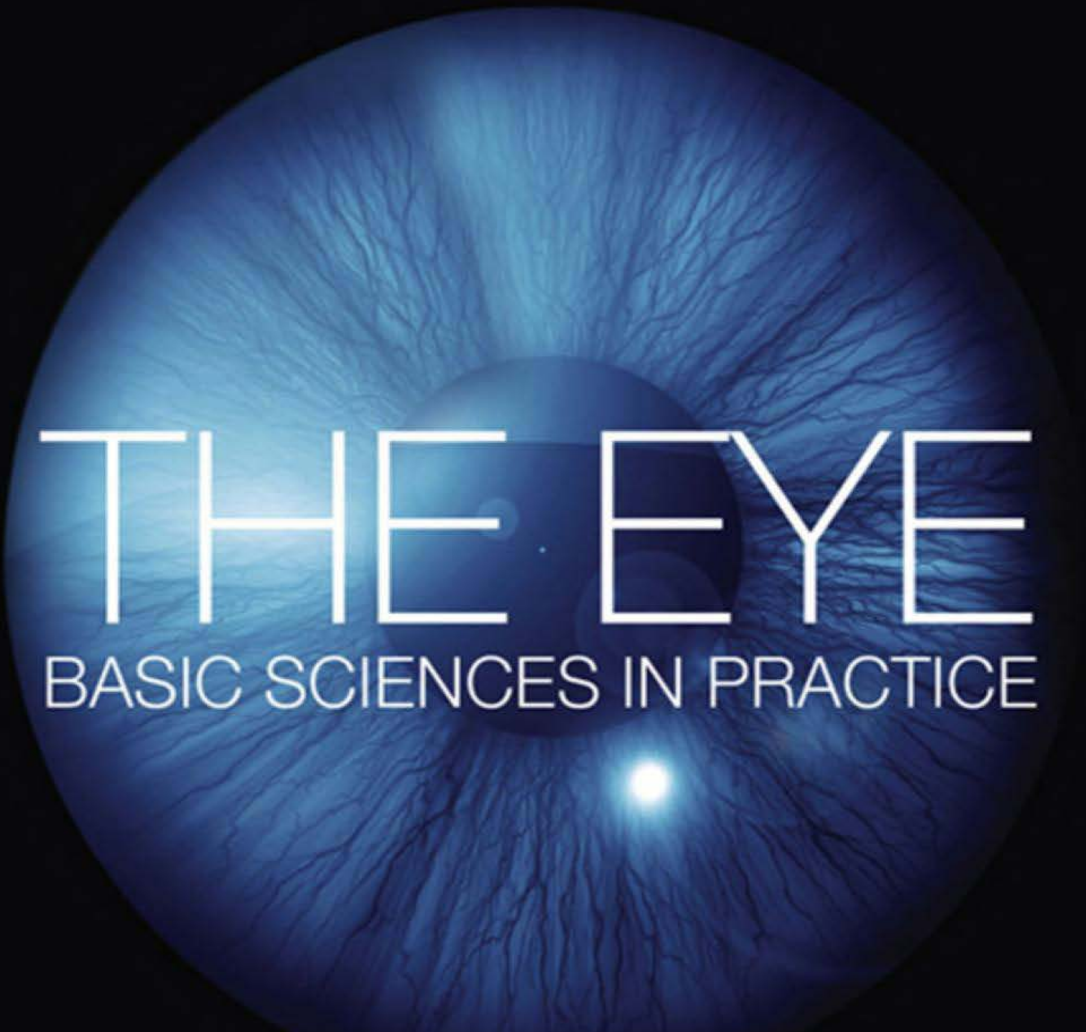
John V. Forrester • Andrew D. Dick
Paul G. McMenamin • Fiona Roberts • Eric Pearlman

THE EYE

BASIC SCIENCES IN PRACTICE



Fourth Edition

ELSEVIER

The Eye

Basic Sciences in Practice

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4th Edition

The Eye

Basic Sciences in Practice

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Preface

The fourth edition of *The Eye* is upon us and, in the intervening years since the third edition, much has happened in the life sciences which have a direct bearing on the basic science of the eye. For instance, the massive strides being taken by the new genetics and functional genomics based on the Human Genome Project, the new understanding of how the microbiome affects all aspects of immunology, the remarkable new imaging technology which is applied to anatomy and neurophysiology, the exciting new molecular, and other, diagnostic methodologies being used in microbiology and pathology, have collectively brought a wealth of new knowledge to students and practitioners in the fields of ophthalmology and visual science. For these reasons alone, we have felt that there is strong need to update the text and allow our continuing and new readership to view these developments as they inform the various scientific disciplines in how they affect the eye and its workings.

And so, *The Eye Fourth Edition* has been extensively revised with much new text as well as many new figures. The aim of the book, as always, has been to provide a concise text which provides as much information in the simplest and most readable format which can be used by a diverse readership. This includes optometrists and ophthalmologists in training, and in practice, as well as new recruits to visual and ophthalmic science who are embarking on a career in the basic science of the eye. We expect readers will take from the text those aspects of knowledge and information which are directly relevant to them and hope that they will also dip into areas which might not seem so immediately important to them but remain part of the whole. As indicated in the preface to the third edition, the purpose is to produce a "basic science of the eye" handbook which is readily accessible.

The book retains its familiar overall organisation in terms of subject matter. Excitingly, however, in this internet dawn, *The Eye* is also being produced as an online text, with links to additional information as well as video clips prepared by the authors which are aimed to help explain and expand on aspects of the basic science. We hope that our new, as well as our previous, students and readers enjoy the new product.

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Anatomy of the eye and orbit

Anatomical terms of reference

The internationally accepted terminology for description of the relations and position of structures in the body requires reference to a series of imaginary *planes* (Fig. 1-1). Thus, relative positions of anatomical structures are referred to in terms of: *medial* (nearer the median or mid-sagittal plane) and *lateral* (away from this plane); *anterior* and *posterior* refer to the front and back surfaces of the body; *superior* (cranial or rostral) or *inferior* (caudal) refer to position in the vertical; *superficial* and *deep* specify distance from the surface of the body. A combination of terms can be used to describe the relative position of structures that do not fit exactly any of the other terms, e.g. ventrolateral, posteromedial, etc.

Osteology of the skull and orbits

GENERAL ARRANGEMENT AND FEATURES OF THE SKULL

The skull is divided into two parts: an upper part shaped like a bowl, which contains the brain, known as the *cranium* or *neurocranium*; and a lower part, the *facial skeleton* or *viscerocranium*. The cranium can be further subdivided into the cranial vault and cranial base.

The skull is composed of a large number of separate bones that are united by *sutures* (fibrous immovable joints). The cranium consists of eight bones (only two are paired), the facial skeleton consists of 14 bones, of which only two are single (Fig. 1-2A,B). The skull contains a number of cavities that reflect its multiple functions:

- *cranial cavity* – houses, supports and protects the brain
- *nasal cavity* – concerned with respiration and olfaction
- *orbits* – contain the eyes and adnexa
- *oral cavity* – start of gastrointestinal tract, responsible for mastication and initial food processing; houses taste receptors.

Many of the cranial bones contain air-filled spaces, the paranasal sinuses (Fig. 1-3). Most of the anatomical features of the whole skull relevant to the study of the eye and orbits are indicated in Figure 1-2A and B (*norma frontalis* and *norma lateralis*). (See video 1-1).

OSTEOLOGY OF THE ORBIT

The orbital cavities, situated between the cranium and facial skeleton, are separated from each other by the nasal cavity and the ethmoidal and sphenoidal air sinuses (Fig. 1-3A–C). Each bony orbit accommodates and protects the eye and adnexa, and serves to transmit the nerves and vessels that supply the face around the orbit. Parts of the following bones contribute to the walls of the orbit: maxilla, frontal, sphenoid, zygomatic, palatine, ethmoid and lacrimal (Figs 1-4 and 1-5A,B). Each orbit is roughly the shape of a quadrilateral pyramid whose base is the *orbital margin* and whose apex narrows at the *optic canal*. Each orbit has a floor, roof, medial wall and lateral wall (Fig. 1-4). (See video 1-2).

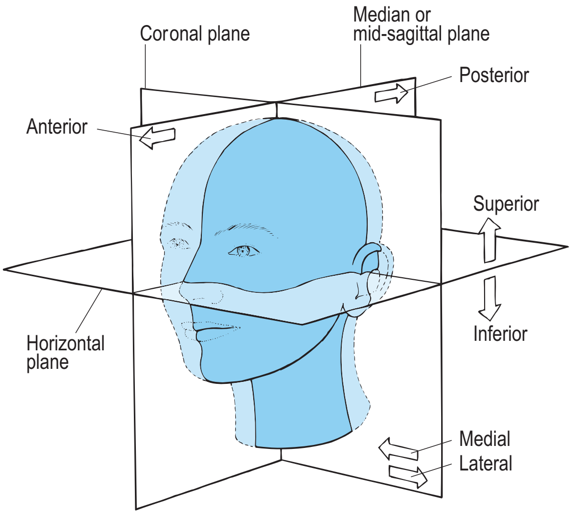


FIGURE 1-1 Diagram illustrating anatomical planes of reference.

