CHAPTER 8

Face, Scalp, Skull, Cranial Cavity, and Orbit

The head is that portion of the body composed of the skull and all the structures on its inside and outside. It is essentially a highly specialized part of the body wall. The only representation of the body cavity is the space occupied by the auditory tube and middle ear. None of the other "cavities" in the head are related to the body cavity. The cranial cavity is only an upward extension of the vertebral canal, and the orbital cavity is simply a forward extension of the cranial cavity toward the surface. The nasal and oral cavities are invaginations from the body surface that rupture through into the pharynx.

The visceral structures of the head (i.e., those that contain smooth muscle or gland tissue) are, for the most part, akin to those found in the body wall elsewhere. Some of these are blood and lymphatic vessels; others are sweat glands. The salivary and lacrimal glands may be viewed as specialized sweat glands that open up onto the surface of the body. Mucous glands of the oral and nasal cavity also open up onto the body surface, specifically onto the part that invaginated to form these cavities. There are some smooth muscles associated with the eye that have no clear counterpart elsewhere in the body.

MUSCLES OF FACIAL EXPRESSION

The subcutaneous tissue of the head is most notable for containing deep within it striated muscles whose contraction causes the skin of the face to move and wrinkle in a wide variety of ways. Such muscles are called **muscles of facial expression**. They all are derived from the facial somitomere and, thus, are all innervated by the facial nerve. The deep layer of subcutaneous tissue in which facial muscles lie (analogous in position to Scarpa’s fascia of the abdominal wall) is called the **superficial musculo-aponeurotic system**, or **SMAS** for short. Some persons refer to the overlying subcutaneous tissue (analogous to Camper’s fascia in position) as the “fascial-fatty layer” of the face.

As could be anticipated, given the complexity of possible facial expressions, there are many facial muscles. The reader who wishes to learn all their names, attachments, and actions should refer to a larger text. I shall mention only those that are particularly important in clinical diagnosis (Fig.8-1).

Occipitofrontalis

The occipitofrontalis begins in the vicinity of the eyebrows and skin above the root of the nose as a flat sheet of muscle fibers that course upward over the forehead onto the top of the skull. This sheet is actually formed by the apposed right and left **frontalis** muscles. At some point before the coronal suture is reached, the muscle fibers give rise to a flat tendon (i.e., aponeurosis) that continues backward over the top of the skull and down onto its posterior surface. This structure is called the **epicranial aponeurosis (or galea aponeurotica)**.

Because the most medial fibers of each frontalis muscle become aponeurotic before the more lateral fibers do, the impression of two bellies apposed at their medial edges is reinforced. The aponeurotic fibers emanating from this midline region of apposition end at the back of the skull by attaching to the external occipital protuberance and to the highest (supreme) nuchal line on either side of this bump (see Fig. 8-8). The more lateral aponeurotic fibers do not gain a direct insertion onto bone. Instead, as they pass downward onto the back of the skull they give rise to another flat muscle belly--the **occipitalis**--the fibers of which continue inferiorly onto the posterolateral aspect of the skull to insert onto the lateral part of the highest nuchal line . Because aponeurotic fibers intervene between the right and left occipitalis, the two bellies are more readily identified than are the those of the frontalis.

When the occipitofrontalis muscles contract, the skin of the eyebrows is pulled upward.

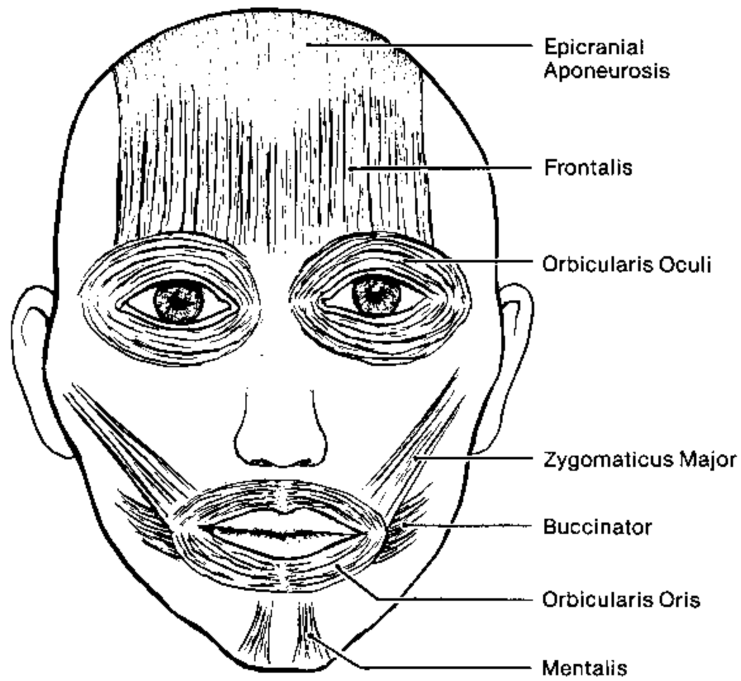

Figure 8-1. Anterior view of some important muscles of facial expression.

More About the Epicranial Aponeurosis and the Subcutaneous Layer of the Scalp

The epicranial aponeurosis is a very important structure, largely because of its relation to the more superficial subcutaneous tissue of the scalp. This subcutaneous tissue is unique in being densely fibrous and bound tightly both to the overlying skin and to the underlying epicranial aponeurosis. No movement between skin and aponeurosis is permitted. Elsewhere in the body, skin freely slides over deeper structures because the immediately subjacent subcutaneous tissue is only loosely fibrous. The sliding of the scalp over the cranium with which we all are familiar is possible because interposed between the epicranial aponeurosis and the pericranium is a very loose connective tissue called the **subaponeurotic fascia**. In fact, it is so sparsely populated with fibrous elements that it is often called the **subaponeurotic space**. Surgery on the cranium or brain first involves a peeling back of the scalp; the plane of this separation must be in the subaponeurotic space.

This specialization of the subcutaneous tissue of the scalp has three consequences important for the physician. First, the densely fibrous nature of subcutaneous tissue tends to hold the walls of superficial blood vessels open even when they are cut and the blood pressure within them drops. Thus, wounds to the scalp tend to bleed profusely and require suturing more frequently than do superficial wounds elsewhere. Second, if a wound to the scalp penetrates the epicranial aponeurosis, the consequences depend on the direction of the tear. A transverse tear in the aponeurosis will lead to a wound that gapes open because the occipitalis and frontalis muscles pull across the defect. A sagittal tear is more easily fixed by sutures. Finally, any wound that penetrates the epicranial aponeurosis is serious because infectious matter can enter the subaponeurotic space and spread over the entire surface of the cranial vault with little interference. The infectious material may even spread through emissary foramina to reach the cranial cavity.

The connective tissue of the SMAS of the scalp does not stop at the lateral edges of the occipitofrontalis muscles and epicranial aponeurosis. Rather, it passes down onto the sides of the head as **temporoparietal fascia** (**epicranial fascia**), which eventually attaches to bone (i.e., mastoid process and zygomatic arch). The temporoparietal fascia splits around the three little muscles that insert into the cartilage of the external ear: **auricularis anterior**, **auricularis superior**, and **auricularis posterior**.

Orbicularis Oculi

The orbicularis oculi is one of the most important of the facial muscles. It consists of three portions, each of which has a different function.

The **palpebral portion** of orbicularis oculi consists of fibers that arise from the outer surface of the medial palpebral ligament and sweep laterally in the subcutaneous tissue of both the upper and lower eyelids toward the lateral palpebral commissure. The muscle fibers of the upper lid meet those of the lower lid in a raphe that lies in the subcutaneous tissue external to the lateral palpebral ligament.

When the eyelids are open, the fibers of the palpebral portion of orbicularis oculi in the upper lid follow a markedly upward arching course. When they contract and straighten out, the upper eyelid is lowered. Electromyographic evidence[29] demonstrates that the fibers coursing near the margin of the upper lid are reserved for blinking. The slow lowering of the upper lid that accompanies downward gaze or voluntary closing of the eyes occurs partly under the influence of gravity (when the levator palpebrae superioris relaxes) and partly by contraction of those fibers of the palpebral portion of orbicularis oculi that lie furthest from the free margin of the lid. Patients with a paralyzed orbicularis oculi cannot completely close the eye.

The muscle fibers in the lower lid follow only a very slightly downward arching course. The lower lid does not move much during closure of the eyes. The clinical observation that older patients with a paralyzed orbicularis oculi often are characterized by a lower lid that droops under its own weight, suggests that passive tension in a normally innervated muscle helps the connective tissue of the lower lid to maintain this structure's resting position.

The orbicularis oculi also has a **lacrimal portion**. These muscle fibers arise from the crest of the lacrimal bone (behind the lacrimal sac) (see Fig. 8-19, p. 262) and course anterolaterally to insert into the medial extremities of the upper and lower tarsi. The lacrimal portion of orbicularis oculi has the very important function of pulling the medial parts of the tarsi backward against the bulbar conjunctiva and, thus, keeping the lacrimal puncta in the lacrimal lake.

The third portion of the orbicularis oculi is its **orbital part**. It consists of muscle fibers that encircle the orbit peripheral to the roots of the eyelids. These fibers come into action only during forceful closure of the eyes, when it is desirable to interpose as much skin as possible between the external world and the eyeball.

[29] Gordon G: Observations upon the movements of the eyelids. Br J Ophthalmol 35:339-351, 1951. Björk A, and Kugelberg E: The electrical activity of the muscles of the eye and eyelids in various positions and during movement. Electroencephalogr Clin Neurophysiol 5:595-602, 1953.

Zygomaticus Major

The zygomaticus major arises from the outer surface of the zygomatic bone at the anterior end of the zygomatic arch. Its fibers pass forward and downward to the corner of the mouth. The muscle obviously pulls the corner of the mouth backward and upward, which is called smiling. It is occasionally assisted in this function by an inconstant muscle called the risorius, which arises from the fascia over the external surface of the parotid gland and goes more or less directly forward to the corner of the mouth. (Smiling also involves muscles such as the levator anguli oris, levator labii superioris, and levator labii superioris alaeque nasae, all of which help to elevate the upper lip.)

Orbicularis Oris

Orbicularis oris is the name given to the mass of muscle tissue that encircles the mouth within the subcutaneous tissue of the lips. A midline microscopic raphe joins the right and left orbicularis oris muscles.[30] When right and left, upper lip and lower lip fibers all contract, they act like a sphincter to close the mouth and seal off the oral cavity from the external world.

Mentalis

Each mentalis muscle arises from the outer surface of the mandible immediately below the lateral incisor tooth. The fibers pass *downward* and forward toward the skin of the chin. When the mentalis muscles contract they obviously pull the skin of the chin toward the incisor roots. It is less obvious, but just as true, that when this occurs the lower lip is caused to protrude forward, as in a pout.

Buccinator

The buccinator is one of the largest and most important facial muscles. It has an origin (1) from the outer surface of the mandible just lateral to the lower molar teeth, (2) from a very thin fibrous band (the pterygomandibular raphe) that runs from this site on the mandible upward to the hamulus of the medial pterygoid plate, and (3) from the outer surface of the maxilla lateral to the upper molar teeth. (It will be recalled that from the back edge of the pterygomandibular raphe arise fibers of the superior pharyngeal constrictor.) From this [-shaped origin of the buccinator, the fibers all course anteriorly to converge on the angle of the mouth and the orbicularis oris. Of course, if the buccinators contracted all by themselves, the angles of the mouth would be pulled backward. The buccinators apparently do participate a making a wide, forced smile.[31] However, this role is trivial. The buccinator has a far more important function under circumstances when the angle of the mouth is prevented from posterior displacement by the orbicularis oris and other facial muscles. Then, the contraction of each buccinator serves to increase the rigidity of the cheek. This is useful when blowing air out of the mouth (Dizzy Gillespie excepted). In fact, the term buccinator is derived from the Latin word *buccina*, which means "trumpet". Even more important in daily life is the role of the buccinator in making the cheek more rigid during chewing. Such an action keeps the inside of the cheek against the gums and, thus, prevents food from accumulating in the oral vestibule between the gums and the cheeks.

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[30] Some fibers of the grossly identifiable orbicularis oris are actually continuations of fibers that run with the levator anguli oris, depressor anguli oris, buccinator, and other tiny facial muscles that converge on the angle of the mouth.

[31] Basmajian, JV: Muscles Alive, ed 5. Williams & Wilkins, Baltimore, 1985.

Platysma

The platysma is a muscles of fascial expression derived from cells of the facial somitomere that have spread out from the lower face onto the neck and upper chest. It lies in the subcutaneous tissue over the anterior aspect of the neck. Each platysma arises from the skin of the chest along a line immediately inferior to the clavicle. The fibers pass upward and medially, insert into the lower border of the mandible and into the skin of the cheek and corner of the mouth. At their origins in the upper chest, the right and left platysma are separated by about a handsbreadth. As they pass superiorly their medial borders converge, meeting just before the muscles pass into the face. The action of the platysma is to pull the skin at the sides of the mouth downward and the skin of the upper chest upward. This produces a grimace of disgust.

The platysma is the most superficial of the named subcutaneous structures over the front of the neck. Even the major cutaneous nerves and superficial veins (described below) are deep to the platysma.

PAROTID GLAND

Behind the ramus of the mandible is a narrow space called the retromandibular (or parotid) region. Much of the parotid salivary gland lies in the retromandibular region. Glandular tissue extends forward onto the lateral surface of the mandibular ramus and a variable distance onto the masseter below the zygomatic arch (Fig. 8-2).

From the anterior edge of the parotid, at a site about 1 fingerbreadth (fb) below the zygomatic arch, emanates the **parotid duct**. This runs straight forward across the superficial surface of the masseter onto the buccinator, which it pierces to open into the oral vestibule opposite to upper 2nd molar tooth. Very often actual glandular tissue extends along the beginning of the duct.

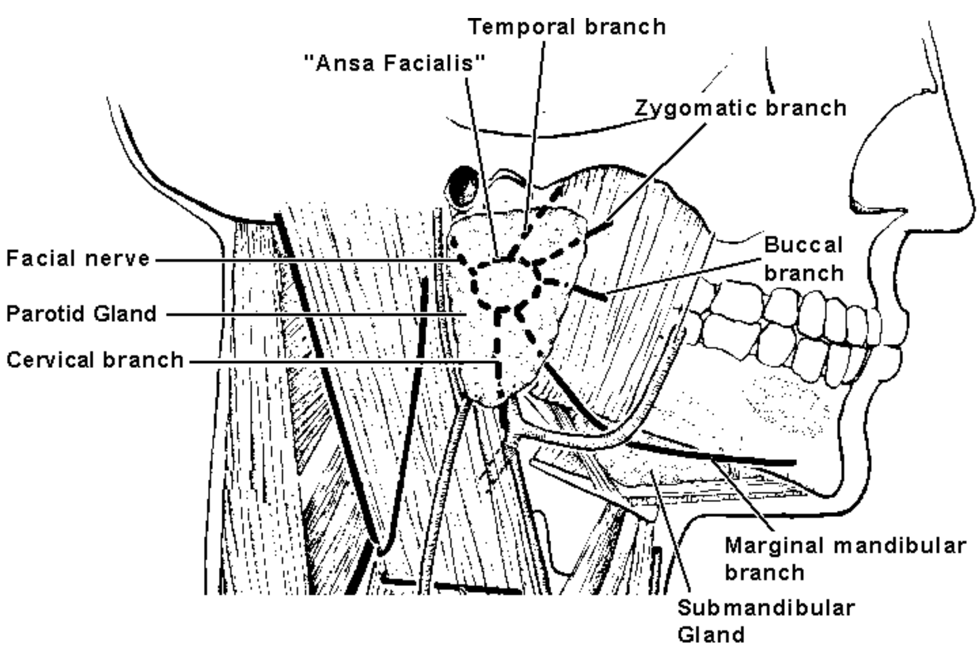

Figure **8-2**. The facial nerve enters the parotid gland where it divides into five branches that supply the muscles of facial expression.

Placed deeply within the parotid gland is the part of the facial nerve I have called ansa facialis (see Fig. 8-2), the branches of which exit from various borders of the parotid. The transverse facial vessels (see further on) run forward in the upper region of the parotid. When they leave its anterior edge, they course between the zygomatic arch and the parotid duct.

FACIAL ARTERY

The facial artery enters the subcutaneous tissue of the face at the lower border of the mandible adjacent to the anterior edge of the masseter. The vessel follows a sinuous course in the subcutaneous tissue toward the angle of the mouth, where it turns more superiorly to run along the side of the nose up to the medial palpebral commissure. In its course through the face, the facial artery runs deep to some facial muscles and superficial to others. The artery terminates at the medial palpebral commissure by giving small branches to nearby structures. This very last bit of the vessel, in the medial "angle" of the eye, is often called the **angular artery**.

Naturally, the facial artery gives off many small unnamed branches to superficial structures near its path. It also has two named branches: the **inferior labial** and **superior labial** arteries. Both pass medially into the substance of their respective lips, close to the mucous membrane lining. The superior labial artery sends a small twig to the lower front part of the nasal septum. The pulse of a labial artery can be felt deep to the mucous membrane by gently compressing a lip between thumb and forefinger.

TRANSVERSE FACIAL ARTERY

The superficial temporal artery, one of the terminal branches of the external carotid artery (see Chapter 10, p. 336), passes through the upper portion of the parotid gland posterior to the jaw joint. While in the parotid, the superficial temporal gives off a small **transverse facial artery** that courses anteriorly within the upper part of the gland below the zygomatic arch. The transverse facial artery then passes out the anterior border of the parotid onto the surface of the masseter, where it runs between the zygomatic arch and parotid duct, supplying nearby structures.

FACIAL VEIN

The course and communications of the **facial vein** that accompanies the facial artery are also deserving of special attention. The facial vein begins at the medial palpebral commissure by the junction of two veins that descend in the anterior scalp. These are the **supratrochlear vein**, very near the midline, and the **supraorbital vein**, about an inch lateral to the midline. (Interestingly, the supratrochlear and supraorbital arteries are branches of the ophthalmic artery off the internal carotid, not branches of the facial artery.) The very beginning of the facial vein is often called the **angular vein**, just as the termination of the facial artery is called the angular artery. Below the orbit, the facial vein follows a more or less straight course toward the lower border of the mandible adjacent to the anterior edge of masseter. Thus, the facial vein and artery are separated by some distance at the level of the mouth before they come together again lower down.

Superiorly, the angular vein and/or its two tributaries are in free communication with the superior ophthalmic vein of the orbit, which in turn drains to the cavernous sinus. There being no valves in any of the involved vessels, blood may flow from the cavernous sinus and orbit into the facial vein, or vice versa.

The communication between the angular vein and the cavernous sinus predisposes the latter to septic thrombosis, owing to passage of infectious material entering the upper part of the facial vein.

FACIAL NERVE

Upon exiting the skull through the stylomastoid foramen, the facial nerve enters the retromandibular region of the neck. Here it sends branches to the auricularis posterior and some small muscles associated with the hyoid bone about which we shall learn later. The nerve then enters the retromandibular part of the parotid gland and divides into upper and lower divisions, which turn forward, pass lateral to the retromandibular vein, and thereby reach the part of the parotid lying in the face (Fig. 8-2). Here, within the gland, the two divisions join again to form the "ansa facialis." From the lower division of the facial nerve comes its **cervical branch**, which descends within the parotid gland to exit at its inferior pole and passes deep to the platysma for supply of this muscle. Also splitting off from the lower division is the **marginal mandibular branch** of the facial nerve (see Fig. 8-2).. After leaving the parotid gland, this branch very frequently enters the digastric triangle (see Chapter 9, p. 292) on the superficial surface of the submandibular salivary gland, deep to platysma, before looping back up to supply the facial muscles that depress the lower lip. The upper division gives rise to the temporal branch that feeds the frontalis and some of the orbicularis oculi. The zygomatic and buccal branches, which supply the facial muscle of the midface and orbicularis oris, come off the loop between the divisions

Although the marginal mandibular branch of the facial does not always follow such a course below the jaw, it is very important to anticipate this possibility so that any damage to the nerve is avoided during surgery on the submandibular salivary gland.

EYELIDS

Each eyelid consists of a fibrous "skeleton" overlain on the outside by subcutaneous tissue and skin, and on the inside by a thin epithelial-lined connective tissue called **palpebral conjunctiva**. At the free margin of each lid, the conjunctiva and skin merge at the so-called **cutaneoconjunctival junction**. The medial part of the upper eyelid joins the medial part of the lower eyelid, and the lateral part of the upper eyelid joins the lateral part of the lower eyelid. Each joining is said to be a palpebral commissure. Thus, there are **medial and lateral palpebral commissures**. At each commissure an angle is formed where the free edge of the upper lid meets that of the lower lid. These angles are known as canthi. Thus, there are **medial and lateral palpebral canthi**.

