cervical chain, since the intermediolateral column of cells does not lie above T1 (occasionally it lies as high as C8). Removal of this ganglion, therefore, interrupts completely the entire preganglionic supply of sympathetic fibers to the head and neck. Horner's syndrome results from interruption of this preganglionic outflow. It consists of loss of sweating, vasodilatation of the affected side, and ocular signs as described previously (constriction of the pupil, enophthalmos, ptosis). Pain in the cervical region may also be encountered. The syndrome may result from surgical interference or from pressure of a tumor at the level of the neck of the first rib (superior sulcus (Pancoast) tumor). It may be avoided in a thoracic sympathectomy by careful separation of the stellate ganglion into an upper (inferior cervical) component and a lower (first thoracic) component, the upper part being left intact. The paralysis of the sudomotor fibers may be demonstrated by painting the skin with starch and iodine powder and then injecting the sudorific drug pilocarpine; areas of skin that sweat normally turn blue.

The sympathetic (postganglionic) nerve supply of the upper extremity enters the limb via the middle cervical and stellate ganglia and the gray rami connecting these with the brachial plexus (Fig. 29). Thus, the sympathetic nerve supply to the upper limb may be cut by removing the middle and inferior cervical ganglia and the intervening chain. In practice, it is necessary to remove also the upper thoracic chain ganglia, owing to variations in the sympathetic outflow. In this operation, the second order neurons are removed, so that the operation is a "postganglionic sympathectomy". Under these circumstances of loss of the trophic unit comprising the second order neuron and the effector organ (sweat gland or smooth muscle of a blood vessel) the latter becomes hypersensitive to epinephrine (Loewi's effect). The results of the operation are accordingly apt to be disappointing since the patient's limb vessels go into spasm during emotional stress. Removal of the lumbar sympathetic chain for peripheral vascular disease of the lower extremity does not remove at the same time the second order neurons of the pelvic sympathetic chain. The operation is thus a "preganglionic sympathectomy", and sensitization of the leg vessels to epinephrine does not occur.

Details of the sympathetic innervation of the nose, pharynx, ear, and larynx will be given later in this chapter in connection with the description of these areas.

Parasympathetic Nerves

The parasympathetic system of the body, unlike the sympathetic system, is subdivided into two outflow components: the cranial and the sacral. The cranial outflow arises in nuclei within the brain stem (Fig. 30) and emerges through the third (oculomotor), the seventh (facial), the ninth (glossopharyngeal), and the tenth (vagus) nerves. The sacral outflow emerges from the lateral gray matter of the spinal cord at the level of the third and fourth sacral nerves; it forms the so-called nervi erigentes, which supply the pelvic viscera, the distal colon, and the external genitalia. The cranial outflow supplies the head and neck as well as the derivatives of the foregut and midgut: pharynx, larynx, esophagus, lungs, stomach, small intestine, liver, pancreas, and intrinsic glands of the gut, and the colon as far distally as the splenic flexure where the superior and inferior mesenteric arterial territories overlap. The sacral outflow supplies the hindgut and cloacal derivatives (descending colon, sigmoid and rectum, pelvic viscera, and external genitalia).

Only the cranial outflow will be considered here (discussed in more detail later in this chapter). The outflow of the third (oculomotor) nerve arises in the neurons of the Edinger-Westphal nucleus, a collection of small cells associated with the motor nucleus of the third nerve in the midbrain at the level of the superior colliculus. The preganglionic fibers leave the inferior branch of the oculomotor nerve within the orbit and enter the ciliary ganglion, a small collection of second order parasympathetic neurons lateral to the optic nerve (Fig. 30). Here, the fibers synapse, and postganglionic fibers are distributed to the eye through the long and short ciliary nerves. They supply the sphincter pupillae and the ciliary muscle. Paralysis of the third nerve, in addition to the loss of function of the levator palpebrae superioris and the extrinsic muscles of the eye (except the superior oblique and the lateral rectus), results in a dilated pupil (mydriasis) and loss of accommodation. Since both preganglionic and postganglionic synapses of the parasympathetic system are cholinergic, they are stimulated by cholinergic drugs (acetylcholine, physostigmine, pilocarpine) and blocked by anticholinergic drugs (atropine, Banthine, Pamine). Atropine-like compounds are used to dilate the pupils. Since they also paralyze the ciliary muscle, they are likely to impede the removal of aqueous humor at the iris-mesh angle and so may precipitate glaucoma in the susceptible patient.

The parasympathetic outflow through the facial or seventh nerves arises in the hypothetical "superior salivatory nucleus", supposed to lie in the midpons. Preganglionic fibers leave the brain in the pars intermedia (nerve of Wrisberg) between the motor branch of the facial and eight nerve in the cerebellopontine angle. The pars intermedia is both motor and sensory. It contains preganglionic parasympathetic (secretomotor) fibers as well as taste fibers from the anterior two thirds of the tongue. It may be involved with the facial and the eight nerve in cerebellopontine angle tumors, usually acoustic neuromas. The preganglionic fibers of the pars intermedia enter the internal auditory meatus with the facial and eight nerves and fuse with the facial nerve proximal to the geniculate ganglion. They leave the facial nerve at the level of the ganglion as the greater petrosal nerve, which supplies preganglionic fibers to the sphenopalatine ganglion. Postganglionic fibers leave the sphenopalatine ganglion and are distributed to the lacrimal gland and the serous and mucous glands of the nose, paranasal sinuses, palate, and nasopharynx. Preganglionic fibers also leave the facial nerve as the chorda tympani about 5 mm above the stylomastoid foramen. They cross the inner surface of the tympanic membrane, emerge from the skull through the petrotympanic fissure (see Fig. 23), descend through the infratemporal fossa lateral to the tensor veli palatini, and join the lingual branch of the mandibular division of the trigeminal nerve. They are distributed through the lingual nerve to the submandibular ganglion where the second order neurons lie and the postganglionic fibers to the submandibular and sublingual glands arise. Sensory fibers (taste) from the anterior two thirds of the tongue are also distributed through the chorda tympani and enter the brain stem through the pars intermedia.

The parasympathetic outflow of the ninth or glossopharyngeal nerve arises in neurons of a hypothetical "inferior salivary nucleus" within the pons. They leave the skull with the glossopharyngeal nerve. Immediately below the jugular foramen these fibers leave the glossopharyngeal nerve as the tympanic branch (Jacobson's nerve). It pierces the floor of the middle ear through a small foramen in the bony ridge between the carotid canal and the jugular foramen and forms a plexus on the promontory of the middle ear. It then leaves the middle ear as the lesser petrosal nerve, which emerges from the anterior surface of the petrous temporal bone in the middle cranial fossa and leaves the skull either through the foramen ovale or through a small accessory foramen (foramen Vesalius). It enters the otic ganglion (see Fig. 23), which lies on the tensor veli palatini muscle, between it and the mandibular branch of the trigeminal nerve. Postganglionic fibers arise from the second order neurons of the otic ganglion and are distributed to the auriculotemporal nerve by which they are carried to the parotid gland.

The parasympathetic outflow of the vagus and of the cranial root of the accessory nerves (vago-accessory complex) arises in the dorsal motor nucleus of the vagus in the floor of the fourth ventricle at the level of the medulla. They are distributed to the wall of the pharynx and larynx as well as to the derivatives of the foregut and midgut distal to these. The second order neurons, unlike those of the sympathetic system, lie in the walls of the structures supplied (Fig. 30), eg, the submucosal and myenteric plexuses of the gut. Postganglionic fibers are supplied from these "mural ganglia" to glandular tissue and smooth muscle. Stimulation of the cholinergic fibers of the vago-accessory complex by acetylcholine, physostigmine, and pilocarpine produces hypermotility of the visceral muscle and promotes a secretion rich in water and enzymes. Blockade of the system by atropine or drugs such as Banthine causes reduction of motility as well as reduction in secretion, especially of hydrochloric acid by the oxyntic cells of the stomach. Dryness of the mouth (xerostomia) is also an unpleasant side effect.