The floor tapers off before reaching the apex; therefore the apex of the pyramid is triangular in shape. The orbit is widest approximately 1.5 cm behind the orbital margin. The medial walls are approximately parallel to the mid-sagittal plane, while the lateral walls are oriented at an angle of approximately 45° to this plane. The *orbital aperture* is directed forwards, laterally and slightly downwards, a characteristic of primates and indeed predators which require binocular vision. Nerves and muscles passing from the apex into the orbit pass forward and laterally (Fig. 1-3A,B). The orbit is approximately 40 mm in height, 40 mm in width and 40 mm in depth. The volume is approximately 30 mL, of which one-fifth is occupied by the eye.

The walls of the orbit

The bones that make up the roof, floor and medial and lateral walls are summarized in Figure 1-4.

Features of the orbital roof

- *Fossa for the lacrimal gland:* lies in the anterolateral aspect of the roof behind the zygomatic process of the frontal bone.
- *Trochlear fossa (fovea):* lies in the anteromedial aspect of the roof, 4 mm from the margin, and is the site at which the trochlea (small pulley) is attached. The tendon of the superior oblique passes through the trochlea.
- *Anterior and posterior ethmoidal canals* Positioned at the junction of roof and medial wall above the frontoethmoidal suture (Fig. 1-5A). They transmit the anterior and posterior ethmoidal nerves and vessels.

Relations. The roof, which is thin and translucent except at the lesser wing of the sphenoid, separates the orbit from the anterior cranial fossa and frontal lobes of the brain. Anteriorly, the frontal sinus lies above the orbit.

Features of the medial orbital wall

- This wall is oblong in shape and thin (0.2–0.4 mm). The four bones that comprise this wall are separated by vertical sutures (Figs 1-4 and 1-5A).
- *Lacrimal fossa* for the lacrimal sac: it is bound by anterior and posterior lacrimal crests and is continuous below with the *nasolacrimal canal* (Fig. 1-5B).

Relations. This is the thinnest of the walls and is largely transparent or semitransparent – the ethmoidal air sinuses can easily be seen through this wall in a dried skull (Fig. 1-5A,B). Medial to this wall in an anterior to posterior sequence lie the anterior, middle, posterior ethmoidal air cells and the sphenoidal sinus.

Features of the orbital floor

- The floor slopes slightly downwards from the medial to the lateral wall.
- It is crossed by the *infraorbital groove*, which runs forward from the *inferior orbital fissure*. Before it reaches the orbital margin this fissure becomes the *infraorbital canal*, which opens as the *infraorbital foramen* 4 mm below the orbital margin on the anterior surface of the maxilla (Figs 1-3C, 1-4 and 1-5A).

Relations. The floor separates the orbit from the maxillary sinus, the bone being only 0.5–1 mm in thickness (Fig. 1-3C).

Features of the lateral orbital wall (Fig. 1-4)

- *Spina recti lateralis:* a small bony spine on the greater wing of the sphenoid near the apex of the orbit which gives origin to part of the lateral rectus.
- *Zygomatic foramen:* transmits zygomatic nerve and vessels to temporal fossa and cheek (zygomaticotemporal nerve and zygomaticofacial nerve) (Fig. 1-5B).

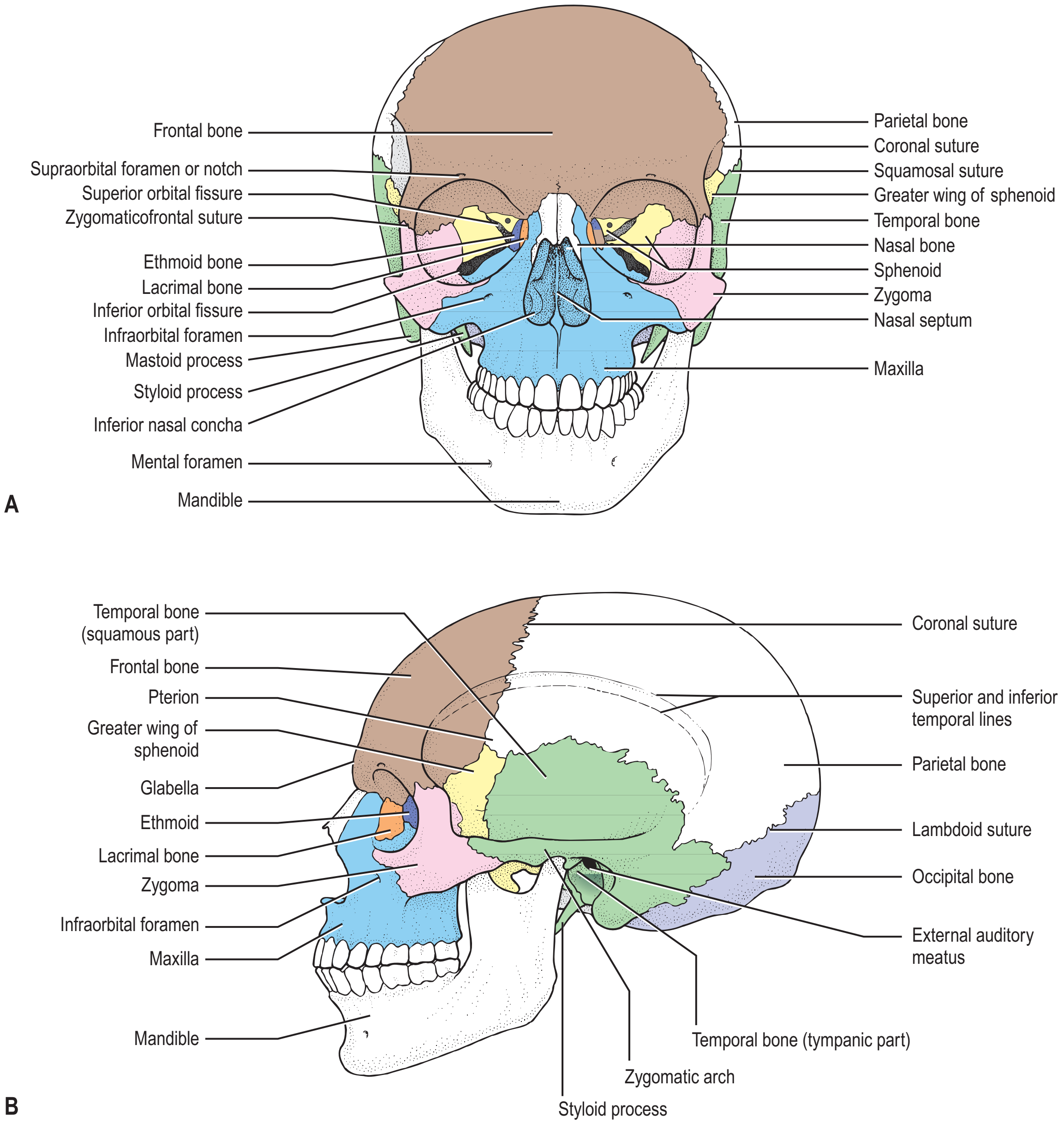


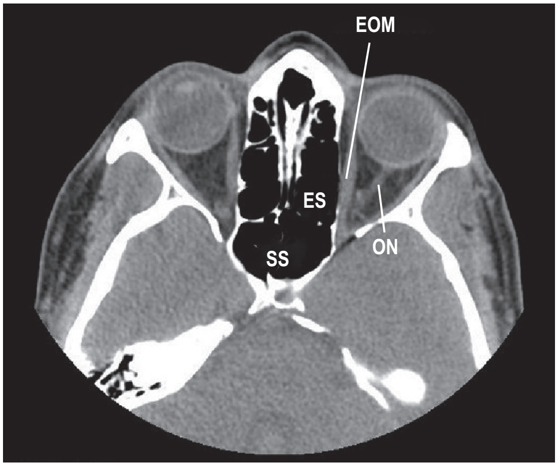
FIGURE 1-2 Osteology of the skull. Two views of the skull: (**A**) norma frontalis; and (**B**) norma lateralis to illustrate the individual bones and important anatomical landmarks.

- *Lateral orbital tubercle:* forms the attachment of the check ligament of the lateral rectus, suspensory ligament (Lockwood's) of the eye, superior transverse ligament (Whitnall's) and aponeurosis of levator palpebrae superioris.
- Foramina for small veins that communicate with middle cranial fossa.

Relations. Laterally – skin, temporal fossa and middle cranial fossa in an anterior–posterior sequence (Fig. 1-3A).