Conjunctival Sac

At the root of each eyelid the palpebral conjunctiva turns into the **bulbar conjunctiva** by reflecting onto the anterior aspect of the eyeball. The bulbar conjunctiva covers the whole front of the eyeball and fuses to the cornea. When the eyelids are closed, a **conjunctival sac** is created. When the eyelids are open, this "sac" opens forward into the environment. The part of the conjunctival sac located at the superior conjunctival reflection is called the **superior fornix**. The part of the sac located at the site of the inferior conjunctival reflection is called the **inferior fornix**. The ducts of the lacrimal gland open up into the lateral part of the superior conjunctival fornix.

Two structures of moderate interest bulge into the conjunctival sac near the medial canthus. One of these is a soft bump called the **lacrimal caruncle**. Posterolateral to this bump is a thin crescentic fold called the **plica semilunaris**. The portion of the conjunctival sac into which the caruncle and plica protrude is called the **lacrimal lake**, because it is toward this site that lacrimal fluid is swept during each blink of the upper eyelid.

Eyelashes

The hairs at the free margin of the eyelid form the eyelashes. Opening onto the surface of the skin just posterior to the eyelashes are modified sweat glands (of Moll). The eyelashes and nearby glands are lacking in the region of the lid adjacent to the medial canthus. Infection of the eyelash follicle produces a painful condition known as a **sty**.

The Fibrous "Skeleton" of an Eyelid - Composed of a Tarsus and an Orbital Septum (Fig. 8-3)

As has been mentioned, sandwiched between subcutaneous tissue and the palpebral conjunctiva lies the fibrous "skeleton"of the eyelid. This consists primarily of a densely fibrous structure called the **tarsus**. Each tarsus is in the shape of a segment of a circle created by an eccentrically placed chord. The chord of the tarsus lies at the free edge of the lid and, in fact, makes a visible sharp ridge here. This ridge not only indicates the underlying tarsal chord, but also marks the site of the cutaneoconjunctival junction. The circumference of the tarsus faces the bony orbital rim. It lies about halfway between the free edge of the lid and its root.

The remainder of the fibrous "skeleton" of the lower eyelid consists of a connective tissue sheet that runs from the periosteum of the bony orbital rim up to the circumference of the tarsus. This sheet is called the inferior part of the **orbital septum**. The journey of the superior part of the orbital septum from periosteum of the orbital rim down to the upper edge of the superior tarsus is interrupted by passage of the aponeurosis of the levator palpebrae superioris muscle (see further on).

At their lateral extremities, the upper and lower tarsi join to form a short **lateral *tarsal* commissure**. From this commissure out to the lateral orbital rim runs a **lateral palpebral ligament** which, therefore, underlies the externally visible lateral palpebral commissure. A short **medial *tarsal* commissure** is formed where the medial extremities of the upper and lower tarsi meet. From this site to the medial orbital rim runs a **medial palpebral ligament** which, therefore, underlies the visible medial palpebral commissure. The medial palpebral ligament crosses in front of the lacrimal sac, located in the lacrimal fossa of the orbit.

Embedded within each tarsus is a series of glands (tarsal, or Meibomian glands) that open up onto the free margin of the lid at the cutaneoconjunctival junction (thus, on the ridge formed by the tarsal chord). The tarsal glands secrete a sebaceous substance onto the free margins of the lids so that a water-tight seal is created when the eyelids are closed. Obstruction of a tarsal gland produces a nonpainful swelling known as a **chalazion**.

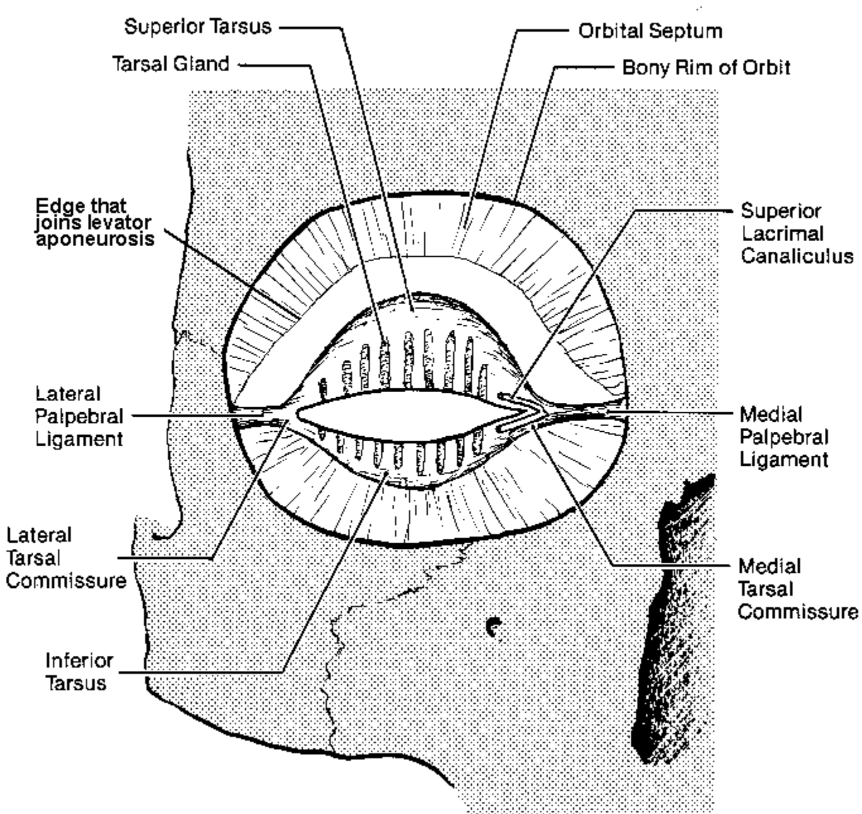

Figure 8-3. Anterior view of the fibrous "skeleton" of the eyelids.

Just as no eyelashes exist in the skin nearest the medial canthus, no tarsal glands exist in the tarsus nearest the medial canthus. What appears to be the particularly large opening of a most medial tarsal gland (a few millimeters from the canthus itself) is in fact the opening of a small tube called the **lacrimal canaliculus**. The opening is called the **lacrimal punctum**, and it raises a tiny bump in the free margin of each lid, which bump is called the **lacrimal papilla**. From the site of the punctum, each canaliculus runs toward the medial canthus following a path deep to the cutaneoconjunctival junction of the lid. Upon reaching the medial palpebral ligament, each canaliculus pierces this structure to empty into the lacrimal sac.

The lacrimal puncta are directed backward toward the lacrimal lake. Lacrimal fluid flows from the lake through the puncta and into the canaliculi, which carries the fluid to the lacrimal sac, and thence through the nasolacrimal duct into the inferior meatus of the nasal cavity.

THE SKULL

The skull consists of (1) the **cranium**, which houses the brain, and (2) the **face**, which surrounds the oral and nasal cavities and has a mobile component called the mandible (Fig. 8-4). The orbits lie at the boundary between face and cranium. Many authors use the word "cranium" as synonymous with "skull." They then refer to the braincase as the **neurocranium** and the face as the **viscerocranium**. There are major developmental differences between the neurocranium and face.

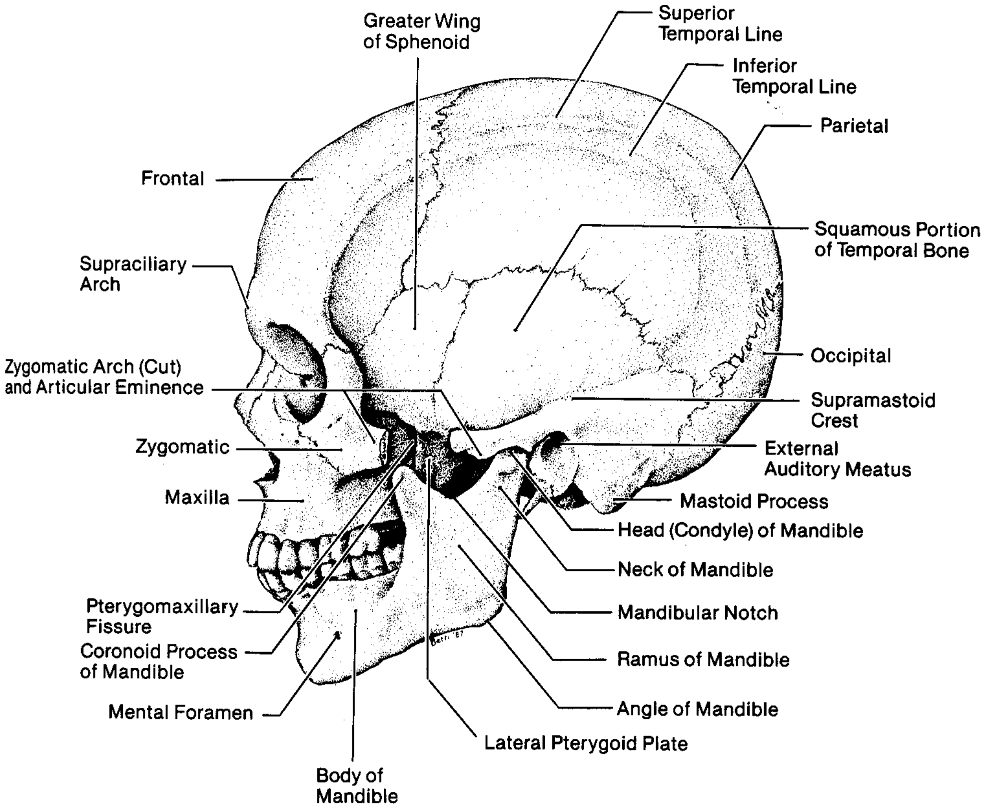

Figure 8-4. Lateral view of the skull.

Development of the Neurocranium

The neurocranium is of composite origin. The bones that form its inferior aspect (i.e., **base**) are laid down first in cartilage (Fig. 8-5). This is not true of the bones that form the sides and top of the braincase. The sides and top of the braincase are first formed as a connective sheet over the developing brain. This connective tissue is continuous with the perichondrium of the cranial base but does not itself chondrify.

Cartilaginous Portion of the Neurocranium–the Cranial Base

The midline of the cranial base is like an upward extension of vertebral bodies. Added to its sides are cartilaginous otic capsules that form around the developing inner and middle ear structures; at its anterior extremity are appended the cartilaginous nasal capsules that develop around the invaginating nasal cavities (see Fig. 8-6). Numerous separate ossification centers soon form within the cartilaginous cranial base of the fetus (see Fig. 8-6). These endochondral ossification centers will ultimately give rise to most of the occipital bone (but not the part above the nuchal plane), most of the sphenoid bone (but not its pterygoid plates, nor the part of the greater wing along the side of the braincase), the petrous portion of the temporal bone (from which the mastoid process will later develop), the ethmoid bone, and the inferior nasal conchae. As the different ossification centers expand, their borders approach one another. Nonetheless, at birth some cartilage still persists between them (Fig. 8-7). Each such zone of cartilage is called a **synchondrosis** (meaning a cartilaginous joining of bone), and each represents a site of growth activity in the cranial base during early childhood. Eventually the bone of the ossification centers encroaches upon and destroys most of these synchondroses, thereby leading to a unitized cranial

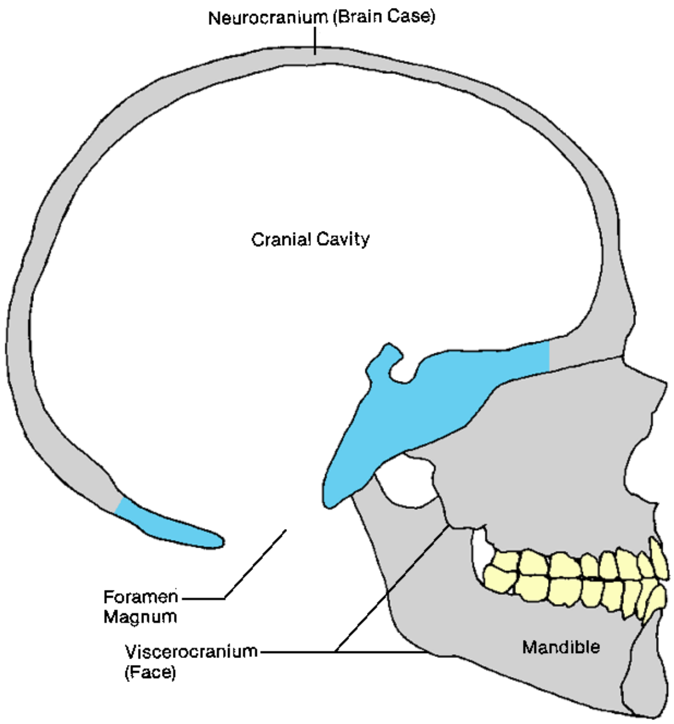

Figure 8-5. Schematic sagittal section of the adult skull illustrating the area *(shaded)* preformed in cartilage during embryonic life.

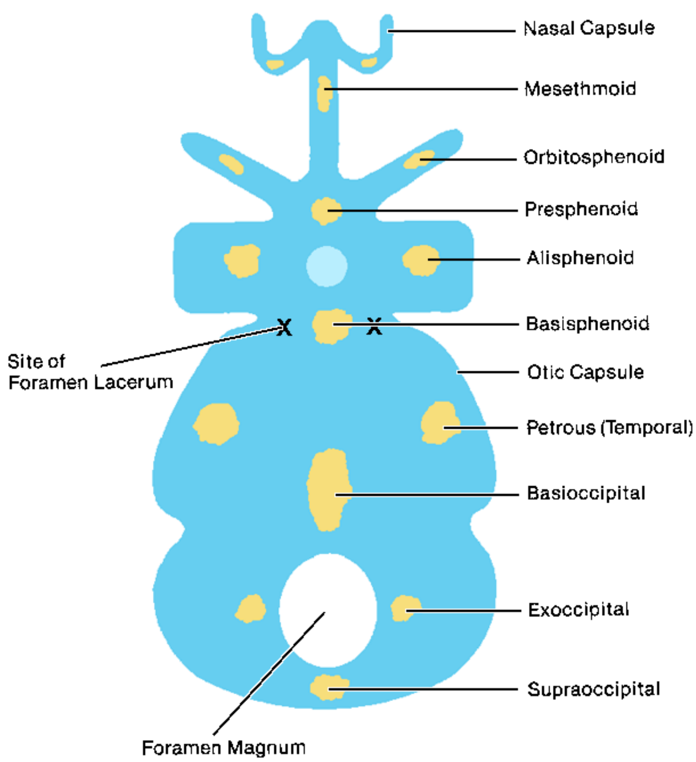

Figure 8-6. Schematic superior view of the embryonic cartilaginous base of the skull. Irregular areas in *white* indicate developing endochondral ossification centers. The *cross-hatched circle* represents the fossa in which the pituitary gland resides.

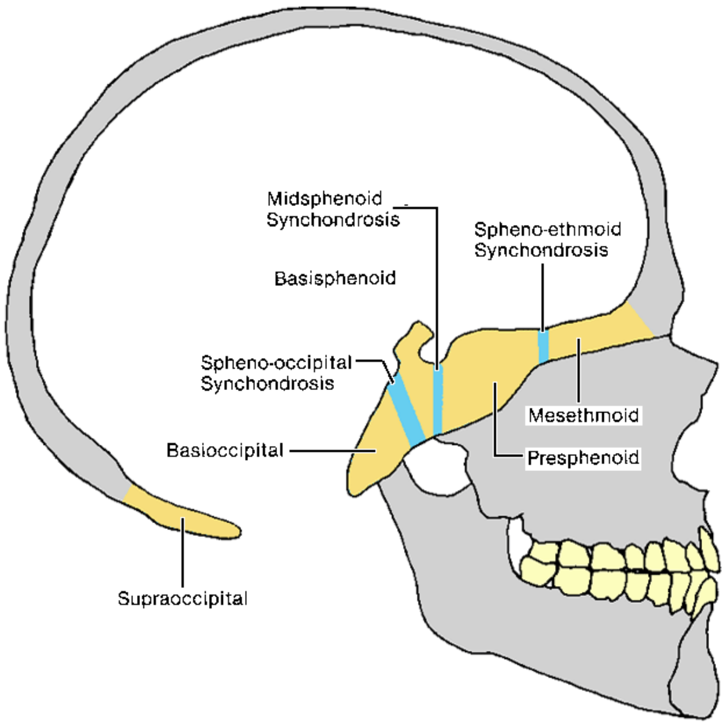

Figure 8-7. Schematic sagittal section of the adult skull illustrating the midline endochondral ossification centers of the base and the midline synchondroses that exist at birth.

base. Some synchondroses are overwhelmed quite early in childhood. However, the ossification center for that part of the occipital bone in front of the foramen magnum (i.e., the **basi-occipital center**) and that for back part of the body of the sphenoid (i.e., the **basisphenoid** center) remain separated by cartilage until puberty is completed. This **spheno-occipital synchondrosis** (see Fig. 8-7) is the major site of lengthwise growth of the base of the skull. In young children it is so thick that lateral radiographs of the skull show a gap between the basilar parts of the occipital and sphenoid bones. One may be tempted to interpret this gap as pathological, but recalling that cartilage does not show up on radiographs explains why this gap is to be expected.

Even in the adult there are regions of the cartilaginous cranial base that persist. The cartilaginous nasal septum, and the lateral nasal cartilages that branch from it, represent such regions. Another is the space on each side between the petrous portion of the temporal bone, on the one hand, and the lateral edges of the basilar parts of the occipital and sphenoid bones, on the other. The cranial end of this cartilage-filled space is expanded into a circular area several millimeters in diameter. Because cartilage is dissolved away during preparation of a skull for study, this circular area is left as the so-called **foramen lacerum**, from the posterior aspect of which extends the **petro-occipital fissure** (Fig. 8-8, see Fig. 8-6).

The base of the neurocranium, being preformed in cartilage, seems to follow a growth curve that is largely determined by genetic factors.

Membranous Portion of the Neurocranium--Sides and Top of the Braincase

Within the membrane overlying the fetal brain, several separate ossification centers form (Figs. 8-9*A*, 8-10*A*). On each side there is one center for (1) the supranuchal part of the occipital bone, (2) the

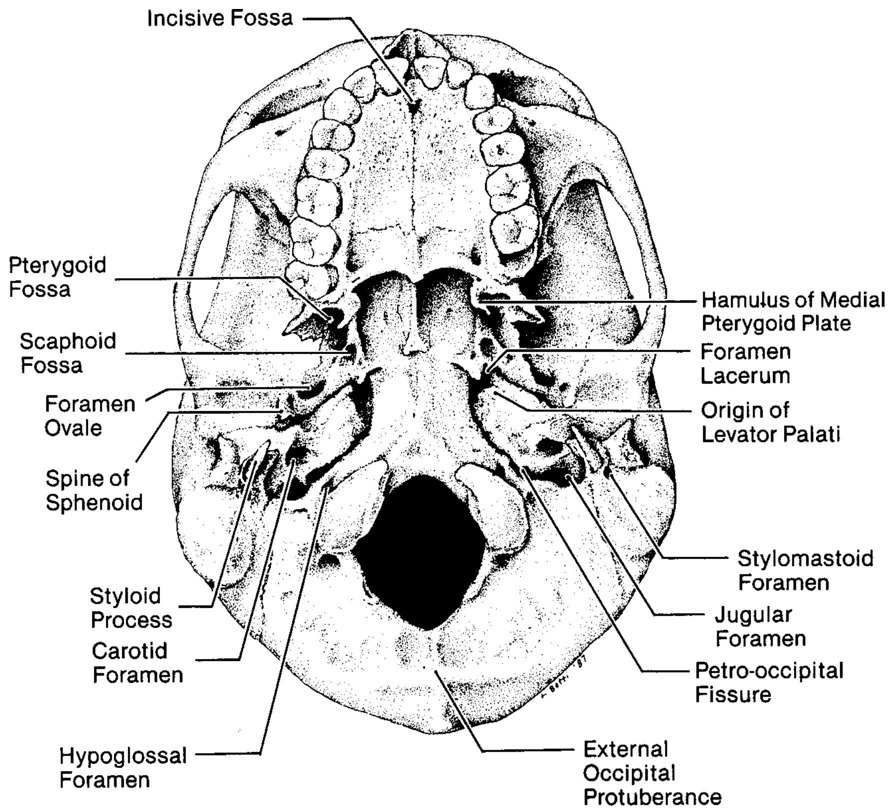

Figure 8-8. Inferior view of the skull (mandible excluded).

parietal bone, (3) the squamous part of the temporal bone, (4) the part of the greater wing of the sphenoid that faces laterally, and (5) the frontal bone. Like the endochondral centers of the cranial base, the intramembranous ossification centers of the vault enlarge so that their borders approach one another (Figs. 8-9*B*, 8-10*B*). The centers for the right and left halves of the supranuchal part of the occipital bone fuse early in fetal life to form a single **interparietal** ossification center. On the other hand, even at birth the other intramembranous ossification centers are still separated by relatively wide strips of connective tissue. These are **neurocranial syndesmoses** (a syndesmosis being a joining of bone by connective tissue). They are given the special name of **sutures**. Between the two parietal ossification centers exists the **sagittal suture**. Between the two frontal centers exists the **metopic suture**. Separating the frontal centers from the parietal centers is the **coronal suture**. Separating the parietal centers from the interparietal center is the **lambdoidal suture**. Finally, a **squamous suture** intervenes between the center for the squamous part of each temporal bone and that for each parietal bone.