Central Connections of the Cranial Nerves

Although the cranial nerves, with some exceptions (eg olfactory, optic, acoustic, oculomotor, and trochlear), are mixed, having sensory, motor, and, often, autonomic components, the central connections of the nerves within the brain are much simpler (Fig. 31). The fibers are regrouped within the brain in relation to function and without regard to the complex composition of the individual cranial nerves. Six major nuclear columns (collections of neurons) are recognized in the bran stem. Three of these (1 to 3) lie in the upper half (alar plate) of the neural tube, which is sensory in function; three of them (4 to 6) are in the lower half of the neural tube (basal plate), which is motor in function. The primary cell bodies of the incoming fibers to the sensory columns are outside the brain or spinal cord in the sensory ganglia of the cranial nerves, eg, the trigeminal ganglion, the geniculate ganglion, the superior and inferior ganglia of the ninth and tenth nerves, or the dorsal root ganglia of the spinal nerves. The cell columns related to these incoming sensory fibers are, therefore, second order neurons and send their axons to other parts of the brain stem or to the cortex. The first three sensory columns in sequence from dorsal areas to ventral are as follows (Fig. 31):

Special Somatic Afferent Column. This column is associated with the special sense organs (nose, eye, ear), which are of ectodermal origin and so are "somatic" in origin. The olfactory neurons of the second order within the olfactory bulb, though situated in the cerebral hemisphere, must be considered to belong to this group. The lateral geniculate bodies, containing late order neurons of the primary visual pathway, represent the special somatic afferent nucleus of the optic nerve. The medial geniculate bodies likewise represent the tertiary end-station of the auditory pathway. The vestibular and cochlear nuclei in the pons represent the second order neurons of the auditory and vestibular pathways. They are also representative of the special somatic afferent column.

General Somatic Afferent Column. This column lies ventral to the special somatic afferent column and contains sensory fibers mediating sensations of pain, temperature, touch, vibration, and proprioception from the skin, joints, and tendons. It receives incoming cutaneous fibers of the trigeminal (fifth) nerve from the face and from the muscles of mastication and the temporomandibular joint. The main sensory nucleus of the fifth nerve (midpons) is believed to receive mostly tactile impulses. The long nucleus of the spinal tract of the fifth nerve, which extends from the midpontine level to the upper cervical region of the cord, is believed to receive predominantly pain stimuli. The ophthalmic, maxillary and mandibular areas of the trigeminal territory are represented upside down in the spinal tract and nucleus (ie the forehead at the bottom, the jaw at the top). Proprioceptive impulses from the muscles of mastication are believed to enter the mesencephalic nucleus of the trigeminal nerve, which lies lateral to the lower part of the midbrain aqueduct. This nucleus is unique in that the primary sensory neurons lie within the neural tube and not outside as do other primary sensory neurons. Also included in this column is the posterior horn of the gray matter, in which first order sensory neurons mediating pain, temperature, touch, and some proprioception have their synapse.

Visceral Afferent Column. This column lies dorsal to the sulcus limitans, delimiting the basal from the alar plate (see Fig. 30). It receives sensory impulses from the foregut and midgut derivatives, mainly taste sensation (conscious or unconscious) from the viscera. It also receives afferent stimuli from the walls of the great vessels (for example, the carotid sinus via Hering's nerve) that enter into important vascular reflexes affecting blood pressure and cardiac output. Sensory impulses from the viscera, not necessarily at the conscious level, entering the visceral afferent column, mediate important visceral reflexes, such as coughing, swallowing, and vomiting. The nucleus of the tractus solitarius, which lies in the medulla oblongata medial to the spinal tract and nucleus of the spinal tract of the trigeminal nerve, forms the visceral afferent column and receives afferent fibers of the facial nerve (eg tympani, chorda tympani, greater petrosal nerve), of the glossopharyngeal nerve (from carotid sinus, tongue, and pharynx), and of the vago-accessory complex (from larynx, pharynx, great vessels of thorax, esophagus, stomach, and small and large intestine as far distally as the splenic flexure). The nucleus is linked by a poorly defined "solitariospinal" tract with the spinal cord and mediates reflexes involving the diaphragm (phrenic C3 and C4) and the intercostal and abdominal muscles. Thus, in swallowing, the reflex is initiated by the contact of food with the posterior wall of the pharynx (ninth nerve); in sneezing, the afferent side of the reflex is the maxillary branch of the trigeminal nerve; in coughing, the afferent impulses reach the solitary tract and its nucleus through the vagus or cranial accessory nerve; and in vomiting, the afferent side of the reflex passes from the mucous membrane of the stomach to the solitary tract and nucleus through the vagus nerve. The efferent or motor side of these reflexes is mediated by connections between the solitary tract and the motor neurons of the medulla (such as respiration) and the spinal cord (diaphragm, intercostal and abdominal muscles).

Visceral Efferent Column. This group of cells, located ventral to the sulcus limitans (see Fig. 30), is the site of origin of the preganglionic fibers of the parasympathetic cranial outflow (see pp. 86 to 87). The neurons of this column supply smooth muscle and glandular tissue through the facial, the glossopharyngeal, and the vago-accessory complex. The nuclei of this column are the "superior salivatory nucleus" (high pons), the "inferior salivatory nucleus" (midpons), and the motor nucleus of the vagus (medulla and floor of fourth ventricle). This column is connected by short, connecting or internuncial neurons with the visceral afferent column (previously discussed) and is concerned in reflexes such as coughing and vomiting. Reflex contraction of smooth muscle, salivation, and gastric hypersecretion, for example, are parts of the vomiting reflex.

Branchial Efferent (Special Visceral Efferent) Column. This column comprises those nuclei concerned in the innervation of the musculature of the pharyngeal or branchial arches. It is, therefore, uniquely based on the embryologic origin of the these muscles (see p. 62 to 63). The nuclei from above down are the motor nucleus of the trigeminal nerve (high pons), the motor nucleus of the facial nerve (midpons), and the nucleus ambiguus (low pons and medulla). The motor nucleus of the trigeminal nerve supplies motor fibers to the muscles of the first arch (the muscles of mastication - tensor veli palatini, tensor tympani, mylohyoid, anterior belly of the digastric). The motor nucleus of the facial nerve supplies fibers to the muscles of the second arch (stapedius, platysma, stylohyoid and posterior belly of the digastric - the muscles of facial expression). The nucleus ambiguus supplies motor fibers to the muscles of the third, fourth, and sixth arches through the glossopharyngeal, superior laryngeal, and recurrent laryngeal branches of the vagus, respectively. Thus it supplies constrictors of the pharynx, the stylopharyngeus, the levator veli palatini, the intrinsic and extrinsic muscles of the larynx, and the striped musculature of the upper esophagus. The branchial efferent column is thus involved in swallowing and phonation. The nucleus ambiguus may be damaged by bulbar poliomyelitis or ascending paralysis of the brain stem, in which case the soft palate and the constrictor mechanism of the pharynx may fail. An ominous sign is regurgitation of fluid down the nose, indicating failure of the palatopharyngeal reflex. Phonation may also be defective following strokes that interrupt the corticobulbar fibers from the motor cortex of the nucleus ambiguus.

General Somatic Efferent Column. This column, which is the most ventral of the six columns, is made up of large neurons of motor type with prominent Nissl substance. The neurons supply fibers to the striated muscle of the head and neck that is derived from the somites. These include the extrinsic muscles of the eye, the muscles of the epipericardial ridge (sternomastoid, trapezius, and infrahyoid), and the intrinsic muscles of the tongue and the styloglossus. The cranial nerves and nuclei of this column are the nucleus of the oculomotor nerve (superior colliculus of midbrain), the hypoglossal nucleus (low medulla), and the lateral group of anterior horn cells of the upper five cervical segments of the spinal cord, which give rise to the spinal root of the accessory nerve. The general somatic efferent column also receives "upper motor neuron fibers" from the motor cortex of the opposite side and so is involved in strokes and injuries to the brain stem. Paralysis of the ocular muscles may occur. Paralysis of the muscles of the tongue and the styloglossus causes the protruded tongue to deviate to the affected side. Paralysis of the sternomastoid and trapezius is easily recognized.

Palate, Nose, and Paranasal Sinuses

Basic Embryology

Development of the Face

The face develops in the mesodermal tissues ventral to the overhanging forebrain (see Fig. 2). The presumptive facial area is covered externally by ectoderm, which also lines the slitlike mouth cavity or stomodeum. The junction between the ectoderm of the stomodeum and the endoderm of the foregut is the buccopharyngeal membrane (see Fig. 2), which disappears in the early somite stage. The position of this membrane, marking the junction of ectoderm and endoderm, is shown in the adult in Figure 44 and will be referred to later. Following the development of the pharyngeal arches, the stomodeum is flanked caudally by the first or mandibular arch, cranially and laterally by the maxillary extensions of the arch, and by the area of mesoderm and ectoderm in the midline which covers the overhanging forebrain (Fig. 32). Rathke's pouch may be seen in the roof of the stomodeum; it lies immediately anterior to the upper attachment of the buccopharyngeal membrane and so marks the posterior limit of the ectoderm in the roof of the mouth. Rathke's pouch gives rise to the anterior and middle lobes of the pituitary gland. Its position in the roof of the embryonic mouth is a useful point of reference during the rapid developmental changes that result in the formation of the nasal cavities and nasopharynx.

