Chapter 15: Surgical anatomy of the skull base

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This chapter presents the surgical anatomy of the undersurface of the skull as it relates to the practice of otolaryngology; the intracranial aspect of the skull base is not discussed.

The description falls into two sections: first, a systematic topographic description of the anatomy of the skull base and structures beneath it; and second, an account of the anatomical basis of the lateral surgical approach to the skull base.

Overall topography of the skull base

The inferior aspect of the skull base is bounded in front by the upper incisor teeth, behind by the superior nuchal line of the occipital bone, and laterally by the remaining upper teeth, the zygomatic arch and its posterior root, and the mastoid process.

The region may be divided into posterior, central and anterior parts. The posterior part is separated from the central part by an arbitrary line drawn transversely through the anterior margin of the foramen magnum. The boundary between the central and anterior parts is the posterior border of the hard palate.

The posterior skull base comprises the occipital (muscular) area.

The central skull base can be subdivided into different bone areas that correspond to compartments underneath (van Huijzen, 1984). It contains the pharyngeal, tubal, neurovascular, auditory and articular areas, and the infratemporal fossa.

The anterior skull base, on a lower level than the part behind, is formed by the hard palate and alveolar arches. It is part of the faciomaxillary structure, and will not be described further here (see Chapters 5 and 8).

Osteology of the skull base

Behind the faciomaxillary bones, the cranial base is made up of the occipital bone, temporal bones and part of the sphenoid bones.

Occipital bone

The occipital bone is convex posteriorly and encloses the foramen magnum, through which the cranial cavity communicates with the vertebral canal. The broad, curved plate behind and above the foramen magnum is termed the squamous part; the occipital condyle on each side of the foramen arises from the lateral part; and the thick, square piece in front of the foramen is the basi-occiput.

The foramen magnum is oval in shape, with its long diameter lying anteroposteriorly. The fibrous dura mater is attached to the margins of the foramen; below, it is projected down the spinal canal as the spinal dura mater (theca); above, it sweeps up into the posterior cranial
fossa. Within the dural sheath in the subarachnoid space, passing through the foramen, lie the lower medulla with the cervical roots of the spinal accessory nerves, the spinal arteries and veins, and the vertebral arteries.

The anterior margin of the foramen magnum gives attachment to a number of ligaments ascending from the axis: the membrana tectoria, vertical limb of the cruciform ligament, and the apical and pair of alar ligaments of the odontoid peg. The anterior atlanto-occipital membrane is attached to a ridge that joins the anterior poles of the occipital condyles; the posterior atlanto-occipital membrane is attached to the posterior edge of the foramen magnum.

The **squamous part** of the occipital bone gives attachment to the muscles of the back of the neck, and is described further in the section on the occipital (muscular) area of the skull base.

The **lateral part** gives rise to the occipital condyle on each side. Each condyle has a convex surface covered in hyaline cartilage which articulates with the concave surface of the atlas; these atlanto-occipital joints permit nodding only, rotation being the function of the atlantoaxial joints. Behind the condyle is a shallow fossa often perforated by the tiny posterior condylar canal, carrying a vein from the sigmoid sinus to the suboccipital venous plexus. In front of the condyle, just medial to the jugular foramen, lies the anterior condylar canal through which passes the twelfth nerve.

The **basocciput** is an oblong block of bone which extends forward from the foramen magnum and fuses with the basisphenoid just behind the nose. The pharyngeal tubercle is a small protuberance in the midline, one-third of the way from the anterior margin of the foramen magnum to the posterior edge of the nasal septum. In front of the tubercle, the bone forms the roof of the nasopharynx and lies in the 'pharyngeal area' described in a following section. Behind it are attached the uppermost prevertebral muscles, with the longus capitis lying in front of the rectus capitis anterior. Separating the nasopharynx from the prevertebral region is the pharyngobasilar fascia with the prevertebral fascia just behind it.

**Temporal bone**

The temporal bone is made up of four parts which ossify separately and later fuse. The squamous part contributes the 'articular area' to the skull base, but most of it is in the temporal fossa on the side of the skull. The petromastoid part forms an important and complicated portion of the skull base lateral to the occipital bone. The tympanic plate, rolled like a tube open at the top, lies below the petrous and squamous parts, and just behind it the styloïd process projects from the petrous bone.

The **squamous temporal bone** contains the hollow of the glenoid fossa, with, in front, the convex eminentia articularis joined laterally to the zygomatic process. This area lies almost wholly within the temporomandibular joint, with only a small triangular part anterior to the joint forming part of the infratemporal surface of the skull.
The petromastoid bone projects forwards and medially at 45°, wedged between the basiocciput and the greater wing of the sphenoid; at the apex of the wedge the three bones do not quite meet, leaving a gap termed the 'foramen lacerum' which is closed by dense fibrocartilage and transmits nothing other than a few minute vessels.

More laterally, along the junction between the petrous bone and the greater wing of the sphenoid, lies the cartilaginous portion of the eustachian tube, running posterolaterally into the bony part of the tube where it is overhung by the spine of the sphenoid. Just posterior to this is the carotid foramen, separated by a ridge of bone from the jugular foramen behind.