Where a fetal suture that courses in one direction runs into another that follows a different direction, the amount of connective tissue between the adjacent ossification centers is often considerable. These areas of extensive sutural connective tissue are called **fontanelles**; two of them are particularly noteworthy (see Fig. 8-9*B*). The **lambdoidal (posterior) fontanelle** is the connective tissue lying in the midline at the junction of the sagittal suture and the lambdoidal suture. A larger fontanelle lies more anteriorly, in the midline at the crossroads of the sagittal, coronal, and metopic sutures. This is the bregmatic (anterior) fontanelle. These two midline fontanelles represent soft regions that can be palpated through the skin overlying the skull of the newborn.

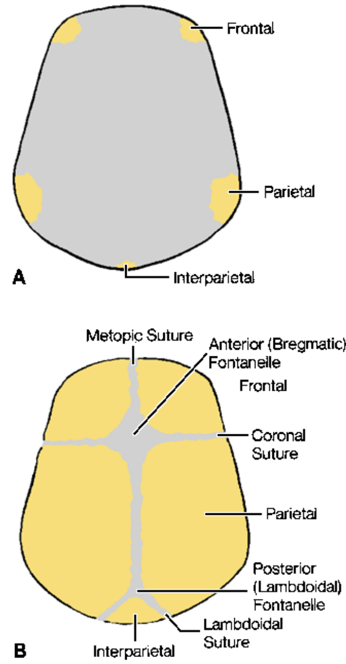

Figure 8-9. Schematic superior views of the fetal skull. *A*, A stage when the cranial vault is largely membranous but the intramembranous ossification centers *(shaded)* have already begun to form. *B*, At birth, when the intramembranous ossification centers have approached one another and now demarcate intervening sutures and fontanelles.

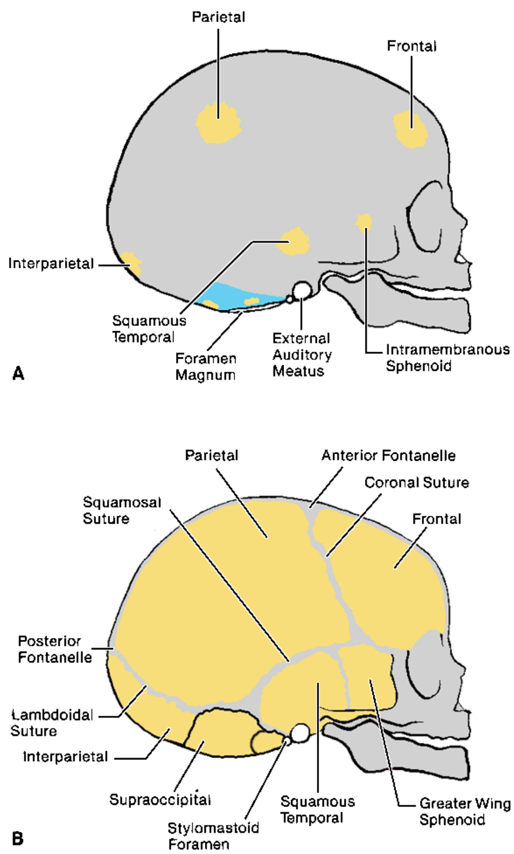

Figure 8-10. Schematic lateral views of the fetal skull depicting the same stages (*A*, *B*) as represented in Figure 7-9.

It is very useful to the fetus to have wide neurocranial sutures. They permit the bones of the vault to slide over one another by a small amount and, thus, allow the skull to yield to the pressures of childbirth without cracking. If you palpate the skull of a newborn you can usually feel the places where the edge of one bone overlaps its neighbor. Within a day or two after birth, the uniform pressure within the cranial cavity will cause such overlapping to disappear.

It would be quite disadvantageous for a postnatal human to have mobile bones of the cranial vault. After all, the function of these bones after birth is to provide a protective case for the brain. Thus, continued postnatal growth of the intramembranous ossification centers causes their edges to approach very close to one another and to interdigitate at their junction. The sutural connective tissue persists only as a very thin wavy band between the interdigitating bony spicules. Such a structure provides for the rigid joining of bones necessary to give strength to the cranial vault, while also maintaining just enough rapidly growing connective tissue to enable the braincase to accommodate the enlarging brain.

The fontanelles disappear as such when the child's sutural connective tissue becomes very thin. The site of a fontanelle merely becomes the point where sutures of different directions intersect. Where there was once a lambdoidal fontanelle, there is now only the **lambda**; the once large bregmatic fontanelle becomes the **bregma**.

It must be emphasized that sutures don't become thin overnight and that the disappearance of the fontanelles is gradual. The posterior fontanelle disappears during the first year of life and can no longer be palpated early during this period. The bregmatic fontanelle does not disappear completely until 18 months of age. It is often palpable during the entire first year of postnatal life. This fact endows the anterior fontanelle with particular clinical import. First, if the anterior fontanelle becomes so small that it cannot be felt as early as 4-5 months of age, the physician must anticipate premature sutural fusion (see further on). On the other hand, if the anterior fontanelle can be palpated well into the second year of postnatal life, the physician must consider causes of decelerated maturation (e.g., malnutrition).

The appearance of the scalp over the anterior fontanelle is another clue to the child's health. Increased intracranial pressure causes the connective tissue of the anterior fontanelle and its overlying scalp to bulge upward. Dehydration causes these tissues to be "sucked" downward, into the cranial cavity.

The importance of sutural connective tissue for growth of the cranial vault cannot be overestimated. The sutures grow in response to tension within them generated by intracranial pressure. Thus, the size of the cranial vault is not controlled genetically, but rather is a function of what is going on inside the braincase. If the newborn is microcephalic and the brain does not grow adequately, the cranial vault stays small. If the cranial contents become excessively voluminous, as in hydrocephalus, the cranial vault responds by excessive enlargement. Normally, the brain follows a growth curve that is very rapid in the first year and a half, and gradually trails off to puberty. It and the overlying cranial vault reach 90 per cent of adult size by the age of 6.

SUTURAL FUSION, BOTH NORMAL AND OTHERWISE

After adulthood, the sutural connective tissue is no longer essential for growth of the neurocranium. Nevertheless, this tissue usually persists well past puberty. In middle age the bones bordering any given suture may bridge across the connective tissue and fuse. The suture is then said to be obliterated. This happens a lot in some people and hardly at all in others. It is of no functional consequence.

The metopic suture is unusual in that its obliteration almost always occurs during early childhood. Typically, the metopic suture fuses completely by the age of 6, leaving the person with one frontal bone rather than the two he or she was born with. In rare instances the metopic suture does not become obliterated. It can then be visualized in anteroposterior radiographs as a wavy radiolucency in the midline of the frontal "bone." It is important to recognize this possibility so that such a wavy midline radiolucency is not mistaken for a fracture (which, by the way, is hardly ever in the midline and never appears wavy). More commonly a bit of the metopic suture just superior to the nasal bones persists well into adult life.

The other sutures are not supposed to fuse before adulthood because they are necessary for proper growth of the cranial vault. If any suture closes significantly before its period of growth normally ends, expansion of the cranial vault perpendicular to that suture is retarded. The remaining normal sutures will undergo excessive growth in order to keep the size of the vault in pace with intracranial contents. This leads to recognizable deformations of the skull. For example, if the metopic suture closes shortly after birth, the forehead ceases growth in width, but the back of the skull compensates. The result is as skull that, when viewed from the top, appears triangular, with the apex anteriorly. This is called **trigonocephaly**. If the sagittal suture closes prematurely, growth in width of most of the cranial vault will be retarded. Compensatory growth in the coronal suture will cause the braincase to become longer than normal, and compensatory growth in the lambdoidal and squamosal sutures will lead to excessive skull height. This condition is called **scaphocephaly**; it is the most common deformation due to premature sutural closure.

Premature sutural fusion is known as **craniosynostosis**. It comes in two varieties: simple (one suture fused) or compound (two or more fused sutures). Either may be primary (there are no other recognizable physical abnormalities) or secondary (associated with other obvious developmental defects). In simple primary craniosynostosis, the rate of mental retardation is 3-6% (somewhat higher when the coronal suture is fused than when the sagittal suture is fused). This value is 2 to 3 times greater than would otherwise be expected. In compound primary craniosynostosis, mental retardation occurs 35-50% of the time. Less severe learning disabilities appear in about half the children with simple primary craniosynostoses. It has not been determined whether the cognitive problems associated with craniosynostoses are caused by an underlying brain malformation, by increased intracranial pressure, or by a distortion of the brain due to the synostosis. Most people believe that the latter possibility is only reasonable when multiple sutures are fused.

Premature sutural fusion is treated surgically. In the simplest case, a strip of bone on either side of the fused suture is removed and some measure taken to prevent regrowth and closure. It has not been possible to demonstrate that surgery to correct the synostosis alters the cognitive development of the patient. One recent study on a small sample of children with simple synostosis, some of whom had surgery to correct it and others of whom did not, found no effect of surgical correction on rate of mental retardation or learning disability. The primary reason for performing such surgery is cosmetic.

Development of the Face

Like the cranial vault, the facial part of the skull is first laid down as a connective tissue sheet. This sheet is continuous with that of the cranial vault and with the perichondrium of the cranial base where it abuts the face. Numerous separate ossification centers form within the embryonic facial connective tissue. Each gives rise to a bone of the face, and sutures are created between these bones.

Also like the cranial vault, the growth of the face is highly dependent on the soft-tissue structures in the vicinity. Orbits are small if the eyes don't grow properly. Growth of the mandible and maxilla is influenced greatly by the tongue. Muscles attaching to the bones of the face play a role in determining the size of such bones.

Normally the eyes, and therefore the bony orbits, follow a growth curve similar to that of the brain. Other soft-tissue structures associated with the face develop at a different pace than do neural tissues. Nasal, oral, and muscular structures follow the so-called "general" body growth curve. General body structures undergo a slow-down in growth at about age 3, long before neural tissues begin their slow-down. From 3 years old to puberty, general body structures undergo steady but only moderate growth. At puberty they increase in size rapidly to reach their final adult size. Neural tissues have essentially stopped growing by puberty. Because the neurocranium and face follow such different patterns of growth, the braincase of a child is much larger in relation to its face than will occur later in life (see Fig. 8-10).

Growth of Two Special Skull Structures--the Mastoid Process and the Tympanic Bone

The mastoid process is a downward projection of the temporal bone behind the ear (see Fig. 8-4). The tympanic portion of the temporal bone is a tubular structure lying in front of the root of the mastoid process and forming the medial portion of the external auditory meatus (see Figs. 8-4, 8-8). If you look at the inferior surface of an adult skull, you will note a foramen located between the root of the mastoid process and the tympanic bone, posterior to the root of the styloid process (see Fig. 8-8). It is called the **stylomastoid foramen**, and it transmits the facial nerve into the retromandibular region of the neck. You should note that the stylomastoid foramen lies well away from the lateral surface of the skull. But such is not the case in newborns (see Fig. 8-10). This is because (1) the tympanic portion of the temporal bone of newborns is not tubular but is a simple ring with no significant mediolateral length, and (2) the mastoid process is undeveloped at birth, and subsequently grows as much outward as downward. Thus, in the newborn, the stylomastoid foramen is located behind the ear at the junction of the lateral and inferior surfaces of the skull (see Fig. 8-10), rather than 1 to 2 cm in from the lateral surface, as in adults.

You can imagine what might happen if you chose to assist delivery of the child by placing forceps behind the ear. The relatively superficial position of the stylomastoid foramen places the facial nerve in jeopardy of being crushed by the forceps, with catastrophic results for the future functioning of facial muscles. It is a cardinal rule of obstetrics that forceps never be placed behind the ears.

A second consequence of the short tympanic bone of newborns is that the eardrum is closer to the surface than in the adult. Like an adult, the child has a lateral cartilaginous part of the external auditory meatus, so the eardrum is not on the surface of the head, only relatively closer to it than will be the case later in life. One wants to be aware of this so that an otoscope is advanced more cautiously in the child than in the adult.

TEETH

Like most mammals, humans possess one set of small teeth that erupt early in life and are shed, and another set of larger teeth that erupt later and are meant to be permanent. The small teeth that will be shed are said to compose a **deciduous dentition**. At birth, the crowns of these teeth exist buried within the maxillae and mandible, below the gums, but they can be seen in radiographs of the skull. As the roots of the deciduous teeth develop, their crowns erupt through the gum surface into plain view. On each side of the upper and lower jaws, 5 deciduous teeth erupt. There are two incisors, one canine, and two premolars. Thus, a total of 20 deciduous teeth will exist. The deciduous incisors and canines look pretty much like the permanent incisors and canines that will come later. The deciduous premolars do not look like adult premolars. Rather, they have a crown structure resembling permanent molars. This makes sense, since the deciduous premolars are the grinding teeth of the child. Some authors simply refer to deciduous premolars as deciduous molars, but one must never lose sight of the fact that this is a functional, not developmental, nomenclature.

The first deciduous tooth to erupt is the medial incisor, at about 7 months. The last is the 2nd deciduous premolar, at about 2 years. The child has only deciduous teeth until about 6 years of age, at which time the 1st permanent molar erupts behind the 2nd deciduous premolar. From the age of 6 until the age of 12 the deciduous teeth are shed as growth of their permanent representatives causes resorption of their roots and pushes them out of the jaw. Following replacement of all deciduous teeth by their permanent representatives, the 2nd permanent molar erupts at about age 12. After a 6-year hiatus, the 3rd permanent molar erupts, although the development and eruption of this tooth is highly variable. It should be clear that the permanent molars have no deciduous precursors, but are simply added at the back of the jaw as its growth in length permits. The adult complement of teeth consist of two incisors, one canine, two premolars, and three molars in each half of each jaw (see Fig. 8-4). The total is, thus, 32.

CRANIAL CAVITY

The cranial cavity houses the brain. Persons interested in osteological details of the cranial cavity must consult a more comprehensive text. I wish to mention only a few salient facts. As you read further, it will help greatly if you can simultaneously look at a skull.

Posterior Cranial Fossa (Figs. 8-11, 8-12)

The floor of the cranial cavity is a three-tiered structure, with the lowest tier at the back and the highest at the front. The lowest tier of the cranial cavity is called the posterior fossa. It houses the cerebellum and much of the brainstem. In the floor of the posterior fossa is the large **foramen magnum**, through which the spinal cord and brainstem connect. We have already learned that the vertebral arteries enter the cranial cavity through this same hole, as do the apical dental ligament, upper band of the cruciate ligament of the atlas, and the tectorial membrane (upper end of the posterior longitudinal ligament of the spine). We shall now note that the spinal accessory nerves enter the cranial cavity through the foramen magnum. These nerves arise from special columns of cells in the upper cervical spinal cord. The cells are believed to have migrated from an origin in the brain. They send bundles of axons laterally out the spinal cord dorsal to the ligamentum denticulatum. On each side, lower bundles turn upward to join higher ones and form a single spinal accessory nerve that passes from the spinal subarachnoid space into the cranial subarachnoid space through the foramen magnum. Each accessory nerve then turns toward the jugular foramen, where it exits the cranial cavity adjacent to the vagus nerve. The extracranial course of the accessory nerve, the symptoms of damage to it, and the mechanism of testing for it, are described in Chapters 10 (p. 347) and 9 (p. 286 and pp. 284-285).

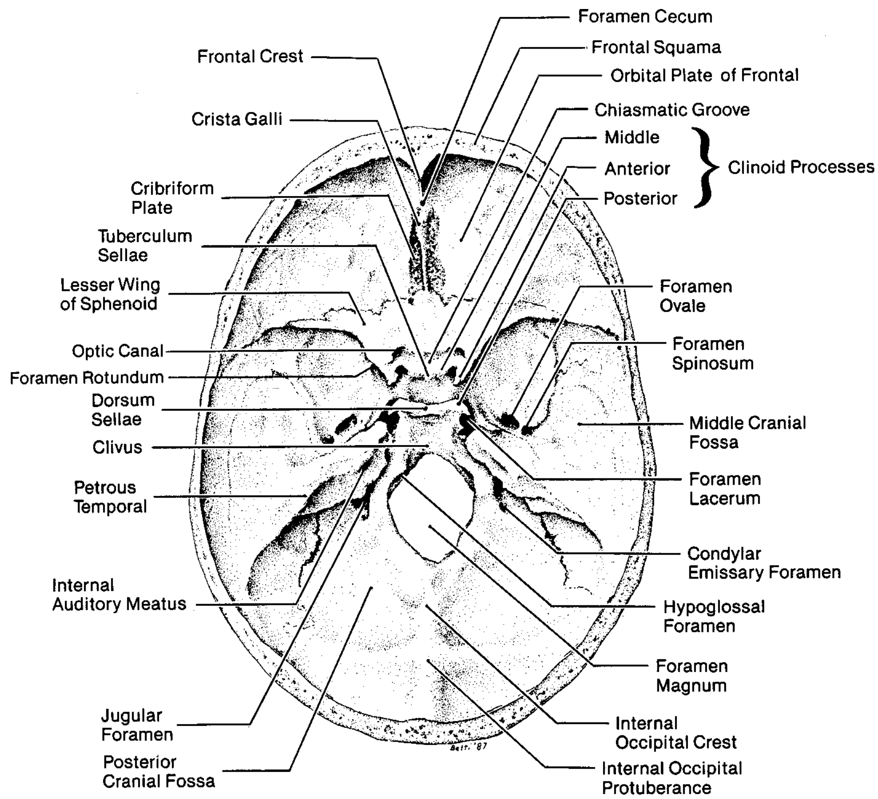

Figure 8-11. Superior view of the floor of the cranial cavity.

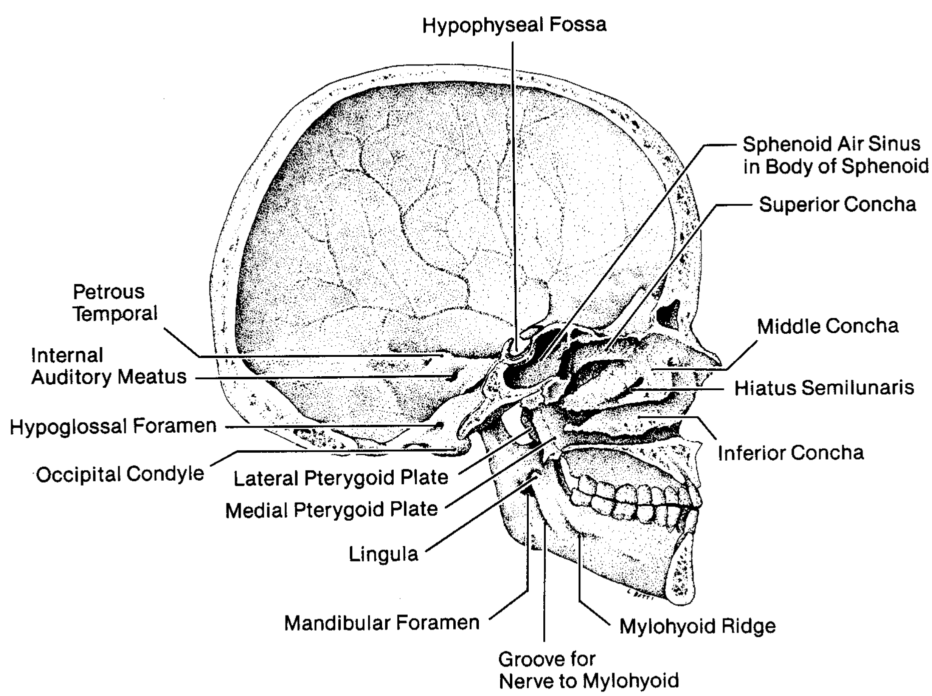

Figure 8-12. View of the skull in sagittal section. The middle concha has been made semitransparent to allow visualization of the hiatus semilunaris.

Superior to the rim of the foramen magnum, anterolaterally, are the **hypoglossal foramina** that transmit the hypoglossal nerves forward out of the cranial cavity. These are separated by a bony ridge from the more laterally placed **condylar emissary foramina**, through which the condylar emissary veins pass backward out of the cranial cavity.