The face of an embryo of about 5 mm (28 days) is shown in Figure 32A. The most significant early event in the formation of the face is the development of the nasal pits. These arise bilaterally as placodes or thickenings of the surface ectoderm, indicated by dashed lines in Figure 32A. The nasal placodes then sink in to form bilateral nasal pits (Fig. 32B). The area between the nasal pits is the frontonasal area ("process"). Note that the frontonasal area is not in any sense a "process" since it is formed inevitably by the sinking in of the nasal pits on either side; it is formed by the mesoderm and its covering ectoderm between the deepening pits. The external openings of the nasal pits are flanked by flaring edges or nasal fins which merge imperceptibly ventrally with the tissues anterior to the mouth. At this stage (Fig. 32B), from an embryo of about 10 mm (33 days), the region of the future upper lip is thickened by the formation of swellings, indicating proliferative changes within the underlying mesoderm. A lateral swelling, which merges with the mandibular area at the angle of the mouth, is the maxillary growth area ("process"). A prominence in the midline between the nasal pits is the frontonasal swelling. There is a shallow groove between the maxillary and frontonasal swellings on either side. Note at this point in the description that there is at no stage a cleft between the frontonasal swellings and the maxillary swellings; in fact, a "harelip" does not exist at any stage in normal development. The external ear or pinna is already foreshadowed at the 10 mm stage (Fig. 32B) by growth centers around the upper end of the second external pharyngeal groove. These growth centers are also reflected as surface swellings, the six auricular swellings or "auricular hillocks" of His. Note that the cranial three of the swellings properly belong to the mandibular arch, and so are eventually supplied by the mandibular division of the trigeminal nerve, while the caudal three swellings lie in the second arch and so are eventually supplied by the seventh or facial nerve.

The face is shown at a later stage (15 mm; 37 days) in Figure 33. The changes in the surface contours of the components of the face are evident. The nasal pits are smaller relative to the face, and the lateral nasal flange or wing is rounded and more prominent. The groove between the maxillary swellings laterally and the somewhat depressed frontonasal area in the midline is deeper. There is another groove extending from the inner side of the eye to the lateral edge of the nasal pits (external nares), which marks the future site of the nasolacrimal duct. The duct is formed somewhat later by the deepening of the groove and the closure of its ectodermal edges to form a duct; a secondary opening into the inferior meatus of the nose is then formed. Apart from these specific changes in the relative proportions and details of the face, there are two other notable changes. One of them is the prominence of the cerebral hemispheres, which now impress themselves upon the overlying ectoderm and mesoderm, forming a definite forehead region. The prominence of the hemispheres is a specifically human feature at this early stage of development. The second change is the progressive displacement of the eyes from the lateral to the anterior surface of the head. This displacement is brought about by the pressures of the rapidly growing mesoderm behind the eyes, that is, in the regions destined to form the parietal bones, the squamous temporal bones, and the greater wings of the sphenoid. This shift in position of the eyes is a necessary prerequisite for binocular vision and involves an overlapping of the visual fields. In the absence of the pressures from the temporal and parietal area of mesoderm, as from some unexplained growth failure, the eyes and ears tend to remain abnormally placed on the side of the head. Other changes in the conformation of the face at this stage (Fig. 33) are the narrowing of the mouth by proliferations of maxillary and mandibular mesoderm at the angles, and a relative increase in prominence of the auricular hillocks. Note that these hillocks are situated far caudally with respect to the angle of the mouth. This is their primitive position and tends to be retained in certain genetic defects often associated with mental retardation and extensive mesodermal defects involving dermal bones of the skull. Its persistence in the adult should alert the clinician to associated genetic defects.

In the final evolution of the face, the salient features are the development of a prominent nasal bridge resulting from delayed growth in the frontonasal area between the medial nasal wings, and smoothing out of the grooves between the various growth centers ("processes") of the face.

Facial Growth Centers ("Processes") and the Genesis of Harelip

For many years, since the classic descriptions of His, it has been customary to describe the components of the embryonic face as consisting of "processes". The early models of His show such processes, which clearly have free extremities coated externally by ectoderm. It was commonly supposed that the upper lip, for example, was completed by fusion of the frontonasal process and the maxillary process, in which the abutting ectoderm first fused and then was absorbed (Fig. 34A). Harelip was supposed to be a persistence of the embryonic condition resulting from failure of the processes to fuse.

Streeter, in his classic "Developmental Horizons in Human Embryos", first pointed out the error of this concept. He observed that processes, in the sense that they were free at some point and had overlying ectoderm, never exist at any stage in the development of the human face. He writes: "In reality they (the processes) are not prolongations having free ends which meet in the nasal region; nor is the ectoderm absorbed over the abutting surfaces ... It is more precise to speak of these structures as swelling or ridges which correspond to centers of growth in the underlying mesenchyme. The furrows that lie between them on the surface are smoothed out as the proliferations and fusion of the growth centers fill in beneath. Under these circumstances no ectoderm requires absorption; it is simply flattened out in adaptation to the changed surface". An attempt to compare the classic concept of "processes" with the revised version of Streeter is shown in Fig. 34A and B. Streeter's version is certainly correct, since a study of embryos at critical periods fails to reveal any processes in the sense of His, nor is any trace of absorbing ectoderm between the so-called processes to be found. The genesis of harelip must be reevaluated in the light of Streeter's concept.

Development of the Upper Lip and the Genesis of Harelip

According to Streeter's concept, the upper lip is completed by the fusion of growth centers in the maxillary and frontonasal areas beneath the overlying ectoderm, the intervening shallow grooves being simply "ironed out" and brought to the general level of the surrounding tissues (Fig. 34B). The defect resulting in harelip may then be considered in the light of a growth failure in the mesoderm involved rather than a failure of free processes to fuse. Thus, if the maxillary or frontonasal mesoderm should be delayed in its proliferation, the intervening groove, far from being smoothed out, might rather be deepened. The cause of such a mesodermal growth failure is, of course, unknown. It could be a nutritional failure or could result from some genetic failure in the growth and differentiation of the mesoderm.

The subsequent development of a frank defect or cleft in the upper lip, either passing through into the vestibule of the mouth or, in more severe cases, extending deeper into the palate lateral to the premaxilla on one or both sides, also requires further explanation. In the genesis of these defects, a further phenomenon may also be involved. This is the formation of the primary dental lamina and its subsequent division into the dental lamina and the labiodental lamina. It occurs much later than the events already described in the formation of the face and begins in embryos of about 18 mm (38 to 40 days). There is an ingrowth of ectoderm in the roof and floor of the mouth near its external opening, in a curving manner following the contour of the future vestibule of the mouth and the line of the teeth. The primary dental lamina then becomes subdivided into an anterior labiodental lamina and a posterior dental lamina (Fig. 35A). Cavitation of these anterior or labiodental laminae results in the formation of the vestibule of the mouth, between the lips and the teeth. The cavitation is incomplete anteriorly, forming the frenulum. More extensive failure of cavitation results in various degrees of "tongue-tie". The teeth are developed from the dental lamina.

It is evident from the foregoing description that soon after the definitive form of the face is laid down there appears on the deep surface of the future upper and lower lip a linear tract of ectoderm, the labiodental lamina, later the labiodental sulcus or vestibule of the mouth. From this point its relationships to the genesis of harelip becomes conjectural. It is conceivable, however, that the coexistence of a deep furrow between the maxillary and frontonasal growth centers, resulting from a delayed growth of one or the other of these centers, associated with the formation of labiodental sulcus, may result in fusion of the ectoderm of the upper lip with that of the labiodental sulcus. Under these circumstances, which probably occur at about the 20-mm stage (end of the sixth week), the possibility of restitution of the upper lip by fusion of the maxillary and frontonasal growth centers is gone forever, and subsequent breakdown of the intervening ectoderm results in a simple harelip. The cases of harelip that also involve the hard palate are to be explained on a similar basis but will be described after the description of the formation of the hard palate.