Lateral to the carotid and jugular foramina lies the tympanic bone. Laterally, it forms the bony part of the external auditory canal, articulating with the squamous bone of the glenoid fossa in front (squamotympanic fissure) and the mastoid bone behind (tympanomastoid fissure). Medially, it forms the floor of the hypotympanum. The medial part of the squamotympanic fissure becomes divided by a thin flange of petrous bone (the projecting margin of the tegmen tympani), so creating a petrosquamous fissure in front and a petrotympanic fissure behind.

Lateral to the jugular foramen, and tucked in close behind the tympanic bone, projects the styloid process, which is of very variable length. Behind its base lies the stylomastoid foramen, and further posteriorly the mastoid bone is indented by the digastric notch, medial to which there is a groove for the occipital artery.

Sphenoid bone

The greater wing of the sphenoid, with the medial and lateral pterygoid plates, contributes to the base of the skull.

The greater wing articulates with the squamous temporal bone to form the roof of the infratemporal fossa. Anteriorly, this infratemporal surface ends in the inferior orbital fissure behind the maxilla. Medially, the greater wing is edge-to-edge with the petrous bone, perforated by the foramen ovale anteriorly and the foramen spinosum posteriorly; in front, it ends in the pterygoid plates, and behind, in the spine of the sphenoid which is an important surgical landmark. Occasionally two smaller foramina exist as well: the foramen of Vesalius (medial to the foramen ovale) and the innominate foramen (posterior to the foramen ovale).

The medial pterygoid plate projects back from the lateral margin of the choanal opening, where it articulates with the vertical plate of the palatine bone. Inferiorly, it ends in the pterygoid hamulus, superiorly in the pterygoid tubercle which projects back into the foramen lacerum. Halfway up the posterior edge is a spur, from which a ridge runs upwards and laterally towards the opening of the bony eustachian tube, enclosing the concave scaphoid fossa lateral to the pterygoid tubercle.

The lateral pterygoid plate extends back and laterally into the infratemporal fossa. Its only purpose is to give attachment to the pterygoid muscles.
Occipital (muscular) area

The superior nuchal line is a rather faint ridge that runs from the mastoid process to the external occipital protuberance, in a curve concentric with the foramen magnum. Halfway between the superior nuchal line and the foramen magnum, and concentric with them, is another ill-defined ridge, the inferior nuchal line. The external occipital crest separates the two sides of the occipital area, running from the foramen magnum to the external occipital protuberance. Each half is then bisected by a very vague line radiating outwards from the foramen magnum to the superior nuchal line.

Thus each half of the occipital region is subdivided into four areas. The two alongside the foramen magnum receive the recti. The medial area receives the rectus capitis posterior minor, which arises from the posterior arch of the atlas, is supplied by the posterior primary ramus of C1, and acts to extend the head. The lateral area receives the rectus capitis posterior major, which arises from the spinous process of the axis, is also supplied by C1, and acts to extend and rotate the head.

Between the superior and inferior nuchal lines, the medial area receives the semispinalis capitis, which arises from the transverse vertebral processes of C4-C7 and T1-T6, is supplied segmentally by posterior primary rami of the spinal nerves, and is the chief extensor of the head. The lateral area receives the superior oblique muscle, which arises from the lateral mass of the atlas, is supplied by C1, and acts primarily as a lateral flexor of the head; this muscle is covered laterally by the posterior parts of the insertion of splenius and sternomastoid into the superior nuchal line.

Pharyngeal area

Situated centrally in the skull base, this area forms the roof of the nasopharynx, and its boundaries are formed by the line of attachment of the pharyngeal wall. The pharyngeal constrictor muscles do not extend right up to the base of the skull but are attached to it by a rigid membrane, the pharyngobasilar fascia, and it is this which makes up the wall of the nasopharynx.

The pharyngobasilar fascia is attached to the skull base and medial pterygoid plates (that is to the back of the nose), and is thickened posteriorly into a pharyngeal ligament that continues inferiorly as the pharyngeal raphe. It is separated from the prevertebral muscles posteriorly by the prevertebral fascia. The origin of the pharyngobasilar fascia can be traced laterally from the pharyngeal tubercle across the basiocciput, to the petrous temporal bone just in front of the carotid foramen. It then swings anteromedially, its attachment running along the cartilaginous eustachian tube to reach the sharp posterior edge of the medial pterygoid plate, to which it is attached all the way down to the hamulus. The lower edge of the pharyngobasilar fascia lies at the level of the hamuli and hard palate, within the superior constrictor muscle.

It will be seen that the apex of the petrous bone (and the foramen lacerum) lies within a lateral recess of the nasopharynx, the fossa of Rosenmüller. The levator palati muscle arises here and is, therefore, intrapharyngeal, covered medially by mucous membrane. A postnasal carcinoma involving the fossa of Rosenmüller may invade upwards through the foramen
lacerum, sometimes producing a lateral rectus palsy by compressing the sixth nerve where it crosses the apex of the petrous bone and enters the cavernous sinus.

**Tubal area**

The tubal area lies just lateral to the pharyngeal area, and simply comprises the region occupied by the eustachian tube. Anteriorly, it includes the scaphoid fossa at the base of the medial pterygoid plate, from where it runs posterolaterally along the slit that lies between the petrous bone and the greater wing of the sphenoid until the bony eustachian tube is reached just in front of the carotid canal.

The bony part of the eustachian tube