The middle part of the anterior wall of the posterior fossa is formed by the so-called **clivus** (which is the internal surface of the apposed basilar portions of the occipital and sphenoid bones) and its upward extension--the **dorsum sellae**. On either side of the clivus, the anterior wall of the posterior cranial fossa is formed by the petrous parts of the temporal bones and, below them, by the parts of the occipital bone from which the condyles are suspended. Between each petrous temporal and the occipital bone is a bipartite gap called the **jugular foramen**. The large posterolateral part of the jugular foramen contains the beginning (bulb) of the internal jugular vein. The small anteromedial part passes cranial nerves IX, X, and XI out of the cranial cavity. On the back wall of the petrous temporal, superior to the jugular foramen, is the **internal acoustic meatus** that leads the facial and stato-acoustic nerves through the bone toward the inner and middle ears.

Extending backward from the posterior rim of the foramen magnum, in the median sagittal plane, is a ridge of bone called the **internal occipital crest**. After a couple of inches it terminates in a bump called the **internal occipital protuberance**. Various grooves (sulci) are found in the posterior and lateral walls of the posterior fossa. They mark the sites of dural venous sinuses to be discussed subsequently.

Middle Cranial Fossa (see Figs. 8-11, 8-12)

The middle of three cranial tiers is the middle cranial fossa. Laterally this fossa houses the temporal lobes of the brain; in the center of the fossa lies the pituitary gland. Each lateral part of the fossa has a floor formed mainly by the superior surface of the petrous temporal and the base of the greater sphenoid wing. Near the petrosphenoid junction, the base of the greater wing has two holes. The smaller more posterolateral hole is the **foramen spinosum**, for passage of the middle meningeal vessels. The larger hole, anteromedial to the foramen spinosum, is the **foramen ovale**, for passage of the mandibular division of trigeminal nerve. Posteromedial to the foramen ovale, on the anterior surface of the petrous temporal near its tip, is a depression that marks the location of the semilunar ganglion of the trigeminal nerve. The bony floor of this depression separates the trigeminal nerve from the internal carotid artery, which is deep within the petrous temporal. The artery leaves its canal within the petrous temporal to enter the middle cranial fossa on the superior surface of the cartilage that occupies the **foramen lacerum**. Here, the internal carotid turns sharply upward, grooving the lateral surface of the body of the sphenoid.

Each lateral part of the middle cranial fossa has an anterior wall formed primarily by the greater wing of sphenoid. At the base of the greater wing, where the anterior wall of the fossa meets its floor, is the **foramen rotundum**, which passes the maxillary division of trigeminal. Superior to the foramen rotundum is a teardrop-shaped gap in the anterior wall of the middle cranial fossa. This is the **superior orbital fissure**, located between the greater and lesser wings of the sphenoid. It passes most of the nerves that enter the orbit and the veins that leave it. Each lesser wing of the sphenoid has a sharp posterior edge that terminates medially in an expansion known as the **anterior clinoid process**.

The middle portion of the middle cranial fossa is formed by the body of the sphenoid, which is excavated for reception of the pituitary gland. The excavation is called the **hypophyseal fossa** and is technically a part of a greater structural complex called the **sella turcica** (“turkish saddle”), which includes other structures on the upper surface of the sphenoid body. However, almost everybody uses the terms "sella turcica" and "hypophyseal fossa" synonymously.

Behind the hypophyseal fossa is the upward sheet of sphenoid bone called the **dorsum sellae**. Its upper lateral angles are expanded as the **posterior clinoid processes**. The broad bump in the middle of sphenoid just in front of the hypophyseal fossa is the **tuberculum sellae**. On either side of the tuberculum sellae are tiny bumps called **middle clinoid processes**. A ligament stretches between a middle clinoid process and the tip of the ipsilateral anterior clinoid process. This ligament is called the **interclinoid ligament**, and its very presence creates in life a foramen, bounded laterally by the anterior clinoid process. Through the foramen passes the internal carotid artery. Thus, the foramen is given the name **caroticoclinoid foramen**. Occasionally the interclinoid ligament is ossified, allowing the caroticoclinoid foramen to be seen in a prepared skull.

Anterior to the tuberculum sellae is the so-called **chiasmatic groove**, which is named for the optic chiasm, although the latter does not actually contact the bone here. At the lateral extremities of the chiasmatic groove are the **optic foramina**, one in each lesser wing of the sphenoid for transmission of the optic nerve and ophthalmic artery between the orbit and cranial cavity.

Anterior Cranial Fossa

The final, highest tier of the cranial cavity is the anterior fossa. At its extreme posterior limit its floor is formed primarily by the body and lesser wing of the sphenoid. The rest of the floor of the anterior cranial fossa is formed almost entirely by the horizontal **orbital plates of the frontal bone**. The anterior wall of the anterior fossa is formed by the vertical **squama of the frontal bone**. Projecting inward from the midline of the squama, just above the site where it joins the floor of the anterior fossa, is a crest of bone called the **frontal crest**.

In the middle of the floor of the anterior fossa is a rectangular area composed of an extensively perforated bony plate from the midline of which a triangular process projects upward, posterior to the frontal crest, and separated from it by a hole in the floor of the fossa. This perforated plate is the **cribriform plate** of the ethmoid bone (L. *cribrum*, meaning "sieve"). The median sagittal triangular process is the **crista galli** (crest of the cock); the hole between crista galli and frontal crest is the **foramen cecum**, which some people say passes an emissary vein.

Periosteum and Dura Within the Cranial Cavity (Fig. 8-13)

In a prepared skull (or radiograph of the skull of a living person), the cranial cavity appears as one large open space with a three-tiered floor. However, when the soft-tissues can be visualized, the situation is quite different, because the dura of the brain participates in some rather complex formations that partition the cranial cavity into smaller regions with narrow communications between them. To understand these formations, we must understand a bit about the periosteum of the skull.

All bones have **periosteum** on their outer surfaces. If the bone has a marrow cavity, this cavity is lined by a connective tissue called **endosteum**. The bones of the skull are no different. However, students are often confused when they think about the bones of the cranial cavity, because both the surface that faces into the cavity, and the surface that faces the scalp or neck are outer, periosteal surfaces. Most of the bones of the cranial vault have only a thin marrow cavity interposed between the inward facing compact bone (**inner table**) and the outward facing compact bone (**outer table**). This marrow cavity is the **diploe**; naturally, it is lined with endosteum.

Wanting to have a name for the periosteum on the outer table of bone (i.e., the periosteum beneath the scalp), anatomists chose to call it **pericranium**. The periosteum on the inner table (i.e., the periosteum lining the cranial cavity) is called **endocranium**. Endocranium is not the same as endosteum.

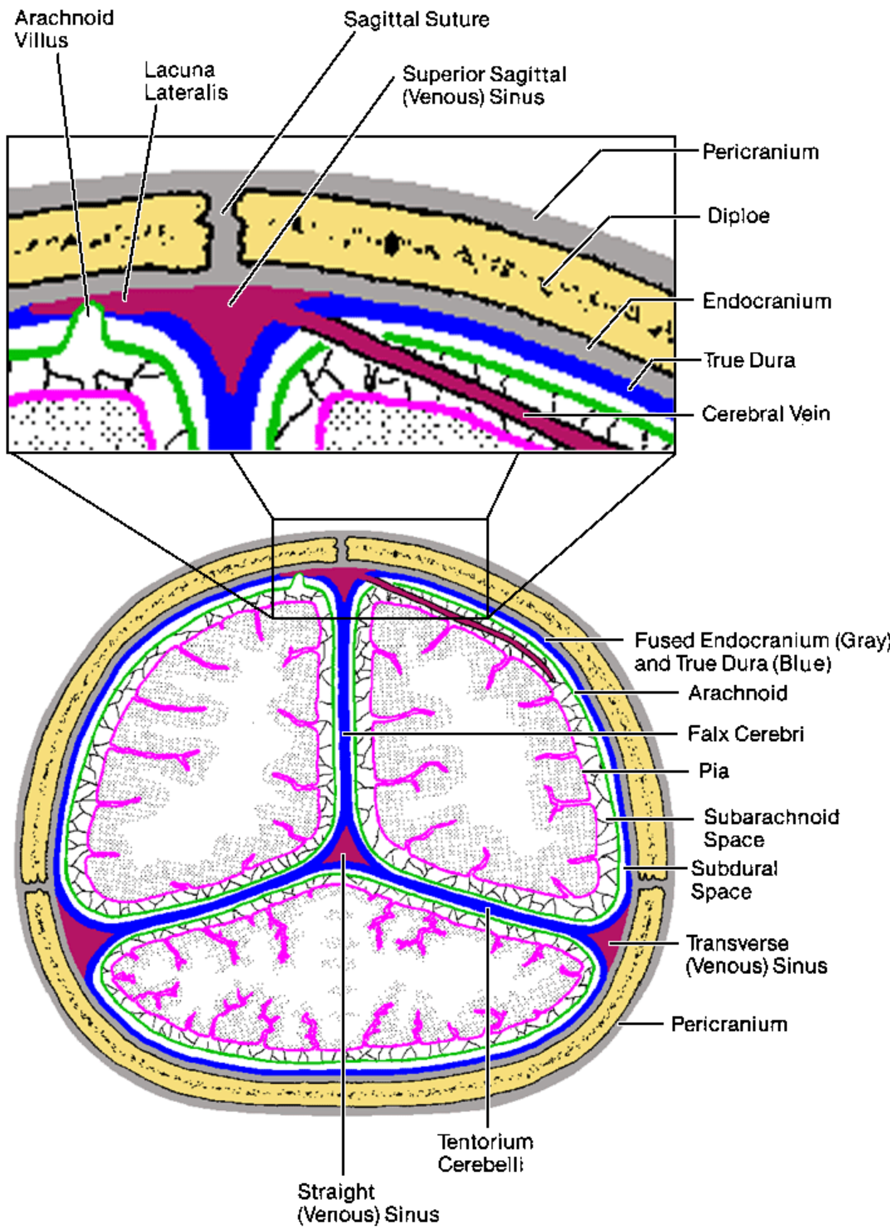

Figure 8-13. Schematic coronal section of the cranium taken posterior to the foramen magnum and illustrating the relationships between the periosteum, meninges, and dural venous sinuses.

Its only unique trait is that it is rather loosely attached to the actual osseous surface. Endocranium and pericranium are continuous at the sutures.

The endocranium is really the same sort of tissue as adheres to the inner surface of a vertebra, facing the vertebral canal. It will be recalled that intervening between the periosteum of the vertebral canal and the dura of the spinal cord is a fatty connective tissue with the internal vertebral plexus of veins running through it. This tissue and these veins are said to occupy an epidural space. In the cranial cavity, the endocranium and dura are actually fused over vast areas. Thus the epidural space is obliterated. The fusion of cranial dura to endocranium has led to a confusion in terminology. Most clinicians choose to call the fused layers by the single term "dura." When they want to refer to endocranium, they speak of the **outer layer of the cranial dura**. When they want to refer to the layer equivalent to the spinal dura, they speak of the **inner layer of the cranial dura**. Using this nomenclature, the term "epidural space" comes to mean the potential space between the endocranium and the inner table of bone. It is this "epidural space" that epidural hematomas occupy (see further on).

I find it useful to be able to refer to the space between endocranium and the true cranial dura. However, I would not want to use the term "epidural" to name this space, for such usage would conflict with common clinical practice. Therefore, I shall coin the term "**subendocranial**" for that space in the cranial cavity homologous to the epidural space of the spine. As we know, the subendocranial space is largely obliterated, but we shall soon learn that it does persist at some locations.

Whereas the spinal dura is pretty much a simple tubular sleeve, the true cranial dura is far more complex. At specific sites it breaks away from the endocranium and invaginates into the cranial cavity as a double-layer fold. Two major dural folds--the tentorium cerebelli and the falx cerebri--are developed.

Tentorium Cerebelli (Fig. 8-14)

On each side, from a line that starts at the internal occipital protuberance, runs laterally and then forward toward the upper margin of the petrous temporal, and finally passes anteromedially along this margin as far as the anterior end of the trigeminal impression, the true dura separates from the endocranium and passes inward to form a dural fold called the **tentorium cerebelli** (tent over the cerebellum). The tentorium cerebelli lies in a transverse plane. The root of the tentorium is continuous at

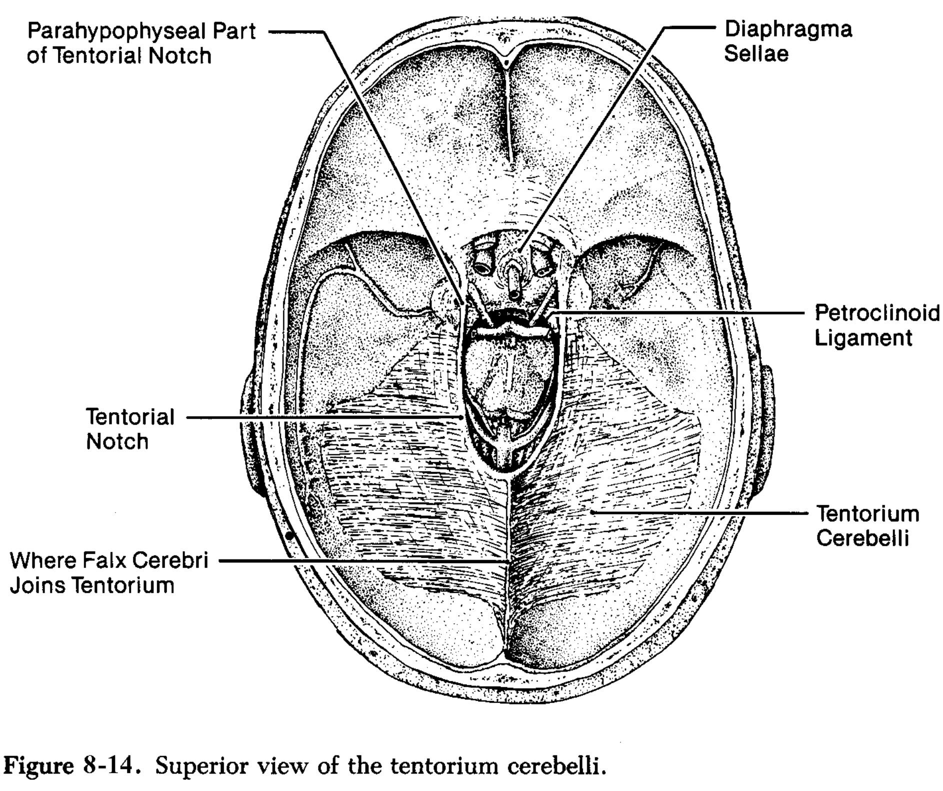

Figure 8-14. Superior view of the tentorium cerebelli.

its anterior end with a small dural fold that stretches from the upper margin of the petrous temporal across to the posterior clinoid process. This dural fold is called the **petroclinoid ligament**.

Fibers sweeping inward from the posterior half of the tentorial root on the right side actually meet their counterparts from the left side at the median sagittal plane. Fortunately, the tentorial fibers arising further anteriorly, from each petrous temporal, stop well short of the midline, so that an oval gap behind the dorsum sellae is created to allow passage of the brainstem from the posterior cranial fossa into the middle cranial fossa. The oval gap is called the **tentorial notch**. Its margins are strengthened by circumferential fibers that pass forward on either side into the middle cranial fossa to reach the anterior clinoid process. Thus, part of the margin of the tentorial notch lies lateral to the hypophyseal fossa and might be said to be "**parahypophyseal**." Dural fibers stretch from the petroclinoid ligament across to the parahypophyseal border of the notch anterior to the point of their crossing. This sheet of dura forms the roof of the cavernous sinus, which we will learn about shortly.

Falx Cerebri (Fig. 8-15)

On the inner surface of the cranial vault, along a line that runs from the crista galli all the way back to the internal occipital protuberance, the true dura separates from the endocranium and dives downward into the cranial cavity. Posteriorly, the layers of this fold meet and merge with the superior layer of the tentorium, forming a triradiate junction (see Fig. 8-13). Elsewhere, this dural fold has a free lower edge that is more or less semicircular in profile (see Fig. 8-15). Looking like a sickle, this median sagittal fold of dura is called the **falx cerebri** ("falx" is the Latin word for "sickle"). It is placed between the right and left cerebral hemispheres, stopping just short of the upper surface of the corpus callosum, which must be able to pass from one side of the cranial cavity to the other. Being interposed between the cerebral hemispheres, the falx cerebri provides a useful mechanical barrier to undesirable side-to-side movement of the hemispheres that would otherwise occur during rapid displacement of the skull.

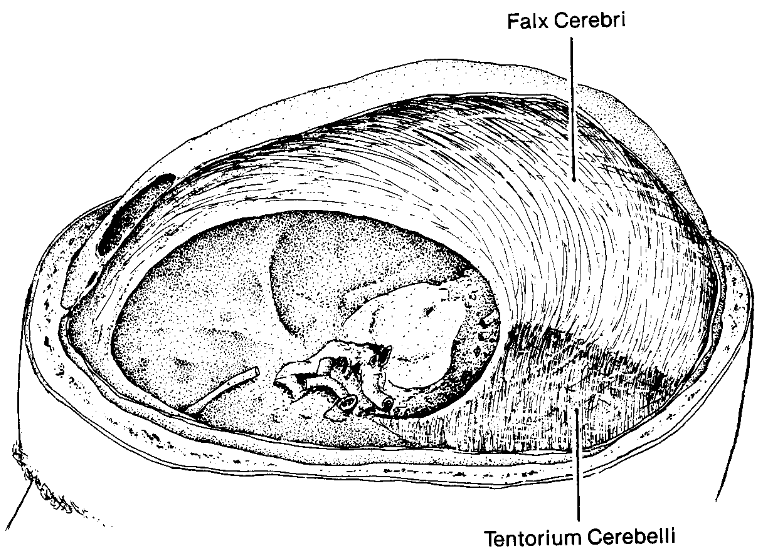

Figure 8-15. Oblique lateral view of the falx cerebri and tentorium cerebelli.

Lesser Dural Folds--Falx Cerebelli and Diaphragma Sellae

The falx cerebri and tentorium cerebelli are the most important folds of cranial dura, but they are not the only ones. Along the occipital crest the dura separates from endocranium to form a small median sagittal fold called the **falx cerebelli**. It passes but a short distance upward between the cerebellar hemispheres. Superiorly, the falx cerebelli merges with the lower surface of the tentorium near the internal occipital protuberance. Thus, just in front of this bump, there is a quadriradiate junction formed by the falx cerebri merging with the upper layer of tentorium and the falx cerebelli merging with its lower layer.

From the roofs of the two cavernous sinuses (see below), from a line connecting the two anterior clinoids, and from a line connecting the two posterior clinoids, the dura sweeps inward toward a point just superior to middle of the hypophyseal fossa (see Fig. 8-14). This fold--called the **diaphragma sellae**--stops short, leaving a circular gap through which the stalk of the pituitary gland descends. The diaphragma sellae forms a roof over the pituitary gland.

Dural Venous Sinuses

Dural Venous Sinuses in the Subendocranial Space at the Roots of Dural Folds (see Fig. 8-13)

At the sites where true dura separates from endocranium to participate in formation of a dural fold, the opportunity arises for the creation of real subendocranial spaces. Such a space will exist until the two dural sheets that form any fold actually adhere to one another. Thus, each of these subendocranial spaces will be triangular in cross section, with the base being formed of endocranium and the side walls composed of true dura. An endothelium lines both the endocranium and dura bounding these spaces, and they are used as venous blood channels. They are called **dural venous sinuses**. Given their location between endocranium and true dura, the dural venous sinuses located in the roots of dural folds can be seen to be nothing more than modified versions of the internal vertebral veins.

The dural venous sinus formed at the root of the falx cerebri is the **superior sagittal sinus**. Narrow anteriorly, it becomes increasingly voluminous as the root of the falx approaches the internal occipital protuberance. At certain sites along the course of the superior sagittal sinus, endothelial outpocketings push laterally a short distance between the true dura and endocranium lining the cranial vault. These outpocketings form the so-called **lacunae laterales** of the superior sagittal sinus. They are particularly important because the subjacent arachnoid covering of the brain sends its own numerous outpocketings through the inferior (dural) wall of a lacuna to be bathed by blood contained therein. These are called **arachnoid villi** (or granulations). Through the wall of each villus cerebrospinal fluid passes into the venous system. With age, the arachnoid villi may become so large as to press on the superior (endocranial) wall of a lacuna and thereby cause resorption of inner-table bone. This is not pathological; it merely explains the depressions in the inner table seen near the groove for the superior sagittal sinus in prepared skulls or radiographs .

Along the root of the tentorium cerebelli, from the internal occipital protuberance all the way around to the petrous temporal, is formed the **transverse sinus**. It is said that there are two transverse sinuses, one on the left and one on the right, but they usually communicate across the posterior midline. Since the root of the tentorium meets that of the falx cerebri near the internal occipital protuberance, the opportunity arises for the superior sagittal sinus to join up with the transverse sinuses. If the communication between transverse sinuses is big, the superior sagittal will empty into this communication. Otherwise, the superior sagittal sinus will pass into one or the other of the transverse sinuses.