Developmental Abnormalities of the Face

In addition to harelip, there are many abnormalities in the development of the face, based largely on its origin from several discrete growth centers in the mesoderm. Microstomia and macrostomia, in which the mouth cleft is respectively narrowed or widened, result from excessive or defective proliferations at the angles of the mouth. Macrostomia may be so severe that the angle of the mouth extends far posteriorly, cutting the ramus of the mandible off from developing its normal articulation with the base of the skull. In this case, there is frequently persistence of Meckel's cartilage (mandibular or first arch cartilage (see discussion earlier in this chapter)), which may be ossified and constitute the only connection between the mandible and the skull on the affected side. There is frequently an associated defective development or failure of the malleus and incus and of the external auditory meatus. In such cases, the stapes and the inner ear are always normal, so that the surgeon may reconstitute the ossicular chain with confidence of restoring hearing.

Microstomia is often associated with and probably results from failure of growth of the mandibular arch. The mandibular arch normally shows a delay in development compared with the more cranial components of the face and skull. This relative delay may result, in its less severe manifestations, in a simple undershooting of the lower jaw, common in new babies and a cause of faulty bite in older children. In more severe cases, in which the mandibular arch is partially or almost completely suppressed, micrognathia or agnathia results. The mouth is usually minute and the mandible vestigial, and there may be fusion of the middle ear cavities in the midline caudal to the mouth. The external ear, which depends on the growth pressure of the mandibular arch in reaching its normal position, retains its primitive position low down in the neck and close to the midline (see Fig. 33). In severe micrognathia or agnathia, the auricles are fused in the midline caudal to the mouth.

Clefts of the face may also exist and may, in some cases, be related to the boundaries between the developmental regions of the face. Macrostomia is a persistence of the normal wide cleft of the mouth. An oblique cleft may run from the medial angle of the eye to the upper lip and may be associated with a harelip. Such a cleft is a persistence of the normal nasolacrimal groove between the maxillary swelling and the lateral nasal wing (see Fig. 33). In such cases, the lacrimal groove is laid open and discharges tears onto the surface of the face. Other clefts of the face may run in almost any direction but do not conform to any normal geographic boundaries of the face and so are not easily explained.

Development of the Auricle or Pinna

The auricle or pinna develops as six swellings or "hillocks" surrounding the upper end of the second external pharyngeal groove (Figs. 32, 33, and 36A). The auricle becomes established by the growth and fusion of these disparate growth centers (Fig. 36B). The first hillock (most anterior on the mandibular arch) becomes the tragus; the second, the crus helicis; the third, the helix. The fourth hillock (most posterior on the second or hyoid arch) becomes the antihelix; the fifth, the antitragus; and the sixth (most anterior on the hyoid arch), the lobule.

Abnormalities or genetically determined variations in the pattern of fusion of the auricular hillocks account for the frequent abnormalities of the auricle and for the striking familiar resemblance between people with respect to the ear. Accessory nodules, usually anterior to the tragus, arise from accessory or additional hillocks. They are of little consequence except cosmetically. Their removal, however, is often accompanied by considerable hemorrhage. Grossly deformed auricles, as described, especially when associated with a low position of the ear on the side of the head, should alert the clinician to accompanying mesodermal and neural defects.

Developmental Territories of the Face in Relation to Nerve Supply

The broad developmental regions of the face, namely, the frontonasal, the maxillary, and the mandibular areas, are reflected in their pattern of sensory supply from the fifth or trigeminal nerve (Fig. 37).

The first or ophthalmic division of the trigeminal nerve (VA) supplies the frontonasal area. The maxillary division (VB) supplies the area derived from the maxillary swellings (see Fig. 33). The mandibular division (VC) supplies the mandibular arch, including the lateral and upper half of the auricle, but excluding the angle of the jaw.

The nerve of the frontonasal "process" is generally held to be the anterior ethmoidal nerve, a branch of the nasociliary nerve arising within the orbit. It leaves the medial wall of the orbit through the ethmoidal canal between the frontal bone and the lamina papyracea of the ethmoid and enters the anterior cranial fossa of the skull on top of the cribriform plate of the ethmoid. It then pierces the anterior cranial fossa lateral to the crista galli and descends into the nasal cavity deep to the nasal bone, lying in a groove in the bone. It reaches the skin between the lower edge of the nasal bone and the nasal cartilage of the ala and, as the lateral nasal nerve, supplies the skin of the lateral surface of the nose. The curious course of this nerve is explained as follows: the nerve originally has a simple course, descending into the frontonasal region of the face. It is later trapped between the cartilaginous nasal capsule (later forming the ethmoid) and the orbital plate of the frontal and nasal bones, both of which are "dermal bones", ie developed "in membrane" in the superficial mesoderm. Thus, the nerve lies in its definitive position before the bones are formed. The bones are then laid down around it and so determine its complex anatomic course in the adult skull. The remaining ophthalmic territory of the face (Fig. 37) includes the forehead (via the supraorbital and supratrochlear nerves); the upper eyelid, including the conjunctiva and upper half of the cornea (via the lacrimal and supratrochlear nerves); and the side of the nose (via the infratrochlear and external nasal nerves).

The maxillary territory of the face includes the area below the palpebral fissure (lower eyelid, including the lower half of the cornea) and the upper lip (via the infraorbital nerve), the zygomatic region, and the side of the temple (via the zygomaticofrontal and zygomaticotemporal nerves)(Fig. 37).

The mandibular territory includes the area below the mouth (via the mental nerve), the cheek (via the buccal nerve), and the side of the temple, including the upper part of the auricle (via the auriculotemporal nerve). Note that the palpebral fissure and the angle of the mark delineate the territories of the three divisions of the trigeminal nerve on the face (Fig. 37). The angle of the jaw is supplied by the cervical plexus through the great auricular nerve (C2 and C3) and so is excluded from the mandibular territory. The lower part of the auricle is supplied by the great auricular nerve and the lesser occipital nerve (C2 and C3), and so is also excluded from the trigeminal territory.

The trigeminal nerve is notorious for mediating referred pain, often making exact diagnosis difficult. Pain arising in the teeth (via the superior and inferior dental nerves) is also referred through the auriculotemporal nerve to the external ear and parotid region, thus imitating the pain of external otitis or an impacted foreign body. Pain may also be referred from the teeth to the temporomandibular joint or in the reverse direction. Note the close anatomic relationship between the auriculotemporal nerve and the posterior surface of the capsule of this point (see Fig. 23). Areas of the trigeminal sensory territory may also be "trigger areas" for pain in trigeminal neuralgia or tic douloureux.

Development of the Palate

The development of the premaxillary portion of the palate (primordial palate), ie that part that carries the incisor teeth, differs fundamentally from that of the rest of the palate both in manner and in the time at which it is formed.

The formation of the premaxillary portion of the palate occurs early (from the 33rd to the 37th day) in conjunction with the development of the face (see Figs. 32 and 33) and as an inevitable consequence of the development of the bilateral nasal pits. As the nasal pits sink into the paraxial mesoderm of the face and deepen, there is left between them a midline mass of mesoderm that constitutes the nasal septum. Ventral to the nasal pits there is a block of mesoderm that constitutes the upper lip and is necessarily continuous above with the primitive nasal septum (Figs. 38A and B). At a slightly later stage, the nasal pits approach the ectoderm in the roof of the mouth just anterior to the point of origin of Rathke's pouch (Fig. 38B). Fusion between the ectoderm of the nasal pits and that of the roof of the mouth results for a time in a thick bucconasal septum, which then becomes attenuated, forming the bucconasal membrane. The bucconasal membrane then breaks down (Fig. 38C), establishing a posterior opening into the roof of the mouth from the nasal pits, the primitive posterior nares. It is now possible to speak of nasal cavities on either side, separated by a thick nasal septum, opening anteriorly through the anterior nares and posteriorly through the primitive posterior nares. The roof of the nasal cavity, which is in close relationship to the overlying forebrain, becomes differentiated into the olfactory epithelium, a primary sensory receptor for smell. Sensory cells from this area send out processes, comparable to axons, toward the overlying olfactory bulbs and establish primary synaptic connections with the cells of the bulbs (Fig. 38C and D). The differentiation of the olfactory epithelium goes hand in hand with that of the olfactory bulb, and the interaction between the two is an example of primary induction. In the absence of the olfactory bulbs, the olfactory epithelium fails to develop, resulting in congenital anosmia.

It is necessary to reemphasize that the primordial palate is merely a block of mesoderm lying transversely ventral to the nasal pits. It represents that part of the mesoderm of the face anterior to the mouth not involved in the formation of the nasal pits, which, from the manner of its formation, must necessarily be continuous above with the nasal septum between the two pits. The primordial palate presents onto the surface of the face as a depressed area between the maxillary swellings, continuous with the frontonasal area (see Fig. 33). As noted elsewhere, at no stage is there a condition resembling harelip; the ectoderm of the tissues anterior to the mouth forms an unbroken stretch from side to side. The primordial palate cannot in any sense be considered a "process".