Orbital margin, fissures and optic canal

Orbital margin. This is a thickened rim of bone that helps protect the orbital contents. It is made up of three bones: the frontal, zygomatic and maxilla



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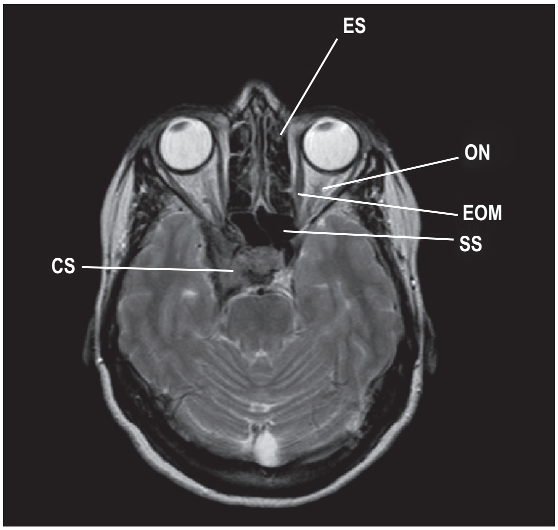

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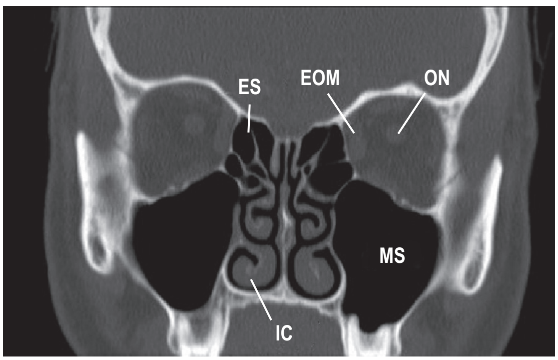
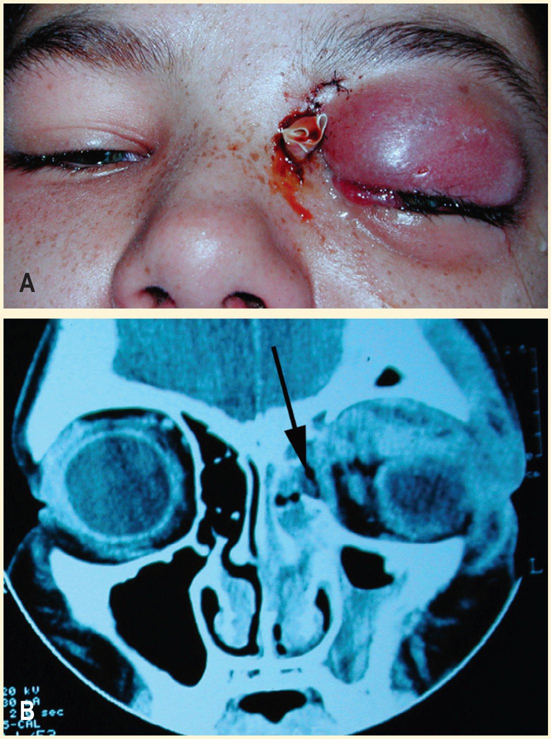


C

BOX 1-1 CLINICAL CORRELATES

Orbital cellulitis

This condition may be a consequence of infection spreading from the air sinuses to the orbit via the paper-thin medial wall (*lamina papyracea*) that separates the two. An example is shown of a patient with orbital cellulitis following creation of a drainage fistula (**A**). A coronal CT (**B**) illustrates the communication with the ethmoidal sinuses and nasal cavity (arrow).



(Images courtesy of Dr Alan McNab.)

FIGURE 1-3 Transverse (**A,B**) and coronal (**C**) computed tomography (CT: **A** and **C**) and magnetic resonance imaging (MRI: **B**) scans of the head displaying the major relations of the orbits. Features identifiable in the scans include ethmoid air cells/sinuses (ES), maxillary sinus (MS), sphenoid sinus (SS), nasal cavity (NC), inferior nasal concha (IC), extraocular muscle (EOM), optic nerve (ON) and cavernous sinus (CS).

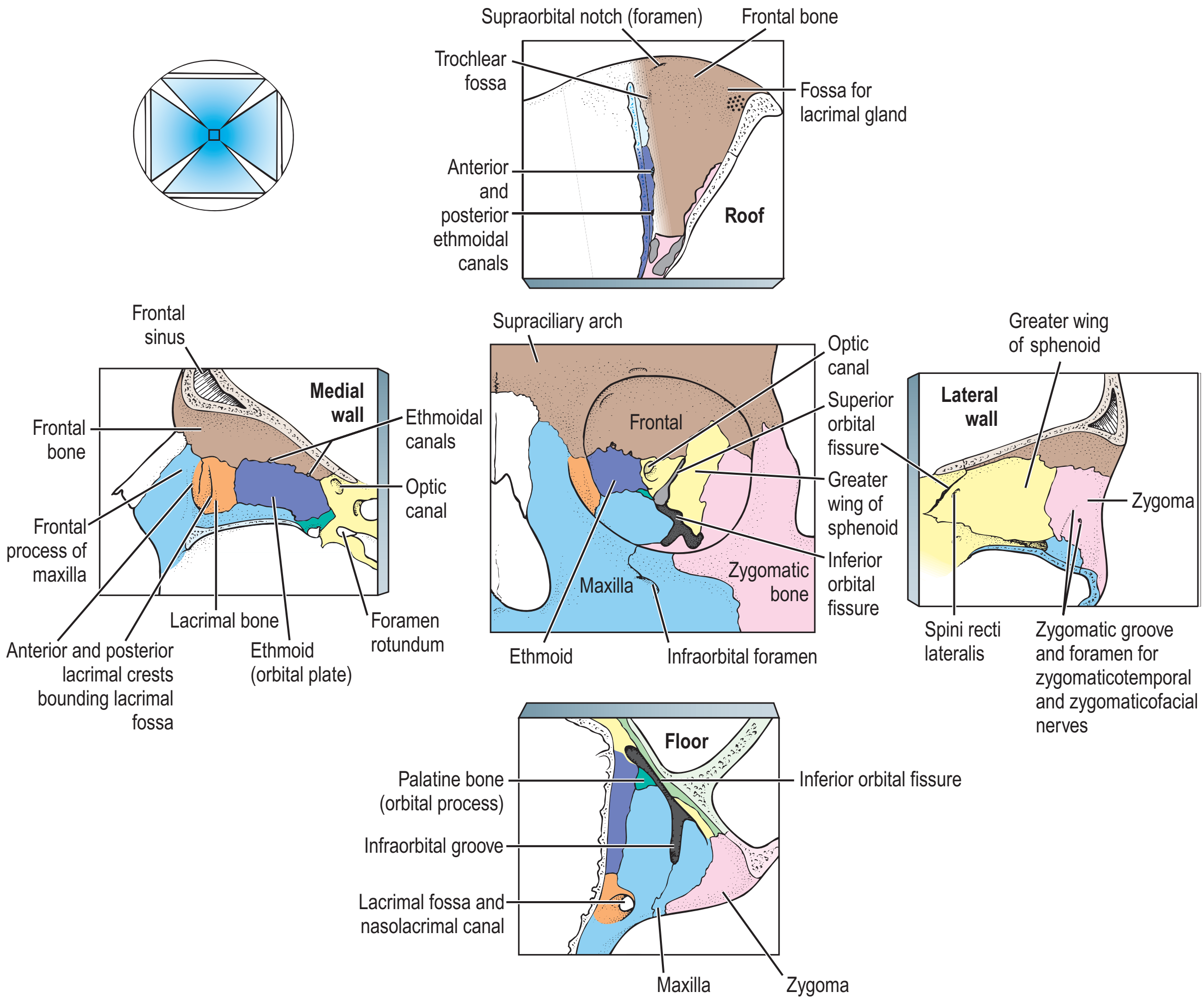
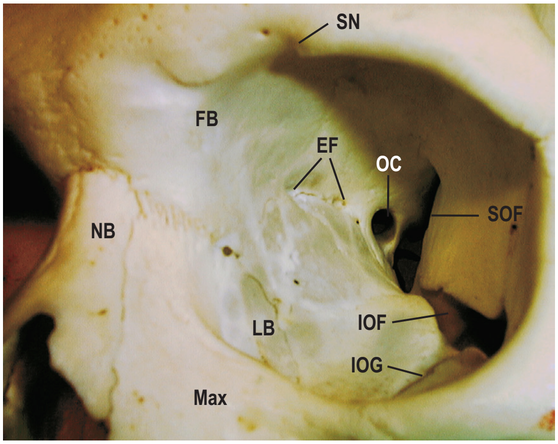


FIGURE 1-4 Osteology of the orbit. The central diagram illustrates the anterior view of the intact left orbit, the four surrounding diagrams ('exploded orbit' – see inset, top left) show the individual bones which form the roof, floor, medial and lateral walls and other noteworthy features. *Roof:* orbital plate of the frontal bone and small area of lesser wing of the sphenoid. *Medial wall:* frontal process of the maxilla, lacrimal bone, orbital plate of the ethmoid and the body of the sphenoid. *Floor:* orbital plate of the maxilla, orbital surface of the zygoma and the orbital process of the palatine bone. *Lateral wall:* orbital surfaces of greater wing of sphenoid posteriorly and zygomatic bone anteriorly.

(Figs 1-4 and 1-5A,B). The lateral margin does not reach as far anteriorly as the medial margin (see Figs 1-2B and 1-5B). The medial margin is sharp and distinct in its lower half because of the anterior lacrimal crest, but is indistinct superiorly (Figs 1-4 and 1-5B).