Along the root of the falx cerebelli is the rather small **occipital sinus**. Inferiorly, the occipital sinus communicates with the internal vertebral venous plexus through the foramen magnum. Superiorly, where the root of the falx cerebelli joins the root of the tentorium, the occipital sinus also opens into one of the transverse sinuses or into the communication between them. We often have a situation in which four sinuses (right and left transverse, superior sagittal, and occipital) all join at one site. This site is called the **confluence of sinuses**.

One more dural venous sinus is created at the root of a dural fold. This occurs along the petrous origin of the tentorium and is called the **superior petrosal sinus**. It is just a smaller anterior continuation of the transverse sinus.

Dural Venous Sinuses in the Subendocranial Space Independent of Dural Folds

Not all the venous sinuses with the subendocranial space are formed at the roots of dural folds. At some sites there simply occurs an endothelial-lined separation of true dura and endocranium not associated with any infolding of the dura. One of the most important of these sites extends from the junction of the transverse and superior petrosal sinuses downward and then medially to the jugular foramen. The sinuous course of this channel accounts for its name of **sigmoid sinus**. It terminates at the jugular foramen of the skull, where it is continuous with bulb of the internal jugular vein. The free part of the vein itself passes downward from its bulb.

Another very important dural sinus not associated with a dural fold is the **cavernous sinus** (Fig. 8-16). It is a simple separation of a square patch of dura from endocranium on the lateral surface of the sella turcica. It is called "cavernous" because strands of connective tissue bridge between dura and endocranium, creating a meshwork that seems to surround caverns within what is actually one blood-filled space.

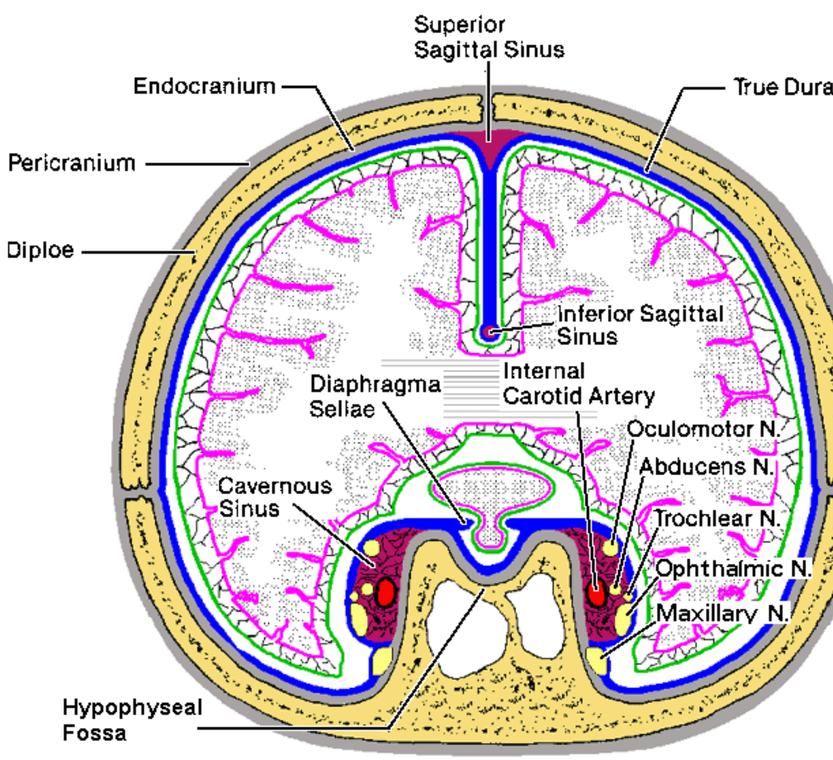

Figure 8-16. Schematic coronal section of the cranium taken through the sella turcica and illustrating the relationships of the periosteum, true dura, and cavernous sinuses.

The cavernous sinus is peculiar not only by possessing a transmural meshwork, but also by virtue of the fact that various nerves and the internal carotid artery run through its blood-filled space. This can be seen to be less remarkable by realizing that any nerve from the brain that wishes to leave the cranial cavity will have to pass through both dura and endocranium to get out. Some nerves first pierce the dura and then run for a while in the subendocranial space before finally going through periosteum. It is simply the case that a few nerves run in the blood-filled subendocranial space called the cavernous sinus. (A similar logic applies to the internal carotid arteries coming from outside the skull and going to the brain.)

Just how each nerve that travels through the cavernous sinus actually gets there will be described later. Suffice it to say now that the oculomotor, trochlear, and ophthalmic portion of the trigeminal run forward in the sinus with their epineuria adherent to the lateral (true dural wall), whereas the abducens runs forward more medially in the sinus, bathed by venous blood on all sides (see Fig. 8-16). The internal carotid artery is also completely bathed by blood but is still further medial than the abducens nerve. The maxillary nerve usually runs inferior to the cavernous sinus, but if the latter is especially large, this nerve too may be applied to the lateral wall of the sinus.

The upper posterior corner of the cavernous sinus is in communication with the superior petrosal sinus. The upper anterior corner communicates with a small sinus formed by separation of true dura from endocranium along the back edge of the lesser wing of the sphenoid. This is the **sphenoparietal sinus**.

A final subendocranial sinus not associated with a dural fold is the **inferior petrosal sinus**. it forms by separation of true dura from endocranium along the fissure between the clivus and petrous temporal. Anteriorly it communicates with the cavernous sinus; posteriorly it ends at the jugular foramen by joining the jugular bulb. Between the right and left inferior petrosal sinuses are communicating channels that altogether are said to form a **basilar plexus** sitting on the clivus. Inferiorly this basilar plexus communicates with the internal vertebral venous plexus through the foramen magnum. Often there are channels are on either side of the foramen magnum connecting the basilar plexus with the occipital sinus. Each such channel is called a **marginal sinus**.

Dural Venous Sinuses Not in the Subendocranial Space

I am sure everyone is tired of reading about dural venous sinuses, but there are still a few more to be mentioned. These are special in that they don't lie in the subendocranial space at all, but rather occupy a space created between the two layers of dura that make a dural fold. Thus, in the free edge of the falx cerebri, just where the left and right layers of dura join, is a longitudinal venous space called the **inferior sagittal sinus** (see Fig. 8-16). Traced posteriorly, this sinus arrives at the site where the free margin of the falx joins the tentorial notch (see Fig. 8-15). Here, the inferior sagittal sinus turns posteriorly, as the so-called **straight sinus** to travel in the intradural space at the triradiate junction of falx cerebri and tentorium (see Fig. 8-13). The straight sinus ends in the confluence of sinuses (or in one of the transverse sinuses).

Between the two layers of dura that form that part of diaphragm sellae in front of the pituitary stalk is a transverse venous channel connecting the right and left cavernous sinuses. This is the **anterior intercavernous sinus**. A similar **posterior intercavernous sinus** exists between the two layers of dura that form that part of the diaphragma sellae behind the pituitary stalk.

Cerebral Veins

The larger cerebral veins course within the subarachnoid space to reach one or another dural venous sinus. Naturally, such a vein must first pierce the arachnoid (actually the arachnoid merges with the vascular adventitia) before finally piercing true dura to empty into a sinus. Because of the pattern of flow within the dural sinuses, most blood from the brain eventually finds its way into the sigmoid sinus and internal jugular vein.

Particularly important is the fact that the veins on the lateral and superior surfaces of the cerebral hemispheres pass to the superior sagittal sinus (see Fig. 8-13). Cerebral veins that are destined for the sinus turn forward while still in the subarachnoid space to approach the dural wall of the sinus at an acute angle. These veins then travel obliquely forward through the dural wall before opening into the sinus.

To some degree the oblique course of cerebral veins into the superior sagittal sinus minimizes the likelihood that forward and backward motion of the cerebrum will cause the veins to shear off the sinus wall. However, apparently such a mechanism is imperfect, for occasionally a severe blow to the front or back of the skull causes such large anteroposterior displacements of the brain that some cerebral veins do shear off the sinus wall. Blood then spills into the subdural space producing a **subdural hematoma**. The blood is under low pressure and accumulation is usually gradual. Symptoms of cerebral compression may not occur until much later, when the blood breaks down and forms a fluid of high osmotic pressure that draws in further tissue fluid causing an increase in size.

Lastly, it should be mentioned that veins from the middle ear find their way to the superior petrosal sinus. This is of clinical significance as a route of spread of infection from the middle ear to the superior petrosal and transverse sinuses.

Emissary Veins

An emissary vein is a venous channel that runs from a dural sinus to a vein outside the cranial cavity. In addition to such channels, there is a giant emissary system formed by the **diploic veins**. The latter lie between the inner and outer tables of the cranial vault, communicate with one another, and empty into either the dural sinuses or veins of the scalp, face, and head. Individual emissary veins are a more direct route of communication. The more important emissary veins take the following paths:

1. Through the foramen ovale and/or foramen lacerum, establishing a communication between the cavernous sinus and veins around lateral pterygoid muscle (pterygoid venous plexus).

2. Through a hole at the back of each mastoid root, establishing a communication between the beginning of the sigmoid sinus and the veins of the scalp. These are the **mastoid emissary veins**.

3. Through a hole immediately behind each occipital condyle, establishing a communication between the termination of sigmoid sinus and the deep veins of the neck. These are the **condylar emissary veins**.

4. Through a hole in each parietal bone just lateral to the sagittal suture (at the junction of its anterior three quarters with its posterior one quarter), establishing a communication between the superior sagittal sinus and veins of the scalp. These are the **parietal emissary veins**.

The **superior and inferior ophthalmic veins** (to be discussed in more detail later) are kinds of emissary veins. The superior ophthalmic vein is in open communication both with superficial veins at the medial corner of the eye and with the cavernous sinus. The inferior ophthalmic vein, which also goes to the cavernous sinus, is connected to the pterygoid plexus via a communicating channel that passes through the inferior orbital fissure.

Although blood from the brain generally reaches the sigmoid sinus and internal jugular vein, it need not do so. Blood that has reached the dural venous sinuses may flow out to extracranial veins via emissary routes. The existence of such alternate routes is insurance that there will never be retardation of venous drainage from the brain.

CLINICAL SIGNIFICANCE OF EMISSARY VEINS

The routes of venous flow permitted by emissary veins are of considerable clinical significance. First, if a dural sinus becomes infected and thrombosed by virtue of some intracranial disease, the superficial veins with which that sinus communicates will become dilated, and the tissue drained by these superficial veins will become edematous. For example, thrombosis at the junction of the transverse and sigmoid sinuses secondary to a middle ear infection will lead to dilated veins and swollen tissue over the mastoid process. The thrombus and infection may even spread to this region.

More important than extracranial signs arising from an intracranial disease is the possibility, afforded by emissary veins, that infections in the face, nasal cavity, and scalp may be carried into the cranial cavity. Because emissary veins, diploic veins, and dural sinuses have no valves, any infectious material that penetrates a small vein of the face, scalp, or nasal cavity may flow through an emissary vein into one of the dural sinuses and produce a septic thrombosis within it. Such a state can progress to bacteremia, meningitis, or encephalitis.

CAVERNOUS SINUS THROMBOSIS

Infections of the face pose the very serious threat of passage to the cavernous sinus. One route is from the communication established between the facial vein and the cavernous sinus by the superior ophthalmic vein. Another, more complicated, route starts out by passing from the facial vein to the pterygoid plexus via the deep facial vein. Then, from the pterygoid plexus infectious material may spread to the cavernous sinus via the emissary vein through the foramen ovale, or via the emissary vein that runs through the inferior orbital fissure to the inferior ophthalmic vein. The cavernous sinus, having numerous transmural trabeculae, is a trap for infectious material.

The potential threats to life resulting from cavernous sinus thrombosis are the same as those of any other sinus thrombosis. However, before these occur, existence of cavernous sinus thrombosis is betrayed by a series of other symptoms. First there occurs a swelling of the eyelids and neighboring tissues, owing to retardation of venous flow through the superior ophthalmic vein (either hydrostatically or because the superior ophthalmic vein itself becomes thrombosed). Second, there is dilatation of retinal veins (which may be visualized ophthalmoscopically) and edema of orbital tissues (which causes the eyeball to move forward--a condition known as exophthalmos). The optic nerve may or may not become swollen.

Because important nerves run through the cavernous sinus, an inflammatory state within it will soon produce symptoms related to axonal malfunctioning. Thus, pain or tingling over the sensory distribution of the ophthalmic nerve will develop. This will be followed by anesthesia over the same area. Weakness (paresis) and then paralysis of the muscles supplied by the oculomotor, trochlear, and abducens nerves becomes apparent. Usually, the abducens nerve is the first to be affected because of its central location within the sinus. In the rare case that the maxillary nerve has a course through the lower part of the sinus, its areas of sensory distribution may be subject to the same disturbances as those of the ophthalmic nerve. Later in the text we will learn enough about the involved nerves to predict the actual symptoms of their malfunctioning.

As if septic thrombosis of one cavernous sinus were not bad enough, the existence of intercavernous sinuses permits spread from one side to the other. Hopefully, long before this happens, the patient will have been treated with antibiotics. Nerve symptoms will then disappear and collateral routes of venous drainage will expand, or the thrombus will resolve.

Cranial Arachnoid and Pia

The **pia** of the brain is actually thinner than the pia of the spinal cord, and also differs from the spinal pia in being only loosely attached to the external surface of the neural tissue. The spinal cord has a ventral median fissure into which the pia naturally follows. The brain has numerous grooves and sulci into the depths of which the cranial pia goes.

The **arachnoid** of the brain differs from that of the spinal cord in three rather important ways. First, the cranial arachnoid is thicker than the spinal arachnoid. Second, cranial arachnoid is connected to cranial pia by numerous fibrous bridges that cross the fluid-filled subarachnoid space. In a dissection, if you pull the cranial arachnoid away from brain, the pia comes with it. Finally, as mentioned above, the cranial arachnoid in the vicinity of the superior sagittal sinus is characterized by numerous villous outpocketings that project into the lacunae laterales and serve to pass cerebrospinal fluid into the blood (see Fig. 8-13).

Unlike the pia, the arachnoid does not dive into the grooves on the external surface of either the brain or spinal cord. Thus, the sulci of the cerebral hemispheres are filled with cerebrospinal fluid (CSF). There exist even larger accumulations of CSF at sites where the cranial arachnoid bridges across larger groves in the external surface of the brain. These accumulations are called **subarachnoid cisterns**.

Probably the most well known subarachnoid cistern occurs where the arachnoid sweeps off the posterior surface of the cerebellum onto the dorsal surface of the medulla. This so-called **cisterna magna** is of particular clinical significance because it can be entered by a needle inserted through the posterior atlanto-occipital membrane and then upward and forward through the foramen magnum. Such a **cisternal puncture** is a more dangerous approach to obtaining cerebrospinal fluid than is the lumbar puncture. It is sometimes done if the physician has evidence of increased cerebrospinal fluid pressure. A lumbar puncture is generally contraindicated in cases of increased intracranial pressure because rapid withdrawal of spinal CSF may cause a pressure differential that results in portions of the cerebellum and brainstem being pushed downward through the foramen magnum. A properly performed cisternal puncture eliminates this risk.

The major vessels of the brain run within the subarachnoid space on the surface of the pia. Leakage from one of these vessels (more often an artery than vein) leads to blood mixing with the cerebrospinal fluid. One reason for performing a lumbar puncture is to enable detection of subarachnoid hemorrhage.

Vertebral Artery Within the Cranial Cavity

Each subclavian artery gives rise to a vertebral artery that travels up the neck (see Chapter 9, page 318) to eventually enter the cranial cavity through the foramen magnum. A vertebral artery gives off a small **posterior meningeal branch**, **anterior and posterior spinal arteries**, unnamed branches to the medulla, and a **posterior inferior cerebellar artery**. Then, on the ventral surface of the brainstem at the posterior edge of the pons, the two vertebral arteries merge to form the single **basilar artery** that travels within the subarachnoid space in the midline groove on the ventral surface of the pons. The basilar artery has unnamed branches to the brainstem, and it also gives off the **anterior inferior cerebellar** and the **superior cerebellar** arteries (see Fig.8-17). At the anterior end of the pons, the basilar artery bifurcates into the **posterior cerebral arteries** (see Fig. 8-17) that go to the occipital lobes of the cerebrum.

Internal Carotid Artery Within the Cranial Cavity

The internal carotid artery enters the carotid foramen in the petrous temporal at the base of the skull (see Fig. 8-8). Immediately the vessel makes a 90-degree turn to travel anteromedially within this bone toward its apex, at which point the internal carotid artery emerges from the petrous temporal at a site superior to the cartilage filling the foramen lacerum, and immediately below the posterior part of the cavernous sinus. The artery then makes another turn of almost 90 degrees upward into the sinus, whereupon it turns forward and runs in the sinus alongside the body of the sphenoid bone, which it grooves. Once past the middle clinoid process, the internal carotid artery turns up again, pierces the dural roof of the cavernous sinus and the arachnoid to pass through the caroticoclinoid foramen into contact with the undersurface of the optic nerve. The internal carotid, now lying within the subarachnoid space, turns backward to run lateral to the optic chiasm and medial to the parahypophyseal margin of the tentorial notch. Upon reaching the lateral edge of the posterior clinoid process, the artery turns laterally toward the brain.

The first turn of the internal carotid that occurs immediately after it enters the petrous temporal is located in front of the anterior wall of the tympanic cavity. It is here that the artery gives off its first branch--the tiny **caroticotympanic artery**, which passes through the anterior wall of the tympanic cavity to contribute to the blood supply of the middle ear.

From the site where it exits the petrous canal until the site where it leaves the cavernous sinus, the internal carotid artery gives off minuscule branches to the trigeminal ganglion, nerves within the cavernous sinus, and the pituitary gland.

When the internal carotid artery leaves the cavernous sinus to achieve a position beneath the optic nerve, the **ophthalmic artery** is given off. The ophthalmic artery enters the optic canal on the inferior surface of the optic nerve.

Alongside the posterior clinoid process, as the internal carotid artery is executing its final turn laterally, the **anterior cerebral artery** is given off (see Fig. 8-17). The continuation of the internal carotid into the sylvian fissure of the brain is then called the **middle cerebral artery**. The anterior cerebrals from each side pass forward and medially toward the longitudinal fissure between the cerebral hemispheres. As they enter it, they are connected by a short communicating channel called the **anterior communicating artery** (see Fig. 8-17). Now the **circle of Willis** is completed (see Fig. 8-17), allowing blood from the vessels on one side of the body to reach those on other side, or for blood from the vertebral distribution to reach the carotid distribution, if exigencies so demand.

Circle of Willis (Fig. 8-17)

On the base of the brain is an anastomotic connection between its major arteries - the right and left vertebrals and the right and left internal carotids. At the hind end of the pons, the right and left vertebral arteries join one another to form the single basilar artery. This runs ventral to the pons, at whose anterior end it bifurcates into the **posterior cerebral arteries** that go to the occipital lobes of the cerebrum. About a centimeter after they arise, each posterior cerebral artery is connected to the internal carotid of the same side by a communicating vessel of variable size. This vessel is called the **posterior communicating artery**. Not infrequently the first centimeter of a posterior cerebral artery is extraordinarily tiny, in which case the posterior communicating artery on that side will be larger than usual so as to carry arterial blood from the internal carotid into the posterior cerebral beyond its constricted portion (Fig. 8-17, *right side*). On each side the posterior communicating artery runs forward to join the internal carotid carotid artery.

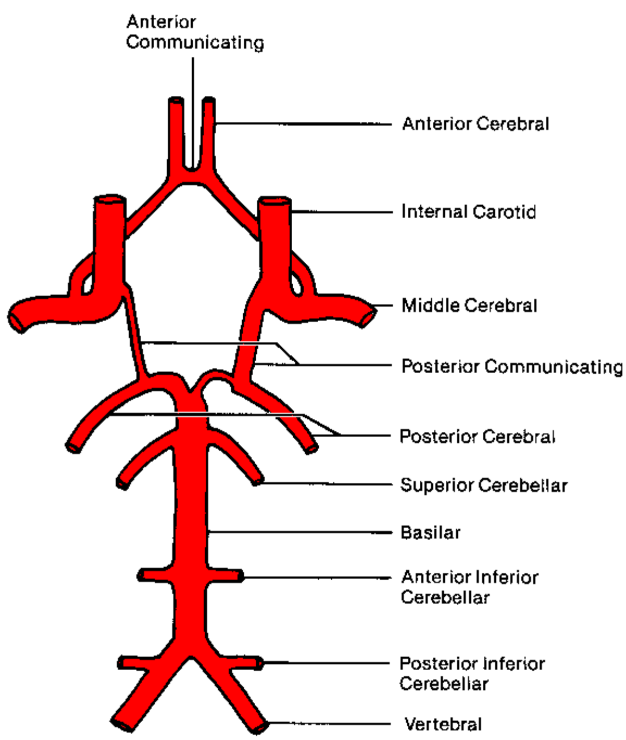

Figure 8-17. Schematic inferior view of the circle of Willis. On the *left side* of the figure is the common condition in which the posterior cerebral artery is large and the posterior communicating artery is small. On the *right side* of the figure is a variation in which a large posterior communicating artery takes over supply of blood to the distal portion of the posterior cerebral artery.