The subsequent growth of the head results in a progressive increase in the anteroposterior and lateral extent of the mouth and pharynx. This process insofar as it affects the nasal septum is illustrated in Figure 39. The posterior nares become progressively enlarged posteriorly (in the directions of the small arrows) as the nasopharynx deepens and, as a consequence, the nasal septum also becomes elongated. It now presents into the roof of the mouth as a broad extensive area between the posterior nares. In this process of extension of the posterior nares, the point of origin of Rathke's pouch must be assumed to be taken up into the area involved in the new part of the nasal septum (Fig. 39). At this stage, beginning about the ninth week, the maxillary and palatal portions of the hard palate are developed and fill in most of the roof of the mouth posterior to the primordial palate (Fig. 39D).

Development of the Palate Posterior to the Premaxilla

The large orifices of the posterior nares resulting from their posterior extension and the increased depth of the nasopharynx and base of the skull (Fig. 39) are now partially closed off by the development of maxillary shelves on either side. The maxillary shelves appear about the 35th day (in embryos of 12 mm) and are true processes in that they have free extremities and are covered on all sides except where they are continuous with the maxillary mesoderm (Fig. 40B). The shelves grow in from the lateral wall of the oronasal cavity and at first lie freely within the paralingual sulcus. They are prevented for considerable time from making contact with the undersurface of the nasal septum by the tongue which is pressed hard against it. The tongue is withdrawn from contact with the nasal septum about the ninth week, thus allowing the free edges of the palatal shelves to fuse with the nasal septum (Fig. 40C). Fusion then occurs rapidly along approximately the anterior three fourths of the free surface of the nasal septum. The palatal shelves fall short of the nasal septum posteriorly and constitute the soft palate (see Fig. 38D). That part of the nasal septum posteriorly that fails to fuse with the palatal shelves forms the definitive posterior edge of the nasal septum. The posterior nares of the adult are not fully established until the process of palatal fusion is complete, by about the 12th week.

The pattern of fusion of the palatal shelves and the nasal septum and the primordial palate is shown in Figure 41. The fissure observed in complete cleft palate also follows this pattern. It may be unilateral or bilateral.

Genesis of Cleft Palate

Understanding of the genesis of cleft palate must take into consideration the normal facts of development. Failure of the palatal shelves to fuse with the undersurface of the nasal septum is clearly the immediate cause of cleft palate. This failure may be partial, complete, unilateral, or bilateral. The soft palate may be divided, since it is developmentally a bilateral structure. The cleft, whether unilateral or bilateral, passes laterally around the primordial palate anteriorly and so passes between the lateral incisor teeth and the canine teeth. The possible factors involved in the formation of harelip have already been considered. Harelip is often associated with cleft palate, though not necessarily. It is obvious from the close clinical association between these two defects that there must be certain common developmental causes. If the primary defect is considered to be a failure of or delay in mesodermal growth centers, notably those of the maxillae, it is reasonable to suppose that not only will a harelip be produced but that also there will be a predisposition for maldevelopment of the palatal shelves. Mechanical factors in the failure of the palatal shelves to fuse with the nasal septum have also been considered. The continued apposition of the tongue to the nasal septum precludes fusion of the palatal shelves, and it is supposed that the withdrawal of the tongue is a definitive factor in determining the success or failure of this fusion. That the mandibular region is relatively delayed in its growth has been observed. It is conceivable that the growth of the mandible finally results in the withdrawal of the tongue from the nasal septum. Extensor movements of the neck of the fetus have also been considered as factors influencing the withdrawal of the tongue. Many teratogenic agents, notably cortisone in susceptible strains of rats, cause cleft palate. It seems reasonable to suppose that such agents affect mesodermal growth or differentiation and that mechanical factors are here relatively less important. The enormous number of chemical and hormonal agents that may result in cleft palate in susceptible strains suggests that (1) genetic factors are involved; (2) there is no specific inducer of cleft palate, but rather the maxillary mesoderm and its palatal shelves are for some reason highly susceptible; and (3) the delayed pattern of fusion of the palatal shelves with nasal septum and possibly the influence of mechanical factors also render the process highly susceptible.

Further Development of the Nasal Cavities and Paranasal Sinuses

The olfactory organs are phylogenetically ancient structures and, like the inner ear, are enclosed within the equally ancient chondroskeleton of the skull. The nasal cavities become surrounded by a condensation of mesenchyme, which then chondrifies, forming the nasal capsule (see Figs. 40B and C). The chondrification spreads down into the nasal septum and also into the lateral wall. Processes of the lateral walls give rise to the superior, middle, and inferior conchae (turbinates), which provide added mucosal surface for the warming of the incoming air. The olfactory epithelium, on the upper surface of the nasal septum, the adjacent roof, and the lateral wall of the nasal cavity, lies in a cul-de-sac relatively secluded from the main flow of air. This arrangement avoids excessive drying and also permits the odorous materials in the air to remain in contact with the olfactory epithelium. The sensory fibers arising from specialized receptor cells in the olfactory epithelium pass through the roof of the nasal capsule (future cribriform plate of the ethmoid) to reach the olfactory bulbs. They are surrounded for a part of their length distal to the olfactory bulbs, with extensions of the meninges that resemble central tracts in that they do not regenerate after section, so that the anosmia resulting from trauma is permanent. The olfactory filaments are also important in that they are able to transmit certain agents such as viruses from the nose to the primary olfactory centers of the brain. This pathway is suggested for rabies, thus accounting for the presence of the inclusion bodies (Negri bodies) in the primary cortical receptor, the hippocampus. They may also be involved in the transmission of other viruses, including poliomyelitis virus. Associated with the olfactory epithelium are serous glands that lubricate the area and keep it moist. They receive their secretomotor supply from the facial nerve via the sphenopalatine ganglion and the nerve of the pterygoid canal (vidian nerve).

The paranasal sinuses are developed as outgrowths from the lateral wall of the nasal cavities, that is, from the lateral wall of the nasal cavities, that is, from the meatus bounded by the three conchae and the adjacent roof and floor. The maxillary sinus appears as an outpouching of the nasal mucosa in the third month of fetal life. The frontal sinus develops as an outgrowth of one of the anterior groups of the ethmoidal air cells. It does not penetrate the frontal bone, as a rule, until after birth. It invades the bone in the first and second years after birth, undergoes a growth spurt about the ninth year, and reaches its full size at about age 20. The ethmoidal air cells, growing from the superior and inferior meatus, are present at birth, grow slowly after birth and reach their full development about puberty. The sphenoidal air sinuses are not enclosed by bone at birth. They increase rapidly about the third year and show additional growth at puberty. The maxillary sinuses are small cavities at birth in the shallow maxillae. They extend laterally as far as the infraorbital nerve by the end of the first year and grow steadily thereafter until about the tenth year. Their subsequent growth occurs in association with the eruption of the permanent teeth. The posteroinferior angle of the sinus is added last in connection with the eruption of the last molar teeth.

Development of the Lacrimal Apparatus

As described earlier, the lacrimal duct is developed along the line of the nasolacrimal furrow between the lateral nasal wing and the maxillary swelling (see Fig. 33). The ectoderm in the floor of the furrow deepens and the margins then close over to form the duct, which loses its connection with the surface. The duct than acquires a secondary opening into the inferior meatus of the nasal cavity. At its upper end, the duct bifurcates and establishes connections with the conjunctival sac at the inner canthus of the eye (lacrimal canaliculi). The lacrimal gland develops as an ectodermal proliferation of the conjunctival sac at the upper and outer angle of the eye. It receives its secretomotor supply from the sphenopalatine ganglion and the facial nerve via the zygomaticotemporal nerve. Note that the gland is an ectodermal structure and quite superficial. It lies external to the orbital septum, and its removal does not involve invasion of the orbit itself.

Development of the Salivary Glands

The parotid gland is ectodermal in origin and arise as a proliferation at the angle of the mouth in embryo of about 12 mm. The opening of the duct (Stensen's duct) then shifts posteriorly and comes to open into the vestibule of the mouth at the level of the second upper molar tooth. The submandibular gland develops as a groove in the endoderm in the floor of the mouth in the paralingual sulcus. The edges of the groove then close over except anteriorly at the external opening of the duct (Wharton's duct). Since the duct arises from the epithelium in the floor of the mouth, the lingual nerve must lie inferior to it. This accounts for the characteristic curving course of the lingual nerve, at first lateral, then under and, finally, medial to the submandibular duct (see Fig. 20). The sublingual glands arise as multiple proliferations of the endoderm in the floor of the mouth.