Superior orbital fissure. This communication between the orbital and cranial cavities lies between the roof and lateral wall of the orbit and is bounded by the lesser and greater wings of sphenoid (Figs 1-4, 1-5A and 1-6). It is wider at its medial end and narrowest at its lateral end. It is around 22 mm long and is separated from the optic foramen above by the posterior root of the lesser wing of the sphenoid. The part of the *common tendinous ring* that gives origin to the lateral rectus spans between the narrow and wide parts of the fissure. Structures passing above or outside the tendinous ring or annulus include the lacrimal nerve, frontal nerve, trochlear nerve, superior ophthalmic vein and recurrent branch of the lacrimal



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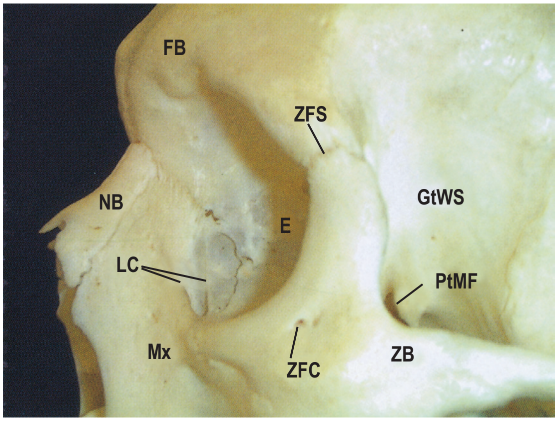

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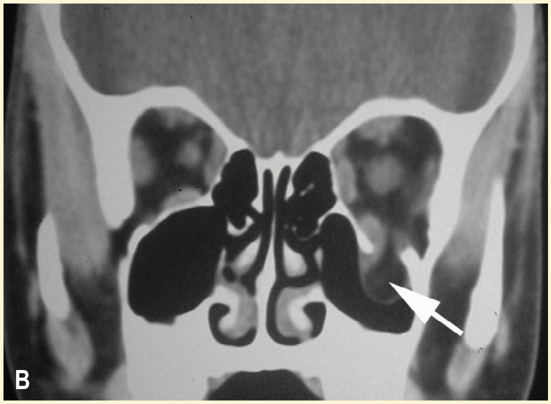
FIGURE 1-5 (**A**) Anterior view of the bony orbit showing important osteological features of the apex including the relation of the superior orbital fissure (SOF), optic canal (OC) and inferior orbital fissure (IOF). IOG, inferior orbital groove; LB, lacrimal bone; EF, anterior and posterior ethmoidal foramina; SN, supraorbital notch; FB, frontal bone; NB, nasal bone; Max, maxilla. (**B**) Lateral view of the orbit. ZB, zygomatic bone; PtMF, pterygomaxillary fissure; GtWS, greater wing of the sphenoid; ZFS, zygomaticofrontal suture; ZFC, zygomaticofacial canal; LC, lacrimal crest; E, ethmoid bone; Mx, maxilla.

artery. The latter anastomoses with the orbital branch of the middle meningeal artery and may more commonly travel in a small cranio-orbital foramen lateral to the superior orbital fissure. Structures passing within the ring, and thus within the apex of the muscle cone, include the oculomotor nerve (superior and inferior divisions), abducent nerve, nasociliary nerve, sympathetic root of the ciliary ganglion, and variably the inferior ophthalmic vein (Fig. 1-6).

BOX 1-2 CLINICAL CORRELATES

Orbital blow-out fractures

The floor, although thicker than the medial wall, is more often involved in orbital blow-out fractures, probably because it lacks the buttress-like supports of the ethmoidal air cells and the protection of the nose. Tumour spread to or from the maxillary sinus may occur via the floor of the orbit.



An example of ocular motility being compromised in left eye following blow-out fracture (**A**) and a coronal CT (**B**) showing the herniation of orbital contents into the roof of the maxillary sinus (arrow).

(Images courtesy of Dr Alan McNab.)

Inferior orbital fissure. This fissure lies between the lateral wall and floor of the orbit below the superior orbital fissure. It forms a communication between the orbit and the infratemporal fossa and pterygopalatine fossa. It runs forward and laterally for approximately 20 mm and ends 20 mm from the orbital margin (Figs 1-4 and 1-5A). The fissure is narrowest in the middle section and in life is covered by periorbita and a sheet

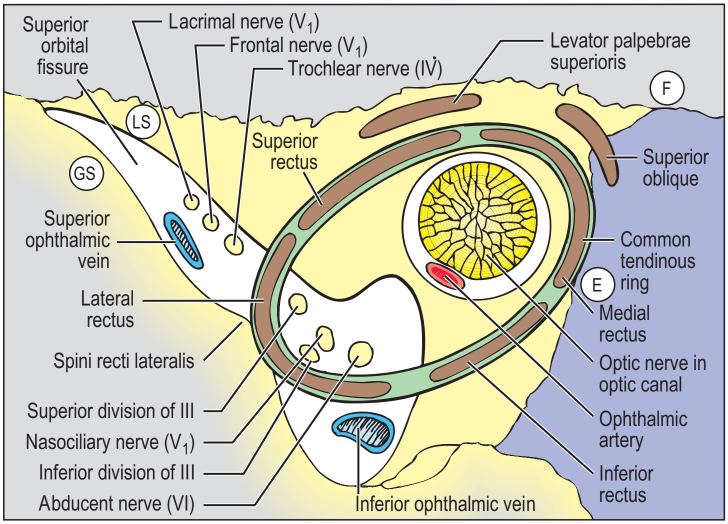


FIGURE 1-6 Schematic diagram of the superior orbital fissure and optic canal in the right orbit. Note the origins of the extraocular muscles from the common tendinous ring and the relative position of the cranial nerves and vessels as they enter or exit the orbit. GS, greater wing of sphenoid; LS, lesser wing of sphenoid; F, frontal bone; E, ethmoid. The positions of the veins are variable. The first letters of each of the structures passing through the superior orbital fissure (LFTSNIA) form a well-known mnemonic.

of smooth muscle of unknown function, the orbitalis or 'muscle of Müller'. It transmits the infraorbital nerve, zygomatic nerve, branches from the pterygopalatine ganglion and the inferior ophthalmic vein may communicate with the pterygoid venous plexus below.

Optic canal. This is a bony channel in the sphenoid that passes anteriorly, inferiorly and laterally (36°) from the middle cranial fossa to the apex of the orbit. The canal is formed by the two roots of the lesser wing of the sphenoid. The optic canals are 25 mm apart posteriorly and 30 mm anteriorly. Each is funnel-shaped and narrowest anteriorly where its opening into the orbit is oval with sharp upper and lower borders and a prolonged roof (10–12 mm in length). The opening at the cranial aspect is oval with a prolonged floor. The sphenoidal and posterior ethmoidal air sinuses are important medial relations, and the olfactory tracts are superior relations of the canal. The canal transmits the *optic nerve* with its meningeal coverings and the *ophthalmic artery*, which lies below and then lateral to the nerve within the dural sheath for part of its course (Fig. 1-6). Sympathetic nerve fibres accompany the artery.

PARANASAL SINUSES

The paranasal sinuses (Figs 1-3, 1-7 and Video 1.3) comprise the frontal, ethmoidal, sphenoidal and maxillary sinuses. They are air-filled cavities in the skull that are in communication with the nasal cavity via a series of apertures. Infection commonly spreads from the nasal cavity into the sinuses. The sinuses function to warm and moisten the air, add resonance to the voice and lighten the skull. They vary in size and shape between individuals.

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CRANIAL CAVITY (FIG. 1-8A,B AND EFIG. 1-1)

The cranial cavity houses the brain, cerebral vessels, the meninges, meningeal vessels and the intracranial portions of the cranial nerves. The base of the cranial cavity can be subdivided for descriptive purposes into three fossae: anterior, middle and posterior. Accounts of the detailed anatomy of these fossae can be found in any standard anatomy text; therefore only features of relevance to the eye and orbit in the anterior and middle cranial fossae will be described.

For discussion of posterior cranial fossa see https://expertconsult.inkling.com/.

Cranial fossae

Anterior cranial fossa. The anterior cranial fossa is limited in front and laterally by the frontal bone and posteriorly by the lesser wing of the sphenoid. Its floor is formed by the orbital plate of the frontal bone, the cribriform plate of the ethmoid (with a median

Frontal Sinuses (Figs 1-4 and 1-7)

The frontal sinuses are paired and lie behind the superciliary arches within the frontal bone (eFig. 1-1). They are separated from each other or further subdivided by thin bony septa that are not necessarily in the midline. The sinuses may extend as far laterally as the zygomatic process of the frontal bone. Each is approximately triangular and extends highest above the medial end of the eyebrow (Fig. 1-7). Each sinus opens into the middle meatus of the nasal cavity, either through the ethmoidal infundibulum or directly via the frontonasal duct. The mucosal lining is supplied by the supraorbital nerves and vessels; hence, referred pain from frontal sinusitis is experienced along the course of the supraorbital nerve.

Recent geometric morphometric studies (elliptic Fourier analysis) of the outlines of frontal sinuses from large numbers of radiographic images have confirmed a long-held belief that each individual's frontal sinus is distinct and unique. This may have important applications for personal identification in the context of forensics.

Ethmoidal Sinuses (Air Cells) (Figs 1-3A–C and 1-7)

These thin-walled sinuses are for the most part situated in the lateral mass of the ethmoid, although frontal, maxillary, lacrimal, sphenoidal and palatine bones contribute to the walls. They are variable in number and are grouped into anterior, middle and posterior. The general pattern of drainage of the sinuses is as follows: the anterior opens into the hiatus semilunaris, the middle on to the bulla ethmoidalis (both middle meatus) and the posterior into the superior meatus. They are related to the frontal sinus anteriorly, the sphenoidal sinus posteriorly, the nasal cavity medially and below, and laterally the orbit (Fig. 1-7A).

Sphenoidal Sinus (Figs 1-3A,B and 1-7)

This sinus lies within the body of the sphenoid bone and possesses an indented roof because of the pituitary fossa that lies above and houses the pituitary gland (Fig. 1-8). It may be divided by a variable midline septum. A transverse ridge in the lateral wall marks the position of the internal carotid artery (within the cavernous sinus). Other important relations of the sinus include the optic chiasma and nerves above, the nasal cavity below, the ethmoidal sinuses anteriorly, and the paired cavernous sinuses laterally (Fig. 1-9C). The sphenoidal sinus drains into the superior meatus or sphenoethmoidal recess. Surgical access to the pituitary gland may be gained via the nasal cavity and sphenoidal sinus; hence, surgeons must be aware of the above-mentioned relations.