The anterior cerebrals turn forward and medially toward the longitudinal fissure between the cerebral hemispheres. As they enter it, they are connected by a short communicating channel called the

anterior communicating artery. This completes a “circular” connection of anastomosing arteries, which is called the **circle of Willis**. It allows blood from the vessels on one side of the body to reach those on other side, or for blood from the vertebral distribution to reach the carotid distribution, if exigencies so demand.

The Absence of Veins Accompanying the Intracranial Parts of the Vertebral and Internal Carotid Arteries

No veins run alongside the intracranial parts of the either the vertebral or internal carotid arteries. Instead, veins from the brain follow independent courses to the dural sinuses. The only branch of the internal carotid to be accompanied by a vein is the ophthalmic artery. Even then, the ophthalmic artery and ophthalmic veins do not really lie alongside one another, although both are in the orbit.

THE INTRACRANIAL PORTION OF THE TRIGEMINAL NERVE (C.N. V) AND MECKEL’S CAVE (CAVUM TRIGEMINALE)

The trigeminal nerve is both somatic sensory and somatic motor. It leaves the brainstem in two separate bundles, one of which contains all the sensory axons--the **sensory root--** and the other of which contains all the motor axons--the **motor root**. After leaving the brain, the two roots travel alongside each other (with the motor root deep to the sensory root) toward the superior edge of the petrous temporal near its apex. They encounter the arachnoid lying on the dura just below the superior petrosal sinus and push both meningeal layers out to form a two-layered pocket that insinuates itself between the endocranium and dura on the anterior surface of the petrous temporal (at the site known as the trigeminal impression) (Fig. 8-18). This pocket is called **Meckel's cave (or cavum trigeminale)**. While the nerve is within Meckel's cave, it is still in subarachnoid space.

The sensory cell bodies of the trigeminal nerve are located in a clump along the sensory root at the site where this root actually pierces the arachnoid/dural floor of Meckel's cave to take up a position between true dura and endocranium (see Fig. 8-18). This clump is crescentic in shape and is often called the **semilunar (Gasserian) ganglion**. The peripheral processes of the sensory axons emerge from the distal edge of the ganglion in three separate bundles. These three bundles are the ophthalmic division (called V_1), the maxillary division (called V_2), and mandibular division (called V_3) of the trigeminal. Also piercing the floor of Meckel's cave is the motor root, which then joins the mandibular division. As we learned previously, the ophthalmic division of trigeminal enters the cavernous sinus to travel (to the superior orbital fissure) applied the inner aspect of the sinus’ lateral wall (see Fig. 8-16). The maxillary division of trigeminal passes forward (to the foramen rotundum) in the plane between true dura and endocranium, usually just inferior to the cavernous sinus. The mandibular division of trigeminal has the shortest intracranial course; it heads inferiorly to exit the cranial cavity through the foramen ovale.

ORBITAL CAVITY AND EYE

Bony Orbit (Fig. 8-19)

The bones of the face form a socket around the optic nerve and eyeball. This socket is called the **orbit**. It is cone-shaped with the apex facing posteromedially. The roof of the orbit is formed by a backward shelf (i.e., orbital plate) of the frontal bone that separates the frontal lobes of the brain from the orbital contents. The lateral wall is formed by the greater wing of sphenoid and the zygomatic bone, which separate the temporalis muscle from the eye. The floor is formed almost entirely by the maxilla

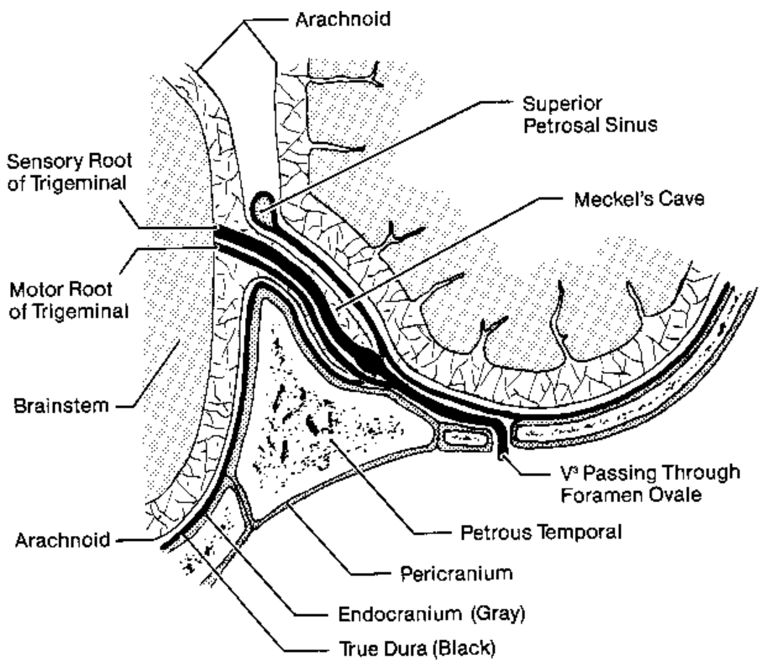

Figure 8-18. Schematic coronal section through the base of the skull at the site of the trigeminal impression on the petrous temporal. This figure illustrates the manner by which the arachnoid and true dura participate in formation of the cavum trigeminale (Meckel's cave), through which pass the sensory and motor roots of the trigeminal nerve.

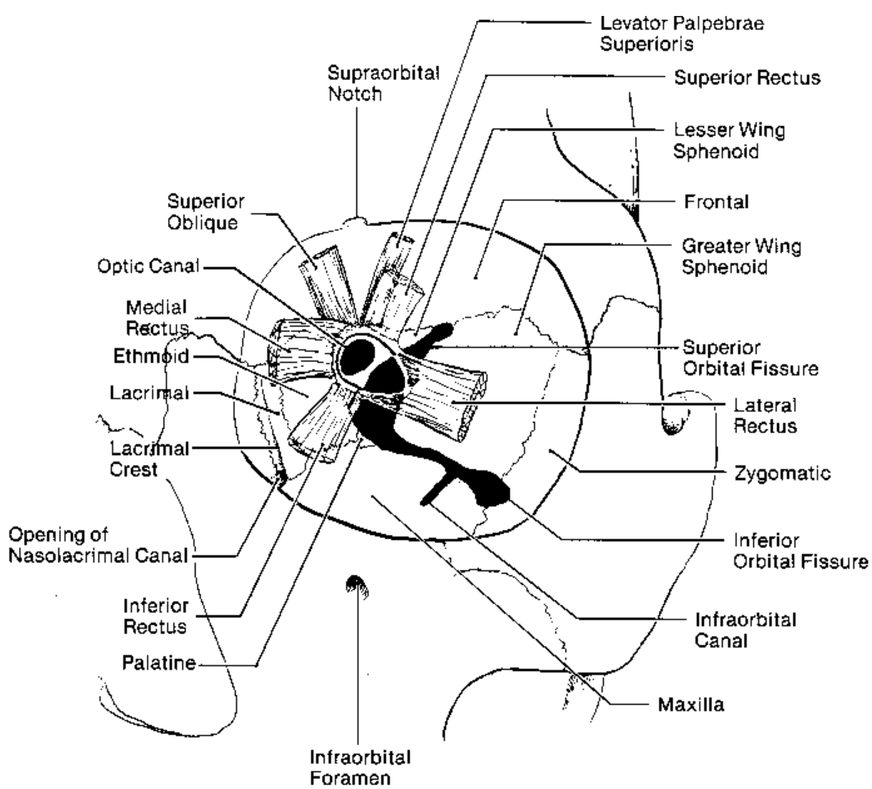

Figure 8-19. Anterior view of the left orbit and the origins of the extraocular muscles.

containing the maxillary air sinus. The medial wall is predominantly formed by the labyrinth of the ethmoid. Anteriorly the lacrimal bone makes its contribution, as does the frontal process of the maxilla. Just behind the inferomedial angle of the orbital rim there is a depression in the medial orbital wall for housing the lacrimal sac. Below this so-called **lacrimal fossa**, the orbital floor presents a large hole for passage of the nasolacrimal duct into the nasal cavity.

The eyeball itself occupies only the anterior half of the orbit. The optic nerve, which leaves the posterior surface of the eyeball medial to its posterior pole, runs through the back half of the orbit toward its apex. At the apex is a round hole in the lesser wing of the sphenoid called the **optic foramen**. The optic nerve leaves the orbit via the optic foramen, and the ophthalmic artery enters the orbit through the same hole.

Inferolateral to the optic foramen is a teardrop-shaped slit between the greater and lesser wings of the sphenoid. Through this so-called **superior orbital fissure** pass all the other nerves to the eyeball and to its muscles, and also the veins from these structures. Running most of the length of the orbit at its inferolateral angle is the **inferior orbital fissure**, which is a route of communication between the orbit and the infratemporal fossa (see further on). Various other small foramina exist in the bony walls of the orbit for other nerves and vessels.

Anulus Tendineus and Compartmentalization of Superior Orbital Fissure

If one peers into the orbit of a prepared skull from the front, a tiny spicule of bone can be seen projecting medially from the lateral border of the superior orbital fissure at a site directly across from the optic foramen (see Fig. 8-19). From this spine two ligamentous bands pass medially and backward toward the borders of the optic foramen. One band attaches to the superior border of the optic foramen; the other attaches to the foramen's inferior border. The two bands meet medial to the foramen. Because the ligaments have a common origin and once again meet medial to the optic foramen, they serve to form a tendinous ring (**anulus tendineus**), which is in fact more egg-shaped than round (see Fig. 8-19). The recti muscles of the eye arise from the anulus tendineus.

The two "transfissural" ligaments forming the anulus tendineus divide the superior orbital fissure into three compartments: superior (above the higher band), middle (between the bands), and inferior (below the lower band). The abducens nerve, the nasociliary nerve and the two divisions of the oculomotor nerve pass through the middle compartment of the superior orbital fissure. The frontal, lacrimal, and trochlear nerves enter the orbit through the superior compartment of the superior orbital fissure. The superior ophthalmic vein passes out of the orbit either through the middle or superior compartments of the fissure.

Periorbita

The periosteum on the bones of the orbit is continuous anteriorly with that covering the bones of the face, and it is continuous posteriorly (through the superior orbital fissure and optic foramen) with the endocranium lining the cranial cavity. This orbital periosteum is usually given the distinct name of **periorbita**. It is rather easily separated from the orbital bone. It also extends from the orbital rim into the eyelids as the orbital septum, which merges with the tarsi to provide a fibrous skeleton for the eyelids (see below).

Extraocular Fat and Fascia

The mesoderm interposed between the bony orbit and the developing eyeball differentiates into a fatty connective tissue. Immediately adjacent to the sclera this extraocular tissue is more densely fibrous, forming a **fascia bulbi** (**Tenon's capsule**) that attaches to the front of the eyeball near the corneoscleral junction and to the back of the eyeball where it is pierced by the optic nerve (see Fig. 8-23, p. 276). The space between sclera and Tenon's capsule is called the **episcleral space**. It is bridged by only thin fibrous strands.

On the anterior surface of the eye Tenon's capsule intervenes between the bulbar conjunctiva and the sclera. Blood or infectious matter that accumulates in the episcleral space may elevate the bulbar conjunctiva away from the sclera at front of the eye. When the eye is removed at surgery, the plane of dissection is between the sclera and Tenon's capsule.

Muscles of the Oculomotor, Trochlear, and Abducens Somitomeres

The prechordal mesoderm and the oculomotor, trochlear, and abducens somitomeres send cells into the extraocular mesoderm surrounding the developing fascia bulbi. These immigrant cells differentiate into the striated muscles that will insert into the sclera and produce rotation of the eyeball within its bony socket. Such muscles are called the **extraocular (external ocular) muscles** to distinguish them from the ciliary and pupillary muscles, which are intraocular. The tendons of the extraocular muscles pierce Tenon's capsule to reach the sclera; the epimysium of the muscles is continuous with Tenon's capsule at these sites.

The trochlear somitomere gives rise to only the superior oblique muscle. The abducens somitomere gives rise to only the lateral rectus. The prechordal mesoderm and oculomotor somitomere gives rise to all other extraocular muscles--superior rectus, medial rectus, inferior rectus, inferior oblique--and to the levator palpebrae superioris, which does not actually attach to or move the eyeball.

The Lateral, Superior, Inferior, and Medial Recti of the Eye

The four recti muscles of the orbit take origin from the anulus tendineus (see Fig. 8-19). The lateral rectus muscle arises from the lateral, narrower end of anulus, the medial rectus arises from its more rounded medial end; the superior rectus arises from its superior band, the inferior rectus from its inferior band. The optic nerve passes through the optic foramen between the origins of superior and inferior rectus. The nerves that pass through the middle compartment of the superior orbital fissure (i.e., abducens nerve, nasociliary nerve, and the two divisions of the oculomotor nerve) run between the optic nerve and the origin of lateral rectus.

The fibers of each rectus muscle pass forward in the orbital fat related to the optic nerve in a manner suggested by the name of the muscle (i.e., lateral rectus is lateral to the nerve, superior rectus is superior to the nerve, and so on). Because of the location of the eyeball in the front half of the orbit, the recti muscles must travel half the length of the orbit before they even reach the vicinity of the eyeball. Upon reaching the eyeball, the recti pass onto its surface, again with a relationship suggested by the name of the muscle. Passing the equator of the eyeball, each rectus becomes tendinous, pierces Tenon's capsule, and inserts into the sclera not far behind the corneal limbus.

Superior Oblique

The superior oblique arises at the back of the orbit, but not from the anulus tendineus. The superior oblique arises from the lesser wing of the sphenoid bone just anterior to the superomedial region of the anulus (see Fig. 8-19). This cylindrical muscle passes forward in the superomedial "corner" of the orbit, above the medial rectus. As it nears the orbital rim, the superior oblique becomes tendinous. The round tendon passes through a fibrous pulley (trochlea) just behind the superomedial corner of the orbital rim. After passing through the trochlea, the tendon turns sharply backward and laterally, to run to the superior surface of the eyeball near its equator. Passing deep to the superior rectus, the tendon fans out before actually inserting into the sclera.

Levator Palpebrae Superioris

The levator palpebrae superioris is a second extraocular muscle that does not arise from the anulus tendineus. Instead, it arises from the lesser wing of the sphenoid bone just lateral to the origin of the superior oblique (see Fig. 8-19). The levator begins as a narrow muscle but broadens considerably as it passes forward on the upper surface of superior rectus. Consequently, at the back of the orbit only the medial part of superior rectus is under cover of the levator, whereas the whole superior rectus becomes covered more anteriorly. At the front or the orbit, the levator palpebrae superioris gives rise to a flat tendon that inserts both onto the anterior surface of the superior tarsus and into the subcutaneous tissue of the upper eyelid.

The levator palpebrae superioris is a striated voluntary muscle. On the deep surface of its aponeurosis are smooth muscle fibers that attach to the superior tarsus. These constitute the **tarsal muscle,** or **Müller’s muscle.** They must receive an innervation appropriate to smooth muscle, and in fact are innervated by postganglionic sympathetic axons derived from cells of the superior cervical sympathetic ganglion. These axons travel with axons for the dilator pupillae. How such axons to get to eye muscles will be described later.

Inferior Oblique

This extraocular muscle does not even arise from the vicinity of optic foramen. Rather it arises just behind the orbital rim immediately lateral to the nasolacrimal foramen. The muscle sweeps backward and laterally, below the inferior rectus insertion, and then turns upward to insert into the sclera near the equator of the eye, deep to lateral rectus.

Actions and Functions of Extraocular Muscles

Levator Palpebrae Superioris

This muscle does what its name suggests--it elevates the upper lid. It is known from electromyographic studies that the striated muscle fibers are continuously active during waking hours. Voluntary lowering of the upper lid is accompanied by relaxation of the striated muscle fibers of levator palpebrae superioris and by slight activity in certain fibers of the palpebral portion of orbicularis oculi. Blinking involves rapid cessation of activity in the levator simultaneous with a burst of activity throughout the palpebral portion of the orbicularis oculi.

When damage to the oculomotor nerve causes paralysis of the striated fibers of the levator palpebrae superioris, the upper eyelid droops markedly. Yet it does not close entirely, and this must be due to continued activity of Müller's muscle.

Movements of the Eyeball (Fig. 8-20A)

The eyeball is capable of rotating about three independent axes: superoinferior (vertical), mediolateral (transverse), and anteroposterior. These are defined when the eye is looking straight ahead. Thus, the anteroposterior axis coincides with the optic axis, which runs from the center of the cornea to the fovea centralis.

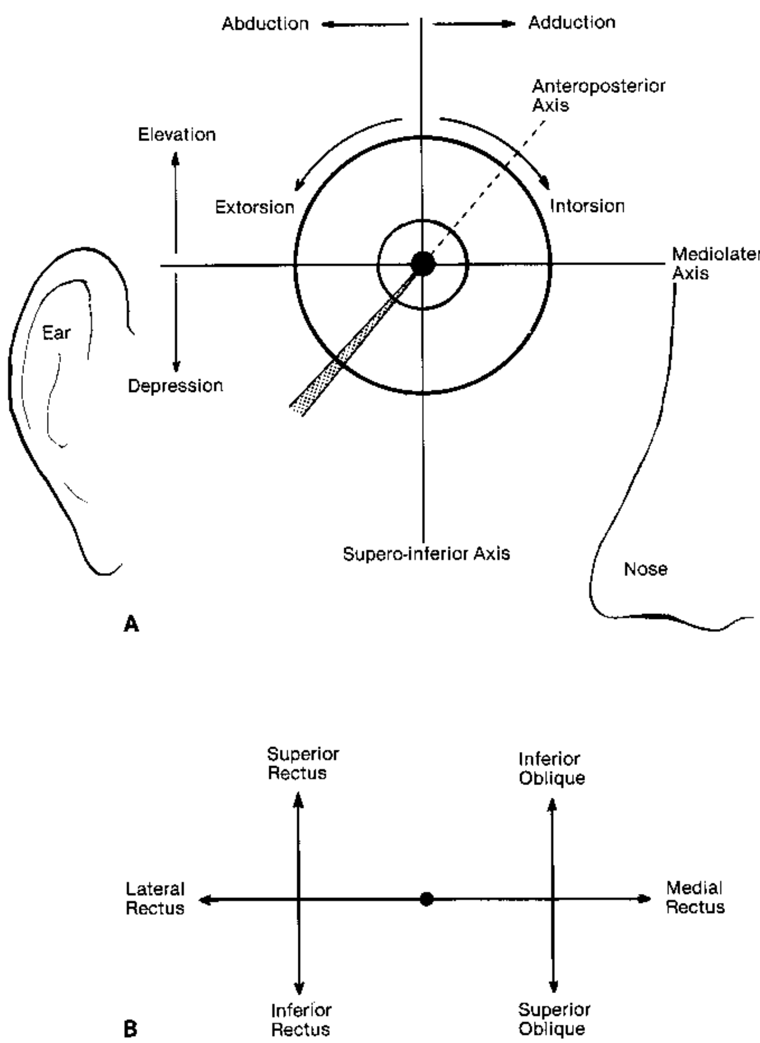

Figure 8-20. *A,* Schematic view of the axes and movements of the eyeball. *B,* Summary diagram of the functions of extraocular muscles (see text for explanation).

Rotation about the vertical axis causes the pupil to swing from side to side, i.e., to face either more toward the bridge of the nose or more toward the temple. Movement of the pupil toward the bridge of the nose is called medial deviation, or **adduction**; the opposite movement is called lateral deviation, or **abduction**. Rotation about the transverse axis cause the gaze to be directed either upward, **elevation**, or downward, **depression**. Rotation of the eyeball around the optic axis produces a spinning in the socket without the direction of gaze changing. If the rotation is such that the superior pole of the eye moves medially, this is called **incycloduction** (**intorsion**). If the rotation is such that the superior pole of the eye moves laterally, this is called **excycloduction** (**extorsion**). In most circumstances both kinds of cycloduction must be prevented, since they cause the individual to see the world as if it were rotating clockwise or counterclockwise, which clearly will be very disorienting. The key to understanding the functions of eye muscles in most situations is to realize that no muscle will be recruited in isolation if its action will produce cycloduction of the eyeball.

Functions of the Recti and Obliques

Regardless of eyeball position, two muscles--the lateral and medial recti--produce no torque about the optic axis and, therefore, have no tendency to produce cycloduction. The lateral rectus is a pure abductor of the eyeball; the medial rectus is a pure adductor (Fig. 8-21*B*). Each of the other four muscles attaching to the eyeball tend to cause cycloduction depending upon the position of the eyeball. This can be most readily appreciated by considering the case when the gaze is straight ahead. The superior rectus has a vector applied to superior surface of the eyeball (see Fig. 8-21*B*). This vector can be resolved into two components--one directed posteriorly, the other directed medially. The posteriorly directed component elevates the gaze by pulling the upper surface of the eyeball backward. The medially directed component pulls the upper surface inward, causing incycloduction. The superior rectus will not be called upon to elevate the eye unless its action as an incycloductor can somehow be negated.