Anatomy of the Nasal Cavity and Nasopharynx

Nasal Cavities and Nasopharynx

The general features of the nasal cavities and nasopharynx (Fig. 42) are familiar and require only superficial comment. Prominent features of the lateral wall of the nasal cavity are the three scroll-like conchae or turbinate bones. The mucosa overlying these, as over the nasal septum and in the sinuses, is a typical mucoperiosteum or, where cartilage is present, a mucoperichondrium. The epithelium is pseudostratified columnar and ciliated. It rests on a basal lamina, which is attached firmly to the underlying bone or cartilage by dense but highly vascular connective tissue. Submucous resection is carried out by separating the mucosa with the periosteum or perichondrium, which together form a structural and functional unit. In certain areas, notably the conchae, the submucosal connective tissue contains large venous channels that are capable of engorgement. They serve to warm the incoming air but may give rise to obstruction when engorged from inflammation. Most of the serous glands that moisten the nasal mucosa (serous glands of Bowman) lie in the upper reaches of the cavity in relation to the olfactory epithelium. There are numerous mucous glands or goblet cells scattered throughout the nasal mucosa. These, like the serous glands, are supplied from the sphenopalatine ganglion and the facial nerve.

The conchae form the boundaries of three horizontal passages or meatuses (superior, middle, and inferior). The sphenoethmoidal recess (Fig. 42) lies above the superior concha and receives the opening of the sphenoidal sinus. The superior meatus (between the superior and middle conchae) receives the openings of the superior, and possibly a few of the middle ethmoidal sinuses. The middle meatus lies between the middle and inferior conchae and receives the openings of the anterior and some of the middle ethmoidal sinuses, the opening of the maxillary sinus, and anteriorly, the opening of the frontal sinus. These will be described in detail later. The inferior meatus between the floor of the nasal cavity and the inferior concha receives the opening of the nasolacrimal duct. Note that the superior and middle conchae are parts of the ethmoid bone, whereas the inferior concha is a bone in its own right.

The roof of the nasal cavity is formed by the cribriform plate of the ethmoid bone (which transmits the olfactory filaments), by the undersurface of the sphenoid bone, and by the nasal area of the frontal and nasal bones. The nasal septum is made up of the vomer and the perpendicular plate of the ethmoid (Fig. 43). The perpendicular plate of the ethmoid rests below on the vomer and projects far forward to carry the nasal bones. The vomer articulates above with the undersurface of the base of the sphenoid, and inferiorly makes contact with the whole length of the hard palate, made up of the horizontal plate of the maxilla anteriorly and the horizontal plate of the palatine posteriorly. The vomer is marked by a groove in which lies the nasopalatine (long sphenopalatine) nerve on its way to the incisive canal. The nasal septum is completed anteriorly by cartilage (Fig. 43). Posteriorly, the nasal cavities open into the nasopharynx through the posterior nares, which are bounded in the midline by the vomer, superiorly by the articulation of the vomer with the vaginal process of the medial pterygoidal plate (see Fig. 47), laterally by the vertical plate of the palatine, and below by the horizontal (palatal) process of the palate bone.

The nasopharynx (see Fig. 42) is a cavity that, unlike the rest of the pharynx, has rigid walls except inferiorly, where it is bounded by the soft palate, and so is never obliterated under normal conditions. In transverse section, the nasopharynx (see Fig. 23) is rhomboidal. It narrows anteriorly, where it joins the posterior nares. Its lateral angles are prolonged out as far as the spine of the sphenoid, forming the lateral recesses of the fossae of Rosenmüller (Fig. 23). The lateral recesses owe their existence to the oblique attachment of the pharynx to the base of the skull along the line of the petrosphenoidal suture. Here the wall is formed by the "eustachian apparatus", comprising the pharyngotympanic tube, the tensor and levator veli palatini muscles and associated fascial layers (see Fig. 22). The lateral recess has important relationships in addition to those structures comprising the eustachian apparatus. It is related posterolaterally to the internal carotid artery and the venous and neural components of the retrostyloid space. Posteriorly, it is related to the retropharyngeal space (see Fig. 24). An abscess in the retropharyngeal space may bulge or point into the lateral recess of Rosenmüller. Likewise, an aneurysm of the internal carotid artery may bulge into the space and result in fatal hemorrhage if mistaken for an abscess and incised. The recess is a useful factor in cannulating the eustachian tube. The instrument is placed first in the recess and slowly drawn forward so that it will traverse the whole inner surface of the cartilaginous tube until it enters the orifice.

The orifice itself (see Fig. 42) lies about 1 cm behind and a little below the posterior end of the inferior concha. It is thickened above and behind by lymphoid tissue, forming the tubal tonsil of Gerlach. The roof and posterior wall of the nasopharynx are continuous and sloping. They are formed by the inferior surface of the body of the sphenoid, the basioccipital, and anterior atlanto-occipital membrane, the anterior arch of the atlas, and the body of the second or axis vertebra (see Fig. 42). Inferiorly, the nasopharynx opens into the oropharynx. The opening is closed off during deglutition by the soft palate and by the contraction of the sphincteric fibers of the superior constrictor (Passavant's sphincter). These fibers may raise up a definite ridge on contraction and come into contact with the soft palate during swallowing. The sphincter may also make examination of the nasopharynx by a mirror difficult.

The oropharynx is the intermediate portion of the pharynx (see Fig. 42) and stretches from the level of the soft palate to the level of the upper border of the epiglottis. Its lateral walls are shown in Figure 19. They include the superior constrictor, the middle constrictor muscle, the gap between these muscles containing the stylohyoid ligament and the styloglossus, and also the curve of the glossopharyngeal nerve and the external maxillary artery. The oropharynx communicates with the mouth anteriorly through the oropharyngeal isthmus. The isthmus is guarded laterally by the palatine tonsils, which lie in the tonsillar fossa between the anterior and posterior pillars of the fauces. The former is produced by the palatoglossus muscle and the latter by the palatopharyngeus muscle. The posterior wall of the oropharynx is formed by the body of the second and possibly part of the third cervical vertebrae (see Fig. 42); like the rest of the pharynx, here it is related to the important retropharyngeal space.

The laryngopharynx extends from the upper level of the epiglottis to the lower border of the cricoid cartilage, where it is continuous with the esophagus (level of the upper part of the sixth cervical vertebra). It is described in connection with the larynx.

Lymphoid Tissue of the Pharynx and Waldeyer's Ring

The lymphoid tissue that surrounds the oropharyngeal isthmus and the opening of the nasopharynx into the oropharynx is referred to as Waldeyer's ring (Fig. 44). It is formed superiorly by the midline pharyngeal tonsil or "adenoids". It is continuous laterally on either side with the tubal tonsil. Lower down on either side are the palatine tonsils. The ring is completed inferiorly by the lymphoid tissue in the posterior third of the tongue (lingual tonsil). In the newborn child and infant, the craniocaudal extent of the pharynx is much less than in the adult, so that the normal hypertrophy of the lymphoid tissue of Waldeyer's ring readily occludes the posterior nares and the opening from the nasopharynx into the oropharynx, especially when inflammation is present. Nasal obstruction and mouth breathing, accordingly, are very common and may require surgical correction.

Nerve Supply of Nasal Cavity and Pharynx

The nasal cavity receives its sensory nerve supply from the maxillary and the ophthalmic nerves. Sensory fibers reach the sphenopalatine ganglion via the nasopalatine (from nasal septum and anterior part of the palate), greater palatine (posterior part of the palate), and lesser palatine nerves (soft palate); by branches from the sphenoidal sinus and ethmoidal sinuses; and by branches from the maxillary sinus via the superior dental nerves. Blocking the sphenopalatine ganglion, therefore, provides satisfactory anesthesia for most parts of the nasal region, including the sinuses. The ethmoidal nerves, branches of the nasociliary branch of the ophthalmic nerve, are exceptions. The anterior ethmoidal nerve supplies the anterior group of ethmoidal cells and the anterior part of the nasal septum. The posterior ethmoidal nerve, which may be absent, supplies the posterior ethmoidal cells and the sphenoidal air sinus.