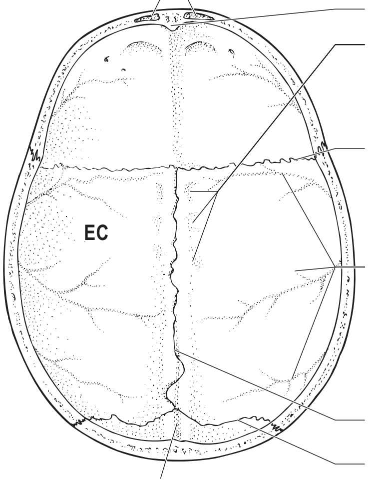
Maxillary Sinus (Figs 1-3C and 1-7)

These are the largest of the paranasal air sinuses. They are pyramidal in shape and lie within the body of the maxilla. The *base* forms part of the lateral wall of the nasal cavity and the *apex* is within the zygomatic process. Each sinus is in communication with the middle meatus of the nasal cavity via an aperture, the maxillary hiatus, on its base, which empties into the lower part of the hiatus semilunaris. The opening is positioned high on this wall and therefore does not facilitate gravitational drainage in the upright position. The *nasolacrimal duct* lies in a thin bony canal in the anterior part of the base. The orbital plate forms the *roof* of the sinus and floor of the orbit.

Orbital Floor Fractures

Rapid traumatic compression of the orbital contents, such as occurs during squash ball injuries, can lead to blow-out fractures; orbital contents may herniate into the maxillary sinus. It was once thought that orbital contents, including extraocular muscles, became trapped in the fractured floor, thus restricting range of movement and explaining the diplopia suffered by these patients. However, recent studies have indicated that in many cases only orbital fibroadipose tissue is trapped in the damaged floor of the orbit (see p. 6).

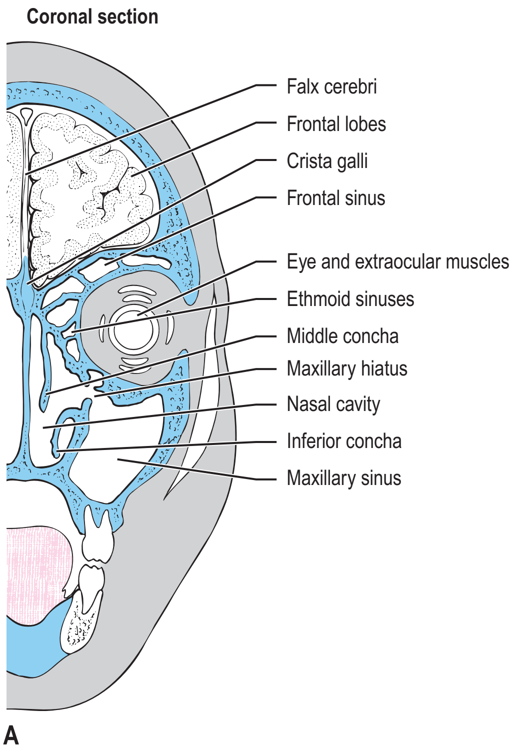
The *floor* of the maxillary sinus is formed by the alveolar process housing a variable number of the roots of the first and second molars that protrude into the sinus, and may be separated from the sinus by only a thin covering of bone or mucous membrane. Thus sinusitis may present as referred pain such as toothache and vice versa. In addition, abscesses in the maxillary sinus may result from infection of these roots. The *anterior/lateral wall* is directed on to the face, and access for drainage of maxillary obstructions or other surgical procedures in the sinus may be gained by this route. The *posterior wall* faces the infratemporal fossa.



eFIGURE 1-1 Features of the vault interior.

Posterior Cranial Fossa

This is the deepest of the three cranial fossae, its floor lying below the level of the middle fossa. Its roof is formed by the tentorium cerebelli. It lodges the hindbrain: the cerebellum, pons and medulla oblongata. The fossa is bound anteriorly by the superior border of the petrous temporal bone and the dorsum sella, and surrounds the foramen magnum, the cerebellum being housed in the cerebellar fossae on the squamous part of the occipital bone. Features and openings on the floor of the posterior cranial fossa are not as relevant to the eye and orbit as those in the anterior or middle fossae; however, readers should be able to identify the following: foramen magnum, jugular foramen, hypoglossal canal, internal acoustic meatus, grooves for the sigmoid and transverse sinuses, internal occipital protuberance and clivus (Fig. 1-8A,B).



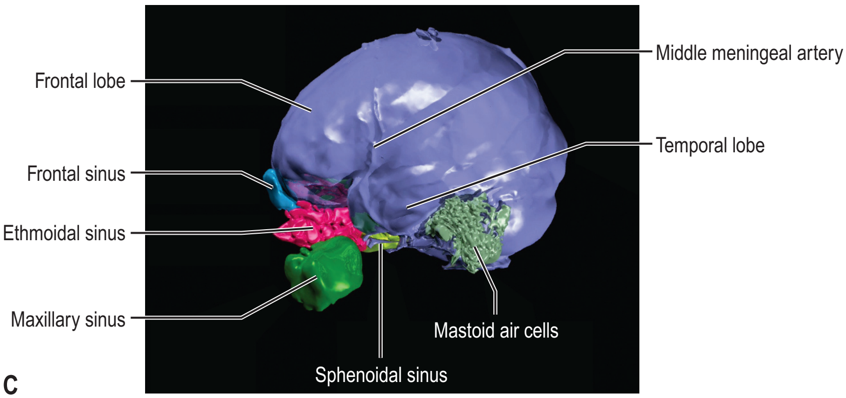


FIGURE 1-7 (**A**) Diagram of a coronal section of the head revealing most of the paranasal sinuses except the sphenoid sinus. (**B**) 3D visualization of paranasal sinuses as seen from anterior aspect and (**C**) lateral aspect. See http://www.oucom.ohiou.edu/dbms-witmer/3D_human.htm or https://expertconsult.inkling.com/ for 3D pdf movies of skull and more details of paranasal sinus anatomy.

crest-like ridge, the crista galli, which forms the anterior attachment of the falx cerebri), and the lesser wings and anterior part of the body (jugum) of the sphenoid. The perforations of the cribriform plate transmit the olfactory nerves. The orbital plate of the frontal bone separates the orbit below from the frontal lobes of the cerebral hemispheres, whose sulci and gyri cause surface impressions on the bone. Projecting posteriorly from the lesser wings of the sphenoid are the anterior clinoid processes that overhang the middle cranial fossa and give attachment to the free edge of the tentorium cerebelli.

Middle cranial fossa. The middle cranial fossa lies at a lower plane than the anterior cranial fossa but is higher than the posterior cranial fossa. Its floor is shaped like a butterfly, with a narrow central or median part and expanded lateral parts. It is bound anteriorly by the posterior free edge of the lesser wing of the sphenoid, the anterior clinoid processes, and the anterior margin of the sulcus chiasmaticus (Fig. 1-8A,B). Posteriorly it extends to the superior borders of the petrous temporal bones and dorsum sellae of the sphenoid, and laterally it is bound by the squamous part of the temporal bone, part of the parietal bones, and the greater wings of the sphenoid. Features and foramina of the floor of the middle cranial fossa and the structures that they transmit are summarized in Table 1-1.

Pituitary fossa. The *pituitary fossa* (hypophyseal fossa) is an indentation in the roof of the body of the sphenoid bone in the middle cranial fossa. It is bound anteriorly by the *tuberculum sellae*, in front of which lies the *sulcus chiasmatica*, and posteriorly by the *dorsum sellae*, a ridge of bone at either end of which lies the *posterior clinoid processes*. The pituitary fossa houses the pituitary gland or *hypophysis cerebri*. This is connected by a thin stalk – the pituitary stalk (or tuber cinereum) – to the brain. The fossa is roofed by a sheet of dura mater, the *diaphragma sella* (Fig. 1-9C,D) which is attached in front to the tuberculum and behind to the dorsum sellae. The pituitary stalk passes through a small opening in the roof. The right and left cavernous sinuses are important lateral relations (Fig. 1-9C).

The meninges (Fig. 1-9A,B and eFig. 1-2A)

The brain and spinal cord are surrounded by three layers of meninges: a tough *pachymeninx*, the dura mater, and the *leptomeninges* consisting of the arachnoid mater and pia mater. Between the arachnoid and pia is the *subarachnoid* space filled with cerebrospinal fluid.

Dura mater. The *dura mater* is theoretically 'divided' into an endosteal layer (really the periosteum on the

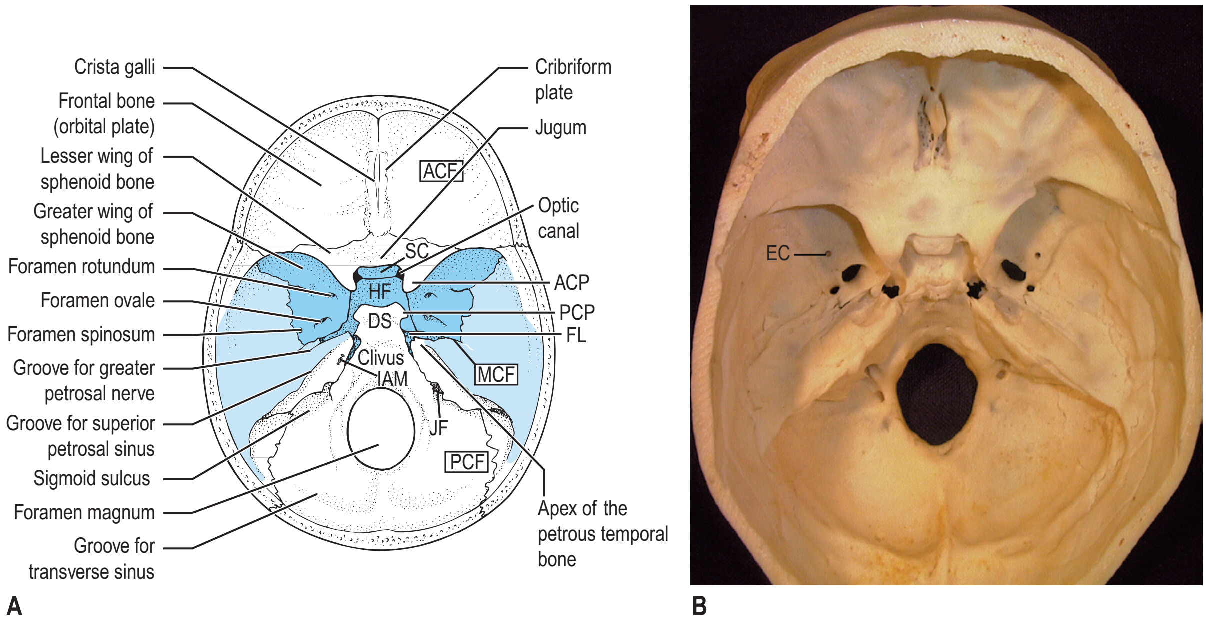
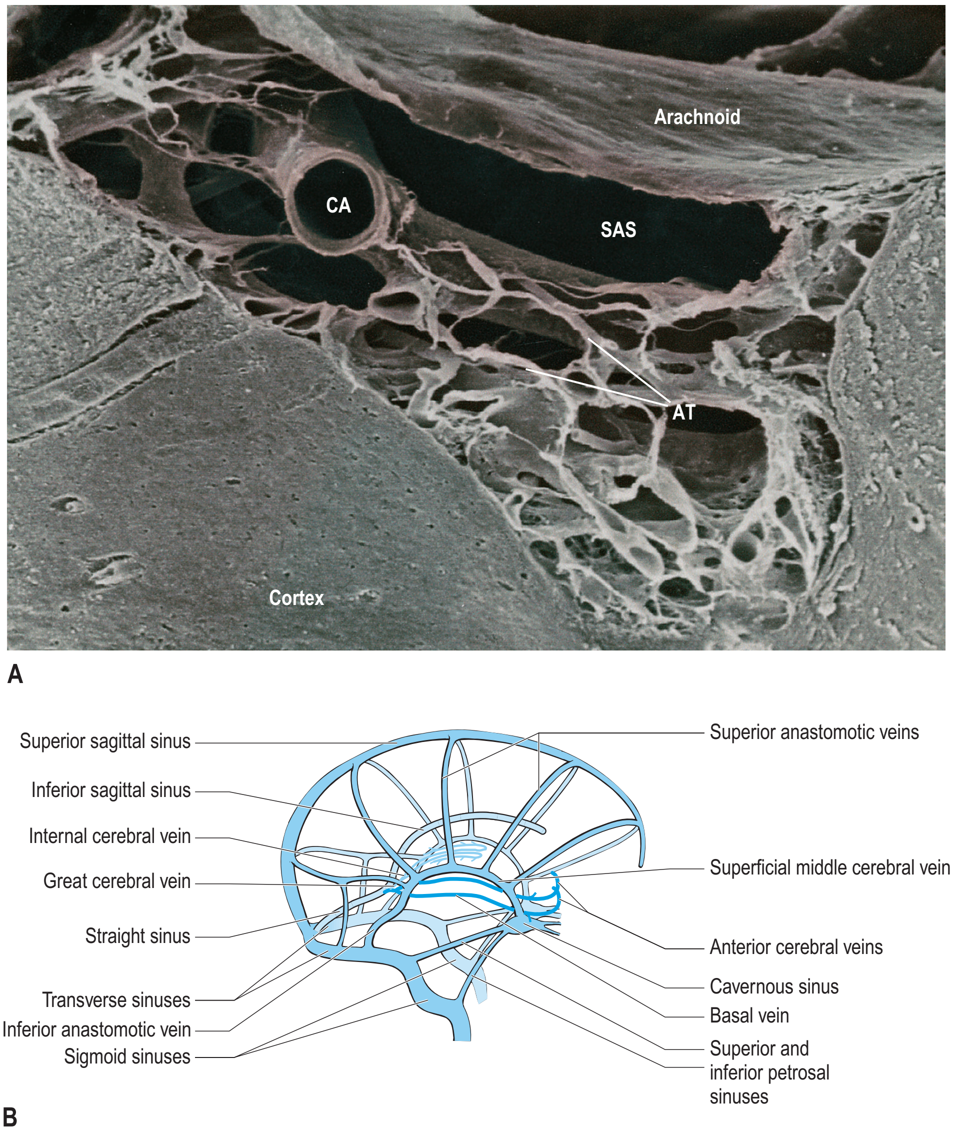


FIGURE 1-8 Osteology of the cranial cavity. (**A**) The boundaries of the anterior (ACF), middle (MCF) and posterior (PCF) cranial fossae together with major foraminae and important landmarks on the base of the skull. HF, hypophyseal fossa; DS, dorsum sella; SC, sulcus chiasmaticus; IAM, internal auditory meatus; JF, jugular foramen and fossa; ACP, anterior clinoid process; PCP, posterior clinoid process; FL, foramen lacerum. (**B**) Photograph of cranial cavity to illustrate features shown in (**A**): EC, emissary canal.



eFIGURE 1-2 (**A**) Scanning electron micrograph of the meninges and cortex of the brain showing the arrangement of the arachnoid trabeculae (AT) supporting the cerebral arteries (CA) as they course through the subarachnoid space (SAS) (× 100). (**B**) Schematic diagram of the dural venous sinuses and their connections with cerebral veins.

TABLE 1-1 Summary of features on the floor of the middle cranial fossa

Feature/foramen	Position	Relevance
Sulcus chiasmaticus	Between the two optic canals anterior to tuberculum sella	Only rarely does optic chiasma lie in contact with this region
Sella turcica ('Turkish saddle')	Central part of sphenoid body between the two cavernous sinuses	The central hollow, the hypophyseal fossa, houses the pituitary gland. Anterior and posterior clinoid processes give attachment to the free and attached margins of the tentorium cerebelli
Optic canal	Between the two roots of the lesser wing of the sphenoid	Transmits optic nerve, ophthalmic artery, sympathetic nerves and meningeal coverings
Superior orbital fissure	Between the lesser and greater wings of the sphenoid. Lies at apex of cavernous sinus	Transmits trochlear, abducent and oculomotor nerves and terminal branches of ophthalmic nerve
Foramen rotundum	Pierces greater wing of sphenoid	Transmits maxillary nerve and small veins from cavernous sinus
Foramen ovale	Pierces greater wing of sphenoid	Transmits mandibular nerve, accessory meningeal artery and occasionally the lesser petrosal nerve
Foramen spinosum	Posterolateral to foramen ovale	Transmits middle meningeal artery and vein and meningeal branch of the mandibular nerve
Foramen lacerum	At apex of petrous temporal bone	The upper end transmits the internal carotid artery before it enters the cavernous sinus. Also transmits sympathetic nerves and a small plexus of veins. The lower end is covered by connective tissue and pierced only by small branches of the ascending pharyngeal artery
Trigeminal impression	Anterior surface of petrous temporal bone behind foramen lacerum	Occupied by trigeminal ganglion in trigeminal cave. Joined on lateral aspect by grooves for the greater and lesser petrosal nerves
Tegmen tympani and arcuate eminence	Tegmen is a thin plate of temporal bone over middle ear cavity. Arcuate eminence is produced by superior semicircular canal in petrous temporal bone	Infections in middle ear may spread through thin plate of bone to middle cranial fossa and temporal lobe of the brain

inner surface of the skull) and a meningeal layer; however, on the whole they are fused except where they separate to form *dural venous sinuses* and *dural folds* (Fig. 1-9A,B). The latter are connective tissue septae that extend into the cranial cavity and serve to subdivide it into compartments. In association with the cerebrospinal fluid they aid in providing physical support and protection for the brain. The position and form of the dural folds are summarized diagrammatically in Figure 1-9A.

The *dural venous sinuses* are valveless, highly specialized, firm-walled veins within the cranial cavity which drain venous blood from the brain and cranial bones (Fig. 1-9B). In common with other veins the sinuses are lined by vascular endothelial cells; however, their walls contain no smooth muscle cells. The arrangement of the sinuses is summarized in Fig. 1-9A and eFig. 1-2B.

Of particular note to those studying the eye and orbit is the pair of cavernous sinuses lying either side of the body of the sphenoid (Fig. 1-9C,D).

The importance of the *cavernous sinuses* (Fig. 1-9C,D) lies in their *position, relations* and extensive *communications*. Each cavernous sinus is around 2–3 cm long in the sagittal plane and consists of a series of incompletely fused venous channels or a single venous channel partially subdivided by *trabeculae*. It has walls of dura mater, like other venous sinuses.

Position. There is one cavernous sinus on either side of the body of the sphenoid. The sinus extends from the superior orbital fissure in front to the apex of the petrous temporal bone behind.

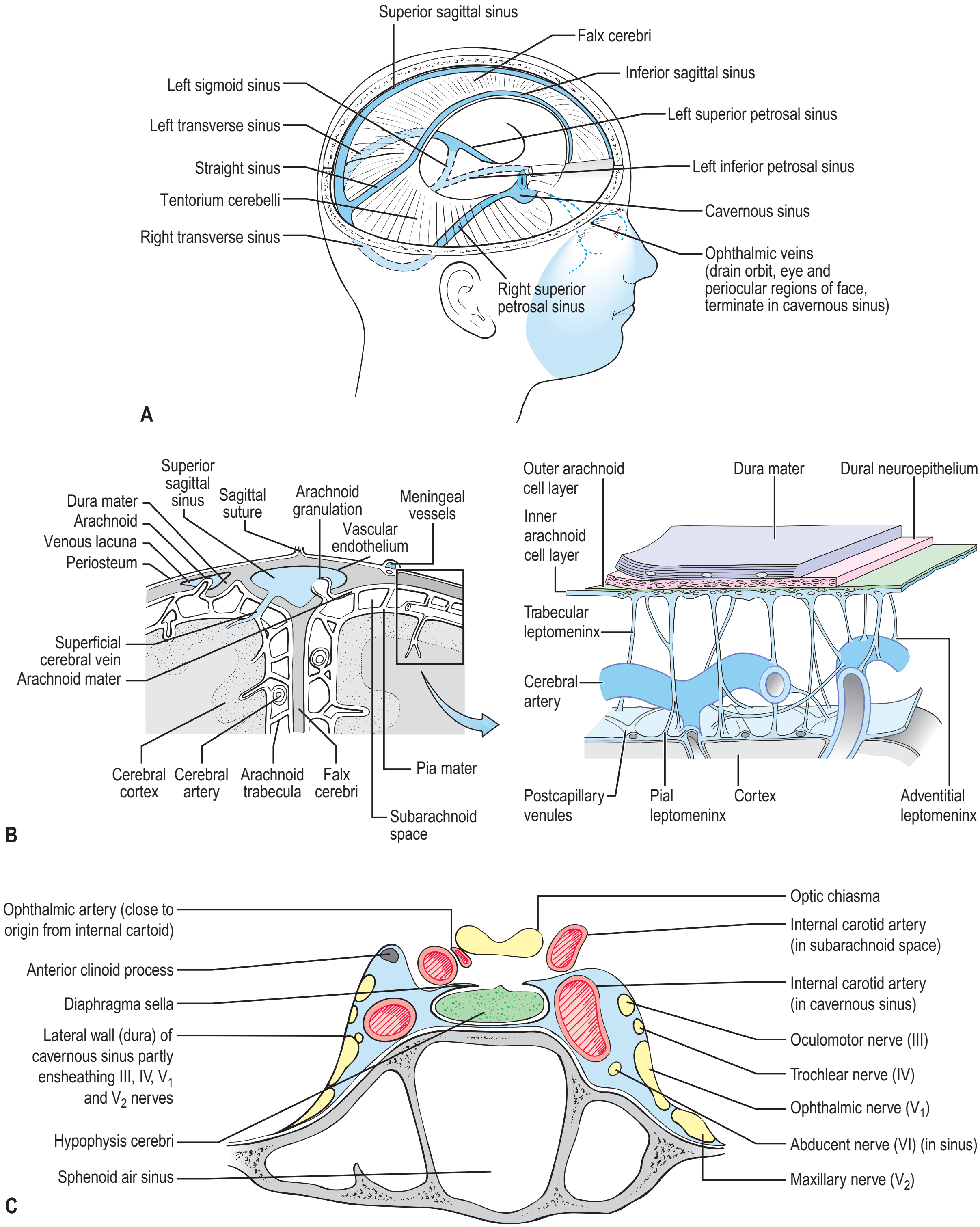
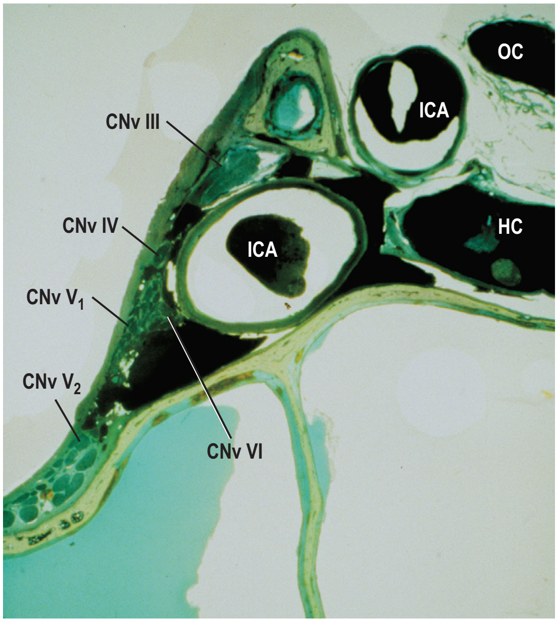


FIGURE 1-9 (**A**) The interior of the cranium with the brain removed to illustrate the arrangement of the dural folds and some of the related dural venous sinuses. (**B**) The meninges as seen in coronal section in the region of the superior sagittal sinus. Inset higher-power diagrammatic representation of the meningeal layers. (**C**) Coronal section approximately midway along the body of the sphenoid bone to reveal the paired cavernous sinuses, one on either side. Note the position of the cranial nerves (II, III, IV, V_1, V_2 and VI), internal carotid artery (cut in two places, within and above the sinus) and hypophysis cerebri (pituitary gland).

Continued



D

FIGURE 1-9, cont'd (**D**) High-power view of the left cavernous sinus (coronal plane, 100 μm thick section of low-viscosity nitrocellulose resin-embedded specimen) upon which eFig. 1-2B was based. OC, optic chiasma; HC, hypophysis cerebri; ICA, internal carotid artery.

Relations. These are summarized in Figure 1-9C and D (coronal section).

Communications. The sinuses communicate with each other via the anterior and posterior intercavernous sinuses. Tributaries draining into the sinuses anteriorly include the superior and inferior ophthalmic veins (which drain the eye and orbit as well as areas of skin around the periorbital region of the face and nose), and the sphenoparietal sinuses. The superficial cerebral vein from the brain drains into the sinus from above (eFig. 1-2B).

Blood from each sinus may, depending on relative pressures, drain via the superior and inferior petrosal sinuses either directly to the internal jugular veins (inferior petrosal) or to the transverse sinuses and thus to the internal jugular veins. Other exits include venous plexi around the internal carotid artery or veins traversing the foramen ovale or sphenoidal emissary foramen to communicate with the pterygoid plexus and other veins in the region of the skull base. Communications with the vertebral venous plexus in the epidural space also exist via the basilar venous plexus on the clivus.

The major dural folds (Fig. 1-9A) are falx cerebri, tentorium cerebelli, cavum trigeminale and diaphragma sella.

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The meningeal arteries lie within the inner (or periosteal) layer of dura with their accompanying veins (Fig. 1-9B) and are responsible for the many fine grooves that ramify over the inner surface of the cranium (see Fig. 1-8B and eFig. 1-1).

The largest and most important of these is the middle meningeal artery, which enters the skull through the foramen spinosum. These arteries supply the meninges and diploë (bone marrow of cranial bones), but they *do not* supply the brain.

Arachnoid mater (eFig. 1-2A)**.** The arachnoid (*Gk.* spider) is a delicate fibrocellular layer beneath the dura (separated by potential subdural space) that is connected to the pia mater covering the brain by numerous fibrocellular bands that cross the cerebrospinal fluid-filled subarachnoid space. This arrangement has led some to consider the leptomeninges as a conjoined pia–arachnoid membrane. The arachnoid bridges over the sulci, gyri and other irregularities on the brain surface, thus creating the *subarachnoid cisterns* or enlargements in the subarachnoid space (Fig. 1-9B, inset, and eFig. 1-2A).

Specialized regions of arachnoid, the *arachnoid villi* and *granulations* (fibrous aggregations of villi), project into several of the dural venous sinuses (Fig. 1-9B) and act as one-way pressure-sensitive valves allowing cerebrospinal fluid to drain from the subarachnoid space into the dural venous sinuses. Structures passing to and from the brain to the skull or its foramina, such as cranial nerves, must traverse the subarachnoid space. In addition, all cerebral arteries and veins lie in this space (eFig. 1-2A).

Since the arachnoid fuses with the perineurium of cranial nerves, the cerebrospinal fluid-containing subarachnoid space extends for a short distance around all cranial nerves. In particular it surrounds the optic nerve in a cuff-like manner as far as the posterior surface of the eye.

Falx Cerebri

A sickle-shaped fold with its attached border in the mid-sagittal plane from the crista galli to the tentorium cerebelli behind. It lies in the vertical fissure between the two cerebral hemispheres, its lower border lying above the corpus callosum. The superior sagittal sinus is situated in the attached border and the inferior sagittal sinus is in the lower free border of the falx cerebri.

Tentorium Cerebelli. This fold lies approximately in a horizontal plane at 90° to the falx, although it is elevated centrally (hence 'tent-like'). It separates the occipital lobe of each cerebral hemisphere above from the cerebellum in the posterior cranial fossa below. The free edge forms the boundary of the tentorial notch, which separates the forebrain from the hindbrain and 'houses' the midbrain. Sinuses related to the tentorium include the straight sinus, right and left transverse sinuses, superior petrosal sinuses and cavernous sinuses.

Cavum Trigeminale. A blind-ended dural recess whose entrance is in the posterior cranial fossa. It is formed by an invagination of the dura beneath the free edge of the tentorium and is roofed by dura on the floor of the middle cranial fossa. It houses the trigeminal ganglion, which sits in a shallow hollow on the apex of the petrous temporal bone, and some accompanying vessels. The ganglion is surrounded by cerebrospinal fluid continuous with the subarachnoid space of the posterior cranial fossa.

Diaphragma Sella. A small circular fold of dura over the sella turcica that is pierced centrally by the infundibulum (Fig. 1-9C). It blends laterally with the roof of the cavernous sinus (Fig. 1-9D).

The area above the tentorium is known as the supratentorial compartment; that below is the infratentorial compartment. The cranial dura of the supratentorial compartment is innervated by sensory branches of the trigeminal nerve, and stimulation of these nerves (stretching, inflammation, compression) gives rise to frontal or parietal headache. The infratentorial compartment is supplied by branches of the upper cervical nerves, and stimulation of these sensory nerves may therefore manifest as occipital and neck pain.

The neck rigidity accompanying acute meningitis of the infratentorial region is most likely the result of reflex contractions, or spasm, of posterior neck musculature in response to stretching of the inflamed cranial and spinal cord meninges.

BOX 1-3 CLINICAL CORRELATES

Arteriovenous Fistulas in the Cavernous Sinus

These cause a variety of symptoms including pulsating protrusion of the globe and congestion of the vessels of the lids and conjunctiva owing to raised venous pressure. Patients complain of hearing noises resembling rushing water, probably because of increased flow rates in the labyrinthine plexus, which is in communication with the cavernous sinus via the superior petrosal sinus.

Cavernous Sinus Thrombosis

Cavernous sinus thrombosis as a sequel to infection spreading to the sinus, from such diverse initial sites as the nose, lids, behind the ear, bony labyrinth, pharynx and temporomandibular joint, can give rise to a variety of symptoms explainable on the basis of structures affected in and around the sinus. Facial pain may be the result of the involvement of the ophthalmic nerve (V_1). Lateral rectus paralysis may follow involvement of the abducent nerve. Involvement of the other oculomotor nerves is less common because they are more protected in the lateral wall of the sinus. Thrombosis is usually bilateral because of the communications via the intercavernous sinuses. Papilloedema may result from obstruction of central retinal venous return.

Pia mater (Fig. 1-9B and eFig. 1-2A). The pia mater, a vascular fibrocellular membrane that is thicker than the arachnoid, closely follows the contours of the brain. Vessels entering or leaving the brain parenchyma carry a pial sheath with them. Pial tissue is rich in astrocytes, which extend along the vessel walls and form an important component of the blood–brain barrier. The perivascular spaces surrounding these vessels, the so-called Virchow–Robin spaces, are potentially in communication with the cerebrospinal fluid of the subarachnoid space and may be dilated in pathological states.

Structure of the eye

The eye (Fig. 1-10) is a highly specialized organ of photoreception, the process by which light energy from the environment produces changes in specialized nerve cells in the retina, the rods and cones. These changes result in nerve action potentials, which are subsequently relayed to the optic nerve and then to the brain, where the information is processed and consciously appreciated as vision. All the other structures in the eye are secondary to this basic physiological

BOX 1-4 CLINICAL CORRELATES

Extradural and subdural haematomas

Damage to middle meningeal vessels, especially the frontal branch of the middle meningeal artery and vein (the latter lying closest to the bone), may result from blows to the head, especially in the temporal region (the pterion; see Figs 1-2B, 1-5B, 1-8B) where the bones are thinnest and most likely to fracture. Slow venous, or more rapid arterial, bleeding will lead to an extradural (epidural) haematoma with a resultant rise in intracranial pressure. Coma and death will occur if such a haematoma is not drained as soon as possible after symptoms of raised intracranial pressure, including papilloedema, manifest. A subdural haematoma may occur if the trauma results in brain laceration or tearing of intradural veins.

process, although they may be part of the system necessary for focusing and transmitting the light on to the retina, for example cornea, lens, iris and ciliary body, or they may be necessary for nourishing and supporting the tissues of the eye, for example the choroid, aqueous outflow system and lacrimal apparatus.

GENERAL SHAPE, SIZE AND POSITION OF THE EYE

The eye is approximately a sphere 2.5 cm in diameter with a volume of 6.5 mL. However, in reality it is the parts of two spheres, a smaller one anteriorly, the cornea, that has a greater curvature than the sclera, which constitutes the large sphere. The cornea forms one-sixth of the circumference of the globe and has a radius of 7.8 mm; the remaining five-sixths is formed by the sclera, which has a radius of 11.5 mm. There is variation in size between individuals but the average axial length of the globe is 24 mm (range 21–26 mm). The diameter is 23 mm and the horizontal length approximately 23.5 mm. Small eyes (<20 mm) are hyperopic or hypermetropic, while large eyes (26–29 mm) are myopic. The eye is situated in the anterior portion of the orbit, closer to the lateral than the medial wall and nearer the roof than the floor. The eye is made up of three basic layers or coats, often known as tunics (Fig. 1-10). These are the fibrous (corneoscleral) coat, the uvea or uveal tract (composed of choroid, ciliary body and iris), and the neural layer (retina). The coats surround the contents, namely the lens and the transparent media (aqueous humour and vitreous body).

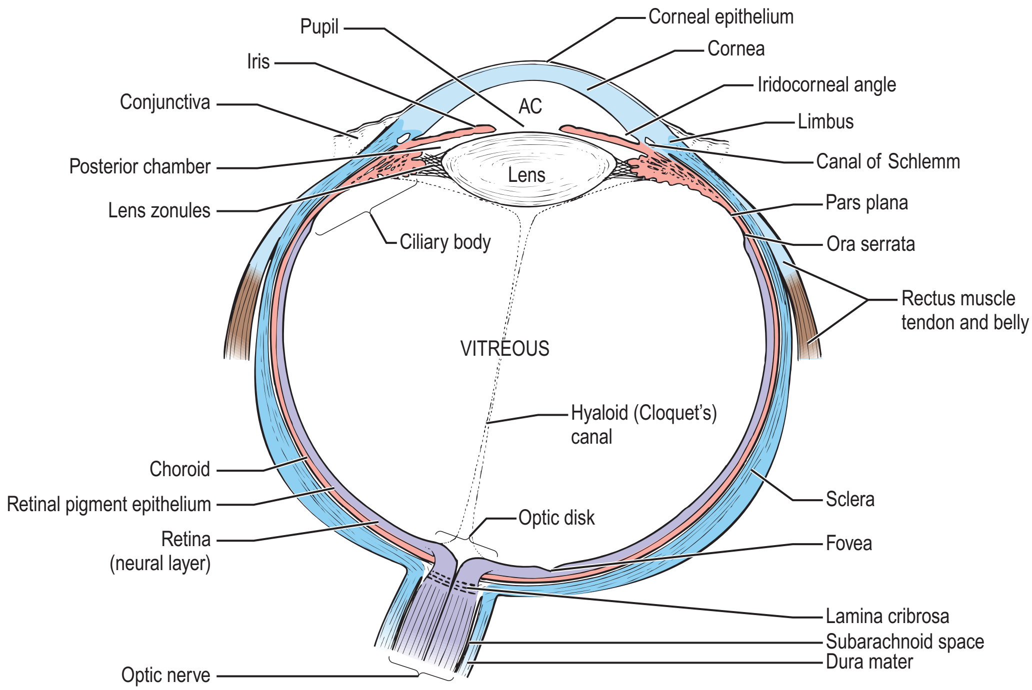

FIGURE 1-10 Schematic diagram of the human eye in horizontal section revealing the major components and the arrangement of the three layers. AC, anterior chamber. The corneoscleral envelope (blue), the uveal tract (orange/red) and the inner neural layer (purple).

The cornea and sclera together form a tough fibrous envelope that protects the ocular tissues. The fibrous coat also provides important structural support for intraocular contents and for attachment of extraocular muscles. The cornea meets the sclera at a region known as the limbus or corneoscleral junction.

THE CORNEA

The surface of the cornea (air–tissue interface) and associated tear film is responsible for most of the refraction of the eye. The transparency of the cornea is its most important property, although because of its highly exposed position it must also present a tough physical barrier to trauma and infection. Corneal transparency is the result of a number of related factors: its avascularity; the regularity and smoothness of the covering epithelium; and the regular arrangement of the extracellular and cellular components in the stroma, which is dependent on the state of hydration, metabolism and nutrition of the stromal elements.

Shape

The cornea is smaller in the vertical (10.6 mm) than in the horizontal (11.7 mm) diameter; however, viewed from behind, the circumference appears circular. The central radius is 7.8 mm with the peripheral corneal curvature being less marked. The cornea is also thicker at the periphery (0.67 mm) than in the centre (0.52 mm).

Structure

The cornea is composed of five layers (Fig. 1-12A).

Corneal epithelium (Fig. 1-12B). The corneal epithelium is a *stratified* (possessing five or six layers) *squamous non-keratinized* epithelium (the superficial cells are flattened, nucleated and non-keratinized). It is 50–60 μm in thickness and adjacent cells are held together by numerous *desmosomes* and to the underlying basal lamina by *hemidesmosomes* and anchoring filaments (Fig. 1-12B). The anterior surface of the corneal epithelium is characterized by numerous microvilli and microplicae (ridges) whose glycocalyx coat interacts with, and helps stabilize, the precorneal tear film. New cells are derived from mitotic activity in the limbal basal cell layer (see p. 211) and these displace existing cells both superficially and centripetally. The corneal epithelium responds rapidly to