The vector of the superior oblique is also applied to the superior surface of the eyeball (see Fig. 8-21*B*). This vector is directed anteromedially, and may be resolved into an anterior component that

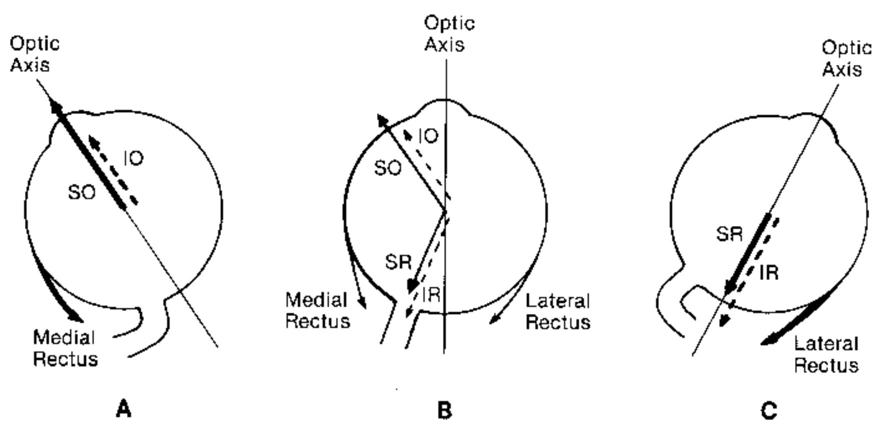

Figure 8-21. Schematic superior view of right eyeball illustrating the interactive functions of the extraocular muscles. *A*, When the medial rectus adducts the eyeball, the superior oblique (SO) can depress the gaze and the inferior oblique (IO) can elevate the gaze without torsion effects. *B*, The medial and lateral recti are the only two muscles that have no torsion effect on the eyeball when the gaze is directed straight ahead. *C*, When the lateral rectus abducts the eyeball, the superior rectus (SR) can elevate the gaze and the inferior rectus (IR) can depress the gaze without torsion effects.

causes the eye to gaze downward and a medial component that produces incycloduction. The superior oblique will not be called upon to depress the eye unless its tendency to produce incycloduction can be negated.

Similar vector analyses demonstrate that the inferior rectus, pulling posteromedially on the inferior surface of the eyeball (see Fig. 8-21*B*), is a depressor and excycloductor. Inferior oblique, for all intents and purposes pulling anteromedially on the undersurface of the eyeball, is an elevator and excycloductor (see Fig. 8-21*B*). Neither of these muscles will be used to produce up or down movements of the eye unless their cycloduction effects can be negated.

Now we must ask what clever means can be used to negate the cycloduction effects of the elevators and depressors of the eye so that these muscles can do their jobs? One method is to employ the lateral or medial rectus to move the eyeball into a position where one or more of the other muscles has no cycloduction effect. For example, let the lateral rectus abduct the eye (see Fig. 8-21*C*). The optic axis now is in line with the pull of the superior and inferior recti. The superior rectus may contract to elevate the abducted eye without producing any cycloduction about the optical axis. The inferior rectus may depress the abducted eye without producing cycloduction. The cycloduction effects of the obliques are accentuated and they become essentially useless as elevators or depressors.

What happens when the medial rectus adducts the eye (see Fig. 8-21*A*)? The cycloduction effects of the superior and inferior recti become accentuated, but the obliques now have a vector pull coinciding in direction with the optic axis. The superior oblique may depress the adducted eye without producing cycloduction; the inferior oblique may elevate the adducted eye without producing cycloduction.

These analyses are reflected in Figure 8-20*B*. The lateral rectus is a pure abductor. When it is acting, the superior rectus elevates and the inferior rectus depresses the abducted eye. The medial rectus is a pure adductor. When it is acting, the superior oblique depresses and the inferior oblique elevates the adducted eye.

This is all well and good. But what happens when a person wishes to look up or down without first abducting or adducting the eye? Then that person must use muscles that have counteracting cycloduction effects. Fortunately, the two elevators (superior rectus and inferior oblique) have opposite cycloduction actions that cancel. They can be used together to elevate the forward gazing eye. Similarly, owing to the opposite cycloduction effects of the superior oblique and inferior rectus, they can be used together to produce depression of the forward-gazing eye.

Many texts refer to the depressors and elevators of the eye as having torques about the superoinferior axis that endow these muscles with the ability to produce abduction or adduction. It is certainly true that such torques do exist in certain positions of the eye, but they are best viewed as nuisances to be overcome by the medial and lateral recti.

Ophthalmic Artery

Entering the optic canal on the inferior surface of the optic nerve, the ophthalmic artery soon pierces the arachnoid and dural sheaths of the nerve to emerge into the orbit still inferior to the nerve but now in the extraocular space. Once in the orbit, the ophthalmic artery usually passes upward around the lateral side of the optic nerve and then turns anteromedially across its top surface, beneath the superior rectus muscle. However, in about 25 percent of cases, the artery simply heads anteromedially below the nerve. Regardless, its anteromedial course takes the ophthalmic artery toward the upper border of the medial rectus muscle, where the vessel turns anteriorly to run all the way to the front of the orbit. Just before reaching the orbital septum, the ophthalmic artery bifurcates into its two terminal branches--the supratrochlear and dorsal nasal arteries.

Although the ophthalmic artery is small, it has quite a few named branches. Additionally, it gives off unnamed muscular branches to the extraocular muscles.

Immediately after entering the orbit, while still beneath the optic nerve, the ophthalmic artery gives off the tiny but very important **central artery of the retina**. This vessel pierces the dural sheath of the optic nerve and travels forward embedded in this sheath until about 1 cm from the back of the eyeball. Here, the central artery of the retina pierces the arachnoid and pia to reach the middle of the optic nerve, where it runs forward into the eyeball for distribution to the optical retina.

While traveling upward on the lateral surface of the optic nerve, the ophthalmic artery gives off the **lacrimal artery**. This vessel travels forward along the upper edge of the lateral rectus muscle. It eventually reaches the lacrimal gland, which the artery supplies, and then terminates in branches to the eyelids. Before reaching the lacrimal gland, the lacrimal artery gives off a tiny **zygomatic branch** that runs through the zygomatic bone with the zygomatic nerve (see further on). More importantly, the lacrimal artery gives off a **recurrent meningeal** branch that turns posteriorly and passes through a foramen between the greater wing of the sphenoid bone and the frontal bone (see Fig. 8-19) to anastomose with the anterior branch of the middle meningeal artery. In this manner, an anastomosis between the internal and external carotid arteries is established.

From the same stretch of the ophthalmic artery that gives off the central retinal and lacrimal branches come two (sometimes more) **posterior ciliary arteries**. They may even come off common trunks with the central retinal and lacrimal arteries. The posterior ciliary arteries run toward the eyeball parallel to the optic nerve, but close to the eyeball they branch several times. Thus, numerous tiny posterior ciliary arteries actually pierce the sclera all around the entrance site of the optic nerve. Most of these ramify in the choroid for supply of the nonretinal tissues. The two largest posterior ciliary branches (one entering the eyeball lateral to the optic nerve and one entering medial to the nerve) pass all the way round to the front for supply of the ciliary body and iris. These two vessels are called **long posterior ciliary arteries**, thereby causing the others to be called **short posterior ciliary arteries**.[32]

As the ophthalmic artery runs anteromedially across the top surface of the optic nerve beneath the superior rectus, it gives off a **supraorbital artery**. This vessel passes onto the superior surface of the levator palpebrae superioris by crossing its medial edge. Traveling forward on the levator palpebrae superioris, the supraorbital artery encounters the orbital septum just below the supra-orbital notch. The vessel pierces the septum and turns superiorly deep to the frontalis muscle. After a variable distance, the artery pierces frontalis and continues backward in the subcutaneous tissue of the scalp.

While running forward in the interval between the superior oblique and medial rectus muscles, the ophthalmic artery sometimes gives off a tiny **posterior ethmoidal artery** and always gives off a slightly larger **anterior ethmoidal artery**. Both course medially (the posterior ethmoidal superior to the superior oblique muscle, the anterior ethmoidal between the superior oblique and medial rectus) to pass through separate foramina in the medial orbital wall and thereby reach the ethmoid air cells, which they

[32] There would be no ciliary arteries specified as posterior if there were not some that are called anterior. The anterior ciliary arteries are not direct branches of the ophthalmic. Rather, the muscular branches of the ophthalmic send tiny vessels that ramify on the surface of the sclera beneath the bulbar conjunctiva. These communicate with the long posterior ciliary arteries through vessels that pass through the sclera.

supply. However, both also continue beyond the ethmoidal air cells into the cranial cavity at the lateral border of the cribriform plate. The posterior ethmoidal artery terminates in the anterior cranial fossa by giving rise to meningeal branches and to nasal branches, which pass through the cribriform plate for supply of the upper nasal septum and lateral nasal wall. The anterior ethmoidal artery gives off similar branches, but it also continues forward on the superior surface of the cribriform plate to pass through a slit at its anterior end and enter the nasal cavity far anteriorly. Here it gives rise to further branches for the septum and lateral nasal wall, but then continues on the deep surface of the nasal bone to its inferior edge, where the vessel emerges between nasal bone and lateral nasal cartilage as a cutaneous artery.

After the ophthalmic artery gives off its anterior ethmoidal branch, it continues forward along the upper edge of medial rectus until very near the orbital septum, where the artery bifurcates into its terminal branches--the **supratrochlear and dorsal nasal arteries**. Both pierce the orbital septum above the medial palpebral ligament, but then the supratrochlear turns upward into the subcutaneous tissue of the scalp, whereas the dorsal nasal turns medially into the subcutaneous tissue over the bridge of the nose. From the supratrochlear, the dorsal nasal, or both, come branches to the eyelids.

Ophthalmic Veins

The major vein of the orbit is the **superior ophthalmic vein**. It begins as a confluence of small, posteriorly directed channels from the backs of the supraorbital, supratrochlear, and/or angular veins. These pass through the orbital septum, join one another, and the resultant superior ophthalmic vein passes backward deep to the superior rectus muscle. As it does so, it picks up tributaries that accompany all the named branches of the ophthalmic artery. The superior ophthalmic vein eventually passes out of the orbit through either the middle or upper compartment of superior orbital fissure, whereupon it empties immediately into the cavernous sinus.

An **inferior ophthalmic vein** begins as tributaries draining the inferior rectus and inferior oblique muscles near the front of the orbit. It passes backward below the eyeball, picks up a few ciliary veins, and then either joins the superior ophthalmic vein or passes separately through the lower compartment of the superior orbital fissure to reach the cavernous sinus. I have already mentioned the important communicating channel that passes through the inferior orbital fissure between the inferior ophthalmic vein and the pterygoid plexus.

Oculomotor Nerve - C. N. III

The oculomotor nerve is a purely motor nerve. It supplies somatic motor input to levator palpebrae superioris, superior rectus, medial rectus, inferior rectus, and inferior oblique muscles. It also carries parasympathetic preganglionic axons for the ciliary muscle and constrictor pupillae. (There are proprioceptive fibers that run back from extraocular muscles, but by some route or another these end up in the ophthalmic division of trigeminal heading toward cell bodies in the brain.)

After the oculomotor nerve exits the midbrain, it passes forward between the superior cerebellar and posterior cerebral arteries to reach the roof of the cavernous sinus slightly anterior to the posterior clinoid process. The nerve pierces the cavernous sinus roof and runs forward in the sinus applied to the inner surface of its dural wall (see Fig. 8-16). Emerging from the front of the sinus, the oculomotor nerve divides into superior and inferior divisions that pass into the orbit through the middle compartment of the superior orbital fissure. The superior division supplies the levator palpebrae superioris and the superior rectus. The inferior division supplies the two inferior extraocular muscles and sends a branch below the optic nerve to reach the medial rectus.

There is a clump of parasympathetic ganglion cells sandwiched between the lateral surface of the optic nerve and the lateral rectus muscle, just anterior to the site where the ophthalmic artery crosses the optic nerve. This clump is called the **ciliary ganglion**. The inferior division of the oculomotor nerve passes forward just below the ciliary ganglion, and, as it does so, sends a bundle carrying preganglionic parasympathetic axons upward to synapse in the ganglion. The postganglionic axons leave the front of the ganglion through two or three **short ciliary nerves** that, after branching a few times, pierce the sclera in a circle around the optic nerve (along with the posterior ciliary arteries). The short ciliary nerves then run forward deep to the sclera to reach the ciliary muscle and constrictor pupillae, which they supply.

CLINICAL CONSIDERATIONS

Damage to the oculomotor nerve has effects which are due both to interruption of its somatic motor and its visceral motor fibers.

Since the oculomotor nerve supplies the levator palpebrae superioris, which is largely responsible for maintaining the eyes open while awake, damage to the nerve causes the upper lid to droop dramatically, almost to the point of closure. No conscious effort can produce elevation of the lid. In compensation, the patient will try to elevate the upper lid indirectly by pulling up on the eyebrow with the frontalis. The elevation of the eyebrow and resultant creasing of the forehead are usually obvious.

Damage to the oculomotor nerve also leads to a paralysis of most of the extraocular muscles that actually insert on the eyeball, leaving only the lateral rectus and superior oblique intact. Thus, the eyeball is essentially immobile. Because of the unopposed pull of the lateral rectus, the eye assumes an abducted position, which is also known as a **lateral strabismus** (or **lateral squint**, or **exotropia**). Because the two eyes do not point in the same direction, double vision (**diplopia**) is present.

Interruption of the parasympathetic input to the constrictor pupillae leads to an unusually wide pupil that does not narrow either when light is shown into the eye or when the eye focuses on a close object (see further on). The ciliary muscle is also paralyzed, with resulting inability to accommodate.

One tests for integrity of the oculomotor nerve by (1) requiring the patient to perform movements of the upper lid or eyeball that employ muscles supplied by the nerve and (2) eliciting contraction of the constrictor pupillae via certain reflexes.

Function of the levator palpebrae superioris is assessed by asking the patient to gaze upward. Normally, such a gaze is always accompanied by elevation of the upper lid. Testing muscles that insert on the eyeball is performed by asking the patient to gaze at the examiner's finger as it is moved in various directions. Eliciting adduction is a clear test of the medial rectus. Which muscles are tested by other movements can be gleaned from the discussion of eyeball movement presented earlier (and summarized in Fig. 8-20*B*). If the medial rectus can adduct, then eliciting elevation of the adducted eye is a test for the inferior oblique. If the lateral rectus (supplied by the abducens nerve) is operative, eliciting elevation of the abducted eye tests for the superior rectus, whereas depression of the abducted eye tests for the inferior rectus.

The pupil normally constricts under two different circumstances. One is when a light is shone in the eye. This is called the **pupillary light reflex**. It is consensual, which means that shining a light into only one eye causes both pupils to constrict. The pupil also constricts when one attempts to focus on objects very close to the eye. Apparently, recruitment of the ciliary muscle and the constrictor pupillae are linked. Because looking at close objects also induces one or both eyes to rotate so that their optical axes converge on the nearby point, the accompanying pupillary constriction is said to be an **accommodation/convergence reflex**. Usually it is elicited by bringing the examiner's finger toward the bridge of the patient's nose, in which case both eyes actually adduct. However, even if the finger is brought close in toward the front of one eye, so that it need not move, the pupillary accommodation reflex still occurs.

Damage to the oculomotor nerve affects both the pupillary light and pupillary accommodation reflexes. Some central nervous system diseases (e.g., neurosyphilis) produce a pupil that constricts on accommodation but not in response to light. This is called an Argyll-Robertson pupil (mnemonic: the initials AR correspond to Accommodation Reactive).

Trochlear Nerve–C.N. IV

The trochlear nerve is purely somatic motor to the superior oblique muscle (i.e., the muscle whose tendon passes through a trochlea). The nerve exits the dorsal surface of the midbrain and sweeps around its side to pierce the dural roof of the cavernous sinus just anterior to the site where the margin of the tentorial notch crosses the petroclinoid ligament. The nerve runs forward in the cavernous sinus, with its epineurium adherent to the dural wall (see Fig. 8-16). About halfway through the sinus, the trochlear nerve encounters the upper border of the ophthalmic nerve and then runs along with it out of the sinus toward the superior orbital fissure. The trochlear nerve enters the orbit through the upper compartment of the superior orbital fissure. The nerve then turns medially and crosses above the origins of superior rectus and levator palpebrae superioris onto the upper surface of the superior oblique muscle, which it penetrates.

CLINICAL CONSIDERATIONS

Isolated lesions of the trochlear nerve are uncommon. Obviously, the effect will be limited to paralysis of the superior oblique. As explained previously, the superior oblique is chiefly active during depression of the eye when it either looks straight ahead or is adducted (see Fig. 8-20*B*). When the muscle is paralyzed on one side, such depression cannot occur, resulting in double vision when the patient attempts to look downward. The two most common daily activities that involve looking down are reading and walking downstairs. A complaint of double vision during these activities is a sign of trochlear nerve damage. A test of trochlear nerve function is depression of the adducted eye. This assumes normal medial rectus function.

Abducens Nerve -- C.N. VI

Discussion of the abducens nerve completes a consideration of the motor nerves to extraocular muscles. The sole function of the abducens is to innervate the lateral rectus--the abductor of the eyeball.

The abducens nerve pierces the dura on the back of the clivus a centimeter or so below the root of the dorsum sellae. The nerve then travels upward and laterally (sandwiched between dura and endocranium) toward the side of the dorsum sellae, around which it passes to enter the cavernous sinus. Here the abducens takes up a position on the lateral surface of the internal carotid artery (see Fig. 8-13). The nerve continues forward in the cavernous sinus, bathed on all sides by venous blood, and eventually leaves it to pass through the middle compartment of the superior orbital fissure onto the deep surface of the lateral rectus muscle. The abducens nerve runs forward on the deep surface of the lateral rectus for a centimeter or so before penetrating the muscle to supply it.

CLINICAL CONSIDERATIONS

The abducens is the most frequently damaged of all nerves feeding extraocular muscles. It is the first nerve to be affected by septic thrombosis of the cavernous sinus. Aneurysm of the internal carotid artery within the cavernous sinus may put pressure on the abducens. A variety of tumors at the base of the brain will tend to compress the nerve against the clivus.

The only effect of abducens injury is paralysis of the lateral rectus. This causes the eyeball to assume an adducted position at rest (due to the unopposed pull of the medial rectus). The name for this is a **medial strabismus** (or **medial squint**, or **esotropia**). Obviously there will be double vision because the two eyes do not face in the same direction. However, patients with ocular abductor palsy have a clever way of avoiding this double vision. For example, consider a person whose right lateral rectus is paralyzed and whose right eye is turned inward, i.e., toward the left. This person will have double vision looking at any object not far to his or her left side. On the other hand, when looking at an object far to the left, the person can use the good lateral rectus of the left eye to aim it in the same direction as the abnormally adducted right eye. Thus, a person with a paralyzed right lateral rectus may avoid double vision by turning his or her head so that whatever is to be viewed is made to occur in the left visual field. If a patient holds the head askance while looking at you, you should suspect that he or she is attempting to avoid the double vision that would occur if the patient were to face you directly.

Testing for the abducens is no more complicated than asking the patient to look at your finger as you move it to the side.

Ophthalmic Division of Trigeminal--V_1

The ophthalmic nerve passes straight forward into the cavernous sinus. Like the oculomotor and trochlear nerves, V_1 runs anteriorly in the sinus with its epineurium adherent to the medial face of the dural wall (see Fig. 8-16). V_1 is the largest and most inferior of the three nerves adherent to the dural wall of the cavernous sinus. While traveling within the sinus, V_1 picks up postganglionic sympathetic fibers from the internal carotid plexus (these probably pass through the abducens n. to reach V_1). The sympathetic axons will distribute with branches of the ophthalmic nerve to supply vasculature of the orbit and forehead, sweat glands of the forehead, and the dilator pupillae.

After V_1 exits the front of the cavernous sinus, it divides into its three main branches--frontal, lacrimal, and nasociliary. These pass through the superior orbital fissure separately--frontal and lacrimal in the upper compartment, nasociliary in the middle compartment.

The **frontal nerve** continues forward in the orbit onto the upper surface of levator palpebrae superioris, and follows it toward the front of the eye. Not far from the nerve is the supraorbital artery. Before reaching the orbital septum, the frontal nerves bifurcates into a **supratrochlear and a supraorbital branch**. The supratrochlear is the smaller and more medial of the two. They both pierce the orbital septum and turn upward into the subcutaneous tissue of the scalp deep to the frontalis muscle. The supraorbital nerve passes through the supraorbital notch, where it is separated from the more inferiorly placed supraorbital artery by a ligament (sometimes ossified) that bridges across the notch. The supratrochlear nerve crosses the orbital rim at its upper inner angle. Both the supraorbital and supratrochlear nerves are cutaneous for supply of the skin of the forehead all the way up to the vertex of the skull (Fig. 8-22). Not surprisingly, they give twigs to the upper eyelid as they leave the orbit.