The parasympathetic fibers to the glandular tissue of the nasal cavities and sinuses, including the lacrimal gland, are derived from the sphenopalatine ganglion. They reach the ganglion through the nerve of the pterygoid canal (vidian nerve), formed by the union of the greater petrosal nerve and the deep petrosal nerve (see Figs. 24 and 30). The greater petrosal nerve arises from the facial nerve at the level of the geniculate ganglion and emerges through the anterior surface of the petrous temporal bone in the middle cranial fossa. Here, it lies deep to the dura, forming the floor of Meckel's cave, in which is lodged the gasserian ganglion. Traction on the nerve at this point in trigeminal ganglionectomy may pull on the facial nerve and give a transient or permanent facial paralysis. The nerve then joins with a sympathetic branch (deep petrosal) from the caroticotympanic plexus on the internal carotid artery, which together form the nerve of the pterygoid canal (vidian nerve). The vidian nerve traverses a canal in the sphenoid at the root of the pterygoid process (see Fig. 47) and emerges in the pterygopalatine fossa where it enters the sphenopalatine ganglion. The parasympathetic fibers have a synapse here, and the postganglionic fibers pass via the branches of the ganglion to the glandular tissue of the nose and sinuses. The sympathetic fibers do not relay, having had their last synapse in the superior cervical sympathetic ganglion, and are distributed to glandular tissue and blood vessels of the nose and sinuses. The branches of the sphenopalatine ganglion described previously are generally accompanied by arteries derived from the internal maxillary artery.

Destruction of the sphenopalatine ganglion, a common operation at one time for hay fever and allergic conditions, is followed by catastrophic atrophy of the glandular tissue of the nose, palate, and sinuses. This results in loss of smell and a chronic malodorous inflammatory condition (ozena) of the nasal passages. The ganglion may be approached for temporary blocking by two routes. One is through the nose, the needle being directed through the mucous membrane at the posterior end of the inferior meatus. The second route is laterally through the cheek, the needle being directed through the infratemporal region until it passes into the pterygopalatine fossa between the pterygoid plates and the maxilla. The sensory supply of the nasopharynx is via the pharyngeal nerve. This small branch of the sphenopalatine ganglion lies in a groove completed by the articulation of the vaginal process of the medial pterygoid plate and the sphenoidal process of the palatine bone (see Fig. 47). It passes backward and innervates the area around the eustachian tube and the lateral pharyngeal recess.

Sensory impulses are transmitted from this nerve to the maxillary branch of the trigeminal nerve; sympathetic and parasympathetic fibers are transmitted by the vidian nerve. The oropharynx derives its sensory fibers from the pharyngeal plexuses on the lateral surface of the middle constrictor muscle. These fibers pass up to the brain in the glossopharyngeal nerve but also in the pharyngeal branches of the vagus and the superior and inferior laryngeal branches of the vagus. Secretomotor branches are distributed to the pharynx via the pharyngeal plexus, comprising fibers of the ninth, tenth, and possibly eleventh cranial nerves. Sympathetic fibers enter the pharyngeal plexus through the sympathetic branches of the superior and middle cervical sympathetic ganglia. The sensory territories of the glossopharyngeal nerve may act as trigger zones for paroxysmal attacks of pain analogous to trigeminal neuralgia. All the afferent fibers from the pharynx on reaching the brain enter the tractus solitarius (general visceral afferent column). They relay in the nucleus of the tractus solitarius and make internuncial or short intermediary connections with other nuclei of the medulla and also connect with the spinal cord through the solitariospinal tract.

The motor fibers to the constrictors of the pharynx belong to the group of special visceral (branchial) efferent neurons. They arise in the nucleus ambiguus in the medulla and pass to the pharynx through the glossopharyngeal, vagus, and possibly the cranial component of the eleventh or accessory nerve. These connections of the tractus solitarius and nucleus ambiguus are important in reflexes such as coughing, sneezing, swallowing, gagging, vomiting, and so forth.

The Mechanisms of Deglutition

Following mastication of the food, the process of swallowing is initiated by the contraction of the tongue and the muscles in the floor of the mouth. The bolus of food is passed through the oropharyngeal isthmus and enters the oropharynx. The mouth is then closed. The opening between the nasopharynx and the oropharynx is then closed by the elevation of the soft palate by the tensor and levator veli palatini muscles and by the contraction of Passavant's sphincter. There is approximation of the palatoglossal and palatopharyngeal arches (anterior and posterior pillars of the fauces) to the back of the tongue. The pharynx is thus converted into a closed box. The larynx and pharynx are then elevated by contraction of the stylopharyngeus and thyrohyoid muscles so that the floor of the pharyngeal compartment rises. The larynx then descends, carrying with it the lower pharynx (hypopharynx), producing a piston-like effect on the closed upper pharynx. The bolus of food is sucked toward the esophagus with great speed, perhaps assisted momentarily by contraction of the middle and inferior constrictors. Most if not all of this phase of swallowing, however, is too rapid to be primarily peristaltic in character. It is so rapid that when corrosive liquids are swallowed, the area of damage may be in the hypopharynx or in the esophagus. That pressure differences are fundamental in the act of swallowing is shown when regurgitation takes place due to failure of closure of the nasopharyngeal "pinchcock". Under these circumstances, fluids are projected through the nose with considerable violence. This may happen inadvertently but may be an ominous sign in a patient with bulbar paralysis, indicating involvement of the nucleus ambiguus, the first sign that the process has ascended to the level of the medulla.

The importance of a proper mechanism for closure of the nasopharynx in normal speech is also recognized.

Limits of Ectodermal and Endodermal Territories in the Adult Nose, Mouth, and Pharynx

The approximate site of the buccopharyngeal membrane, which marks the posterior limit of the ectoderm and the anterior limit of the foregut endoderm, is indicated by the double line in Figure 44. The line begins superiorly near the pharyngeal tonsil, at the approximate site of origin of Rathke's pouch. It then passes down the lateral wall of the nasopharynx, anterior to the eustachian orifice, which is of endodermal origin. It then passes into the floor of the mouth anterior to the palatoglossal fold (anterior pillar of the fauces) and inside the line of the teeth. It finally reaches the symphysis menti to join the line of the opposite side. All structures posterior to this line are endodermal in origin and are supplied by nerves caudal to the fifth (seventh, ninth, tenth, eleventh, and twelfth).

Anatomy of the Paranasal Sinuses

The paranasal air sinuses comprise the maxillary, the ethmoidal, the frontal, and the sphenoidal sinuses. They are developed as diverticula of the nasal mucosa and, like it, are lined by a mucoperiosteum. The mucoperiosteum consists of a pseudostratified ciliated columnar epithelium, with scattered mucus-secreting goblet cells, firmly attached to the periosteum. The cilia beat toward the nasal cavities, though drainage is often hampered by the small size of the opening from the sinus to the nose and by the absence of mechanical and gravitational effects. The sinuses are poorly developed or absent at birth, reach more or less adult size by puberty but may continue to extend (pneumatization) until 20 or more years of age.

Maxillary and Ethmoidal Sinuses

The maxillary sinus occupies the pyramidal body of the maxilla and lies in relation to the canine, premolar, and molar teeth. The apex of the sinus lies at the root of the zygomatic process of the maxilla. The base faces toward the lateral surface of the nasal cavity. The roof of the sinus is separated by a thin plate of bone from the orbital cavity and its contents. The anterolateral wall is related to the face in the somewhat concave region of bone lateral to the incisive fossa. The posterior wall of the sinus is related to the infratemporal fossa or pterygoid region, where it is in contact with the buccal pad of fat and the posterior superior dental nerves. The infraorbital branch of the maxillary nerve traverses the roof of the sinus in a thin-walled or partly dehiscent canal. The nerve gives off the middle and anterior superior dental nerves within the roof of the sinus, which then descend along its anterolateral wall, supply the mucoperiosteum of the sinus, and innervate the upper teeth. The maxillary nerve emerges from the anterior wall of the sinus as the infraorbital nerve (see Fig. 37). The lower part of the anterolateral wall of the sinus is covered by the mucous membrane of the vestibule of the mouth, through which it may be drained, as in the Caldwell-Luc procedure.