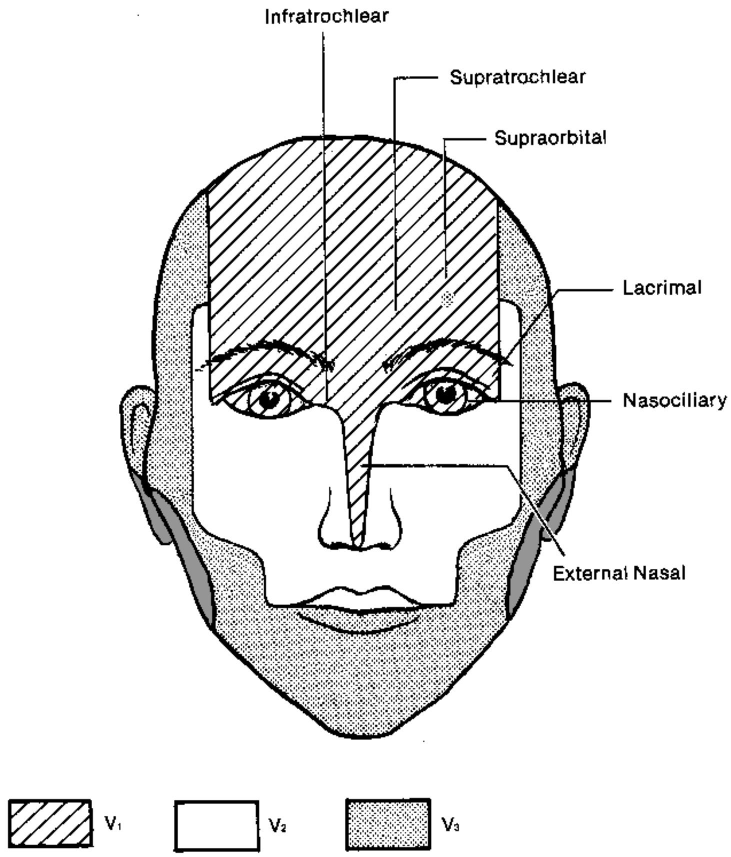

Figure 8-22. Sensory innervation of the face by V1.

The small **lacrimal nerve** passes along the upper edge of the lateral rectus along with the artery of the same name. The nerve passes inferior to the lacrimal gland, to which it sends branches, and then pierces the orbital septum above the lateral palpebral ligament for cutaneous innervation of the upper eyelid (see Fig. 8-22).

The **nasociliary nerve** passes through the middle compartment of the superior orbital fissure (thus, inferolateral to the optic nerve). The nasociliary then follows a path identical to the most common course of the ophthalmic artery (i.e., upward on the lateral side of the optic nerve, anteromedially across its top surface, and then forward along the upper border of medial rectus). It gives off branches corresponding to branches of the ophthalmic artery (other than the supraorbital, supratrochlear, and lacrimal arteries, which are accompanied by branches of the frontal and lacrimal nerves). Early in its course, the nasociliary nerve gives off two **long ciliary nerves** that run with the long posterior ciliary arteries parallel to the optic nerve and pierce the sclera adjacent to it. These carry sensation from the eyeball and, notably, the cornea. They may also carry postganglionic sympathetic axons to the dilator pupillae and vasculature of the eye. After giving off the long ciliary nerves, the nasociliary sometimes gives off a **posterior ethmoidal nerve** but always gives off an **anterior ethmoidal nerve**. These accompany the arteries of the same name and carry sensation from the areas to which the arteries send blood. The terminal branch of the anterior ethmoidal nerve accompanies the cutaneous branch of the anterior ethmoidal artery onto the surface of the nose (see Fig. 8-22). The cutaneous branch of the artery has no separate name, but the accompanying nerve is called the **external nasal nerve**. (Of course, when we do this, we must then refer to the branches of the anterior ethmoidal within the nasal cavity as internal nasal nerves.)

Once the anterior ethmoidal nerve is given off by the nasociliary, the latter has no function other than to innervate the skin on the bridge of the nose supplied by the dorsal nasal branch of the ophthalmic artery (see Fig. 8-22). This part of the nasociliary nerve is called the **infratrochlear nerve**.

The nasociliary nerve, immediately after it enters the orbit, is connected to the ciliary ganglion by a small twig. It has been suggested that some sensory fibers from the eyeball travel with the short ciliary nerves to the ganglion and then pass through it into this twig to reach the nasociliary nerve, which carries them back to V_1. It has also been said that postganglionic sympathetic axons in the nasociliary nerve leave it and run in the twig to the ganglion, which they pass right through to enter the short ciliary nerves and thence reach the eye either for supply of vascular smooth muscle or the dilator pupillae. The validity of these statements remains unknown, as does the pathway of sympathetic fibers that reach the smooth muscle portion of levator palpebrae superioris.

Eyeball

Each eye begins as a laterally directed tubular outpocketing--the **optic diverticulum**--from the diencephalic region of the embryonic brain. Later during development the eyes rotate to their normal position facing toward the front. Any term of direction that I use assumes this normal position.

As the tip of the optic diverticulum approaches the body wall ectoderm, the diverticulum expands into a cup-shaped structure (**optic cup**) connected to the brain by a narrower **optic stalk**. The cells that form the cup will become the **retina**, with an inner **neural layer** that is photosensitive and an outer **pigmented layer** that is not (Fig. 8-23). Axons from cells of the neural layer of the retina grow back to the brain through the optic stalk, which then becomes the **optic nerve**. The site where the optic nerve joins the retina is called the **optic disc**. It is located a few millimeters medial to the posterior pole of the eyeball. The most discriminating part of the neural retina lies at the posterior pole of the eye. For reasons that histologist will explain to you, there is a depression here called the **fovea centralis**. When we want to see something clearly, we always position our eyes so that the image falls on the fovea.

The retina forms almost a complete sphere, but has a circular defect - the **pupil -** anteriorly (see Fig. 8-23). That anterior one-quarter of the neural layer (i.e., the quarter near the pupil) does not

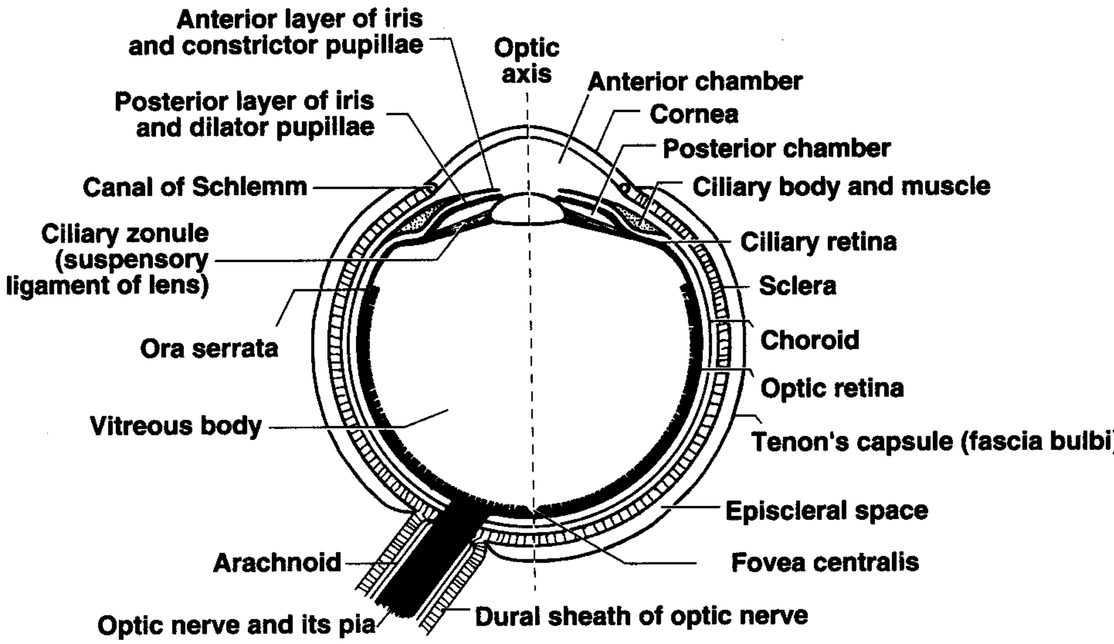

Figure 8-23. Schematic transverse section of the eyeball. The retina, uvea, and sclera have been drawn as if they do not adhere to one another, but in fact they do.

participate in differentiation of photosensitive cells. Thus, encircling the pupil is the **nonoptical** part of the retina.

The presence of the optic cup near the embryonic ectoderm induces the development of the **lens**, which is an invagination of this ectoderm that pinches off, solidifies, and assumes a position deep to pupil. Once the lens vesicle pinches off, the surface ectoderm is reconstituted. It will eventually become the **bulbar conjunctiva**.

The mesoderm surrounding the optic cup organizes itself into two concentric layers. The outer layer forms a complete sphere (see Fig. 8-23). It is relatively thick and tough, and is called the **fibrous tunic**. It gives strength to the eyeball and serves as a structure into which muscles can insert. In front of the pupil the fibrous tunic bulges out a little and undergoes a specialization to make it transparent to light. This specialized region is the **cornea;** its circular margin is called the **corneal limbus**. The remainder of the fibrous tunic sphere is opaque white and is called the **sclera**. The cornea contacts the ectoderm that will become bulbar conjunctiva.

The inner layer of mesodermally derived connective tissue is called the **uvea**. This uveal layer is coextensive with and adherent to the retina (see Fig. 8-23). Thus, it also has a circular defect and contributes to the rim of the pupil. Almost all of the uveal layer will become thin connective tissue (**choroid**) through which run the blood vessels of the eye. However, two regions do become specialized. Deep to that part of the sclera nearest to the cornea, the uveal layer is thickened by the presence of smooth muscle to form the **ciliary body**. The adherent nonoptical retina forms a **ciliary part of the retina**, which gives rise to fibers (similar in composition to elastin) that run inward to the periphery of the lens. The mass of fibers is called the **ciliary zonule, or suspensory ligament of the lens**. Tension within the zonule fibers pulls on the periphery of the lens and keeps it from assuming a more rounded shape to which it is naturally inclined.

Anterior to the ciliary body the uveal layer thins down again to form a connective tissue that adheres to the outer surface of the nonoptical retina. Here these adherent layers form the **iris**, which surrounds the pupil. Just as the uveal layer of the ciliary body contains smooth muscle, so does that of the iris. The part of the nonoptical retina adherent to the uveal part of the iris is the highly pigmented **iridial retina**. If the uveal part of the iris contains no pigment itself, the individual will have blue eyes. However, most persons have additional pigment in melanocytes scattered within the uveal component of the iris, giving it a brown color overall.

Intraocular (Internal Ocular) Muscles

The smooth muscles within the ciliary body and uveal layer of the iris are said to be intraocular muscles. The fibers of the **ciliary muscle** are complex in arrangement, but their effect is to change the shape of the ciliary body so as to reduce tension within the suspensory ligament of the lens. As a consequence, the lens assumes a more rounded shape, light rays are more strongly bent, and the eye can focus on nearer objects. This process is called **accommodation**; thus, the ciliary muscle is the muscle of accommodation.

There are two separate smooth muscles within the iris. One causes the pupil to get smaller, thereby reducing the amount of light that enters the eye. This muscle is called the **constrictor pupillae**. The other causes the pupil to get larger, permitting more light to enter the eye. This muscle is called the **dilator pupillae**.

Being smooth muscles, the three internal ocular muscles are innervated by the autonomic nervous system. The dilator pupillae receives its motor axons from cells that lie in the superior cervical sympathetic ganglion. The constrictor pupillae and ciliary muscle are innervated by the parasympathetic component of the oculomotor nerve (see further on).

Cavity of the Eyeball (Fig. 8-23)

The layers of the eyeball surround a cavity. This cavity is divided into a **retrolental portion**, behind the lens and ciliary zonule, and a **prelental portion**, in front of these same structures. The retrolental portion of the eyeball cavity is filled with a transparent gelatinous material said to form the **vitreous body**. The prelental part of the cavity is itself divided into two chambers because the deep surface of the iris near the pupil rests upon the front surface of the lens. The part of the prelental portion of the eyeball cavity that lies just deep to the iris and in front of the lens and its suspensory ligament is called the **posterior chamber** of the eye (though it is certainly not as far posterior as is the vitreal cavity). An anterior chamber lies in front of the iris and lens, just deep to the cornea. The retinal epithelium in the roof of the posterior chamber secretes a clear fluid into this region of the prelental cavity. The fluid is **aqueous humor**. It seeps through the suspensory ligament to permeate the vitreous body, and it also passes around the free margin of the iris into the anterior chamber of the eye.

It should be obvious that continuous secretion of aqueous humor without removal would tend to a continuous increase of intraocular pressure. Removal is accomplished by a specialization of the inner surface of the fibrous tunic (at the corneoscleral junction) facing the anterior chamber. The aqueous humor filters through trabecular meshwork here to reach a circular "vein" that encircles the cornea. This vein is called the **canal of Schlemm**, and it is peculiar in that it contains not blood, but aqueous humor. The canal of Schlemm is connected to the other veins of the eyeball, which carry away the aqueous humor.

The resistance to flow through the trabecular meshwork into the canal of Schlemm is sufficiently great to build a "head" of intraocular pressure that maintains eyeball shape. However, if resistance to flow should increase and pressure build within the eyeball cavity, the optical retina may be seriously damaged. Such a condition arises from causes unknown. It is called **glaucoma** and often must be treated by surgically creating a new path of egress of aqueous humor.

Meninges of the Optic Nerve

The optic nerve, being an outgrowth of the brain, is surrounded by sleeves of pia, arachnoid, and a dura all the way up to the point where it pierces the sclera. Naturally, the pia is adherent to the nerve. A thin but definite subarachnoid space lies between the pial sleeve and arachnoid sleeve. For this reason, any increase in cerebrospinal fluid pressure is transmitted around the optic nerve and may cause partial collapse of the veins within it.

Evidence of retardation of optic venous return is seen ophthalmoscopically in engorgement of the retinal veins. The optic disc itself becomes edematous (swollen), causing its margins to be blurred and its surface to be elevated from the surrounding retina. This condition is called **papilledema, or choked disc**.

Optic Nerve -- C.N. II

The optic nerve is a purely sensory nerve. (By this I mean that it carries no motor fibers to glands or muscles; it does contain efferent axons that influence retinal function.) The sensory axons within the optic nerve originate in cells of the optical retina and pass backward to the lateral geniculate body located inferior to the back end of the thalamus. Gross anatomists tend to be most concerned with the optic pathway from the eye to the brain, leaving the rest for neuro-anatomists.

The part of the world seen by the eyes is known as the **visual field**. The entire visual field is divided into regions *defined when the eyes are looking straight ahead*. Objects that are toward the sky lie in the upper part of the visual field; objects toward the ground lie in the lower part. Objects to our left are in the left visual field; objects to our right are in the right visual field.

Each eye has its own visual field (i.e., the part of the world seen by that eye alone) (Fig. 8-24). The left visual field of the left eye is often called its temporal field, whereas the right visual field of the left eye is often called its nasal field. Similarly the right visual field of the right eye is its temporal field, whereas the left visual field of the right eye is its nasal field. Because of the interference presented by the bridge of the nose, the temporal field of vision of an eye is wider than that same eye's nasal field. Thus, although the fields of vision of the two eyes overlap greatly, the left eye sees things far to the left that the right eye cannot see. Similarly, the right eye sees things far to the right that the left eye cannot see.

The image of the visual field created on the retina is inverted. Thus, the higher an object is out there in the real world, the lower on the retina is its projected image. The further to the right is an object, the further to the left on the retina is its image. As a result, the left visual field of each eye is seen by the right half of its retina, and the right visual field of each eye is seen by the left half of its retina (see Fig. 8-

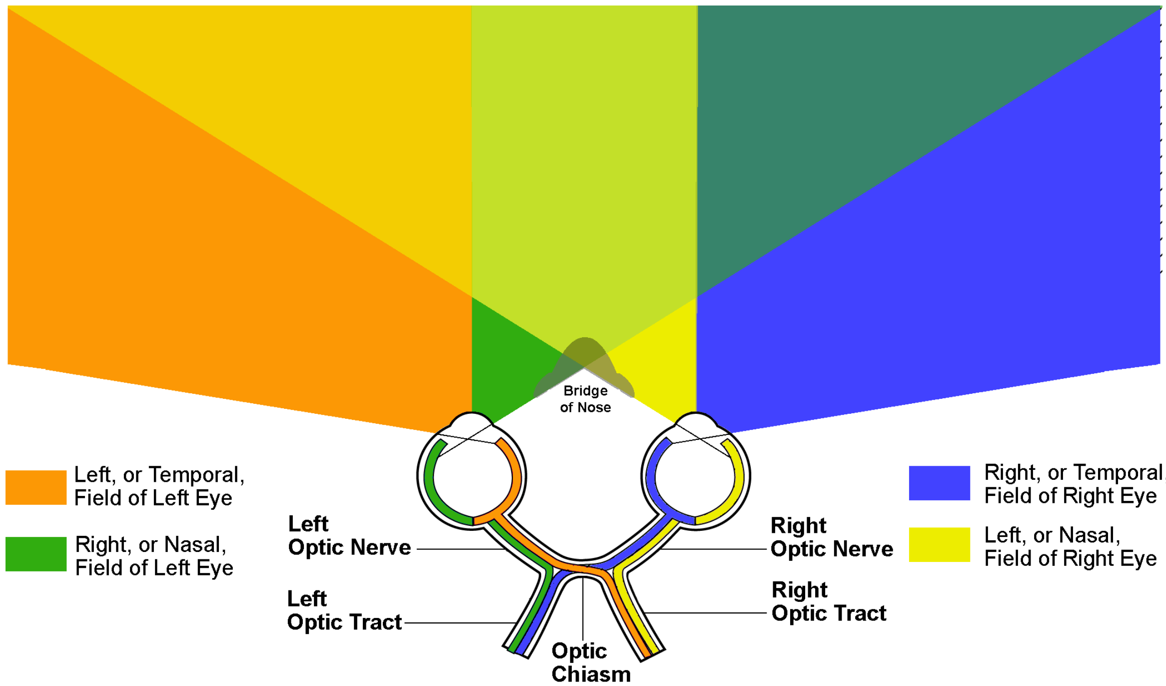

Figure 8-24. Fields of vision and the optic chiasm (superior view). Where different fields overlap, their colors have been blended.

24). Expressed in terms of "nasal" and "temporal," the nasal half of a retina sees the temporal field of vision, and the temporal half of a retina sees the nasal field of vision.

Each optic nerve carries axons from the entire retina of its corresponding eye (see Fig. 8-24). However, after passing backward through the optic foramina, the right and left optic nerves engage in a redistribution of axons at the so-called **optic chiasm**, located just anterior to the pituitary stalk. The optic chiasm is formed of fibers from the nasal half of each retina crossing over to the opposite side (see Fig. 8-24). Emerging from the optic chiasm are the two **optic tracts**. The right optic tract contains axons from the temporal half of the right retina and the nasal half of the left retina, thus carrying information about the entire left visual field. The left optic tract contains axons from the temporal half of the left retina and the nasal half of the right retina, thus carrying information about the entire right visual field. The optic tracts are named according to the side of the body on which they lie. These names belie the fact that each is concerned with the contralateral visual field.

CLINICAL CONSIDERATIONS

If one optic nerve is put out of commission (e.g., by tumor or inflammation) the eye served by that nerve cannot see. This is simply called **unilateral blindness**. Quite a different result occurs if one optic tract is inoperative. Loss of function in the right optic tract causes loss of sight in the left visual field. This is called left **homonymous hemianopia** (where hemianopia means that half the visual field of *each* eye is lost, whereas homonymous means the lost half-field of one eye is the same side as the lost half-field of the other eye). Interruption of function in the left optic tract causes right homonymous hemianopia (loss of vision in the right visual fields of both eyes). Finally, pituitary tumors may press forward onto the optic chiasm. Each eye undergoes loss of the field served by the nasal half of its retina. Thus, each eye has a hemianopia (loss of half its visual field) that involves its temporal field. In other words, lesions of the optic chiasm are said to produce a **bitemporal hemianopia**. Since the temporal field of the right eye is its right field, but the temporal field of the left eye is its left field, a bitemporal hemianopia is **heteronymous**.

Neuro-ophthalmologists have ways of accurately assessing visual field defects. In the more typical physical exam, the exploration of visual fields is usually done simply by bringing a wiggling finger into view of the patient from the sides, from above, and from below. The patient looks straight ahead and is requested to state when the finger can first be seen.