The base of the maxillary sinus, which faces into the nasal cavity, is the most complex and also the most important surgically. When the isolated maxilla is examined (Fig. 45A), the opening or ostium of the maxillary sinus is seen to be large and involves almost all the nasal surface of the bone. This large opening is filled in by a series of bones, which, along with the overlying mucous membrane, reduce the definitive opening to a small hole. The lacrimal bone occludes it anteriorly and articulates inferiorly with the inferior concha. The inferior concha, which is a bone in its own right, fills in the lower part of the sinus. Its articulation with the lacrimal bone completes a bony canal through which the nasolacrimal duct discharges into the inferior meatus of the nose. The vertical plate of the palatine bone occludes the ostium posteriorly. It articulates anteriorly with the inferior concha and above with the ethmoid and the base of the sphenoid. The ethmoid bone occludes the upper part of the maxillary ostium and is hollowed out by air cells. A slender uncinate process springs from the anterior part of the ethmoidal labyrinth and articulates inferiorly and posteriorly with the inferior concha. These relationships are shown in Figure 45B, in which the nasal wall of the sinus has been exposed by removal of the conchae. A prominent middle ethmoidal sinus, the bulla ethmoidalis, bulges into the middle meatus above the uncinate process. The entire nasal surface of the sinus with its accompanying bones is overlaid with mucous membrane except for a small hole, the definitive maxillary ostium, which lies immediately below the bulla and above the uncinate process (Fig. 45B). The curving space between the uncinate process and the bulla is the hiatus semilunaris, into which the definitive maxillary ostium opens. The frontal sinus opens anteriorly into the hiatus semilunaris under cover of the anterior group of ethmoidal cells. The ethmoidal air cells are variable in number and disposition but are generally disposed of in three overlapping groups: an anterior, middle, and posterior group. The anterior group opens into the hiatus semilunaris separately or with the frontal air sinus. The middle group, of which the bulla ethmoidalis is one, opens into the middle meatus above the uncinate process. The posterior group opens into the superior meatus between the superior and middle conchae (Fig. 45B) or, rarely, into the sphenoethmoidal recess.

A series of sections through the maxillary sinus and adjacent parts of the nose along the places A, B, and C (Fig. 46B) may clarify the complex anatomical interrelationships of the air sinuses. In Figure 46A, the section passes through the maxillary ostium. The mucosa is shown in dotted lines. Note that as the mucosa of the middle meatus is traced into the sinus, it passes over the uncinate process and forms a recess or sulcus on the lateral side of the process before ascending again to enter the sinus. This recess or cul-de-sac is the floor of the hiatus semilunaris, which appears from the medial surface of the nasal cavity as a curving slit between the uncinate process and the bulla ethmoidalis (see Fig. 45B). In order to enlarge the maxillary ostium surgically, is necessary to break the uncinate process of the ethmoid and also to enlarge the ostium, which is purely mucosal, lateral to the uncinate process. In this way, adequate drainage can be established.

In the second section (Fig. 46B), anterior to the first section (see Figure 45B for plane of sections A, B, and C), the uncinate process is fused anteriorly with the bulk of the ethmoid. This fusion, plus the disappearance of the maxillary ostium at this level, converts the mucosal recess or cul-de-sac into a channel, the infundibulum. In the third section (Fig. 46C), anterior to B, the infundibulum is shown receiving the frontonasal duct or duct of the frontal air sinus. In about 50 per cent of the population, the frontal air sinus open directly into an infundibulum. In the remaining 50 per cent, it opens into the anterior ethmoidal cells before opening into the hiatus semilunaris.

The premolar, molar, and sometimes the canine teeth lie in the floor of the maxillary sinus. The roots of the teeth may be covered by an extremely thin shell of bone, and infection of the sinus from infected roots is not uncommon. Infection originating in the sinus may extend through the thin roof, setting up serious intraorbital infection. Spread of infection from the sinus backward into the infratemporal fossa, though rare, is possible and is one way in which the lateropharyngeal deep space may become infected, as well as from an infected last molar tooth.

Frontal Sinuses

The drainage of this sinus and its relationship to the other paranasal sinuses has been described (Fig. 46). The sinus is usually asymmetric, extending for considerable distances into the orbital plates, as well as superiorly and laterally into the diploë of the frontal bones. It is frequently loculated. The important relationships of the sinus are anteriorly to the skin of the forehead, inferiorly the orbit and roof of the nasal cavity, and posteriorly the anterior cranial fossa with its contents (frontal lobe, olfactory tracts, meninges). Also posteriorly are the falx cerebri and the superior and inferior sagittal sinuses contained within its attached and free borders, respectively. These sinuses receive venous tributaries from the diploë and from the bone around the frontal sinus, constituting pathways of infection. Direct infection of the sinus is most common following a crushing injury of the forehead, and there may be extension to the frontal lobe and the meninges.

Sphenoidal Sinuses

The sphenoidal sinuses are deeply situated. Their relationships are complicated and can occasion important clinical signs when the sinuses are infected. The two sinuses open anteriorly into the sphenoethmoidal recess above the superior concha (see Fig. 45 B). The large opening of the sinus in the base of the sphenoid on either side is partially enveloped by a scroll-like bone, the sphenoidal concha or turbinate (bones of Bertin). The bone resembles a small trumpet with its long axis lying anteroposteriorly. The opening of the trumpet is anterior and opens into the sphenoethmoidal recess.

The anatomic relationships of the sinuses are considered in sections at two levels of the skull in Figures 47 and 48.

The first section is at the level of the superior orbital fissure and optical foramen (Fig. 47). Immediately lateral to the sinus on either side, separated from them by bone of variable thickness, are the optic foramina, containing the optic nerve and the ophthalmic artery, and also the superior orbital fissure and its contents. The medial part of the fissure contains the superior ophthalmic vein and four components of the cranial nerves: the superior branch of the oculomotor nerve, the nasociliary nerve and inferior branch of the oculomotor nerve, and the abducens or sixth cranial nerve. These nerves, the vein, and the contents of the optic foramen are encircled by a fibrous ligament, the annulus tendineus or annulus of Zinn. This gives origin to the extrinsic ocular muscles, which thus arise in the form of a cone at the apex of the orbit. These structures enter the orbit within the cone of muscles. More laterally placed structures that enter the orbit outside the muscle cone are the lacrimal nerve, the frontal nerve, and the trochlear or fourth nerve. Lateral spread of infection from the sinus may involve the optic nerve and its coverings or meninges. It may involve the superior ophthalmic vein, possibly leading to retrograde thrombosis of the cavernous sinus. It may cause irritation of the nerves within the medial end of the superior orbital fissure. Irritation of abducens nerve leads to spasm of the lateral rectus muscle. Irritation of the superior and inferior branches of the oculomotor nerve causes spasm of the muscles supplied by it (superior rectus, inferior rectus, inferior oblique). Retro-orbital pain and pain in the eye may be caused by irritation of the nasociliary nerve. Autonomic effects may also ensue, since this nerve carries parasympathetic fibers through the ciliary ganglion to the sphincter pupillae and ciliary muscle.

The sphenoidal sinuses are related above to the anterior cranial fossa in the region of the jugum sphenoidale. Here, they are related to the orbital surfaces of the frontal bones and the olfactory tracts. Inferiorly, the sphenoidal sinuses are related to the roof of the nasal cavities and to the nasopharynx behind them. The small pharyngeal nerve, a branch of the sphenopalatine ganglion, lies below the sinus in a small canal formed by the apposition of the vaginal process of the medial pterygoid plate and the sphenoidal process of the palatine bone (Fig. 47). The nerve carries secretomotor fibers from the vidian nerve to the region around the eustachian tube and lateral recess of the nasopharynx. It also carries fibers to the maxillary nerve via the sphenopalatine ganglion. It may serve as a trigger for trigeminal neuralgia. Inferolateral to the sinus is the canal for the maxillary nerve and inferiorly is the pterygoid or vidian canal.

On a more posterior plane, the sphenoidal sinuses have important relationships to the cavernous sinus and adjacent parts of the middle cranial fossa (Fig. 48). The sinuses are separated above on either side by a thin plate of bone from the sella turcica containing the dura mater and the pituitary gland. The transsphenoidal approach to the pituitary is once more in vogue. Above and laterally the sinuses are related to the cavernous sinuses. The cavernous sinuses are traversed by the internal carotid arteries. The abducens nerve on either side lies lateral to the internal carotid artery within the cavernous sinus. In the lateral wall of the cavernous sinus, from above down, are the oculomotor nerve, the trochlear nerve, the ophthalmic nerve, and the maxillary nerve. The mandibular nerves are situated more laterally and are not in immediate relationship with the cavernous sinus or the sphenoidal air sinus.

The sphenoidal sinuses are related inferiorly to the roof of the nasopharynx and the pharyngeal tonsils. The section (Fig. 48) passes through the lateral recess of the pharynx or fossa of Rosenmueller and shows the attachment of the eustachian apparatus at the base of the skull. The eustachian tube lies immediately below the foramen lacerum at the level of this section; further laterally, the tube lies obliquely in the petrosphenoidal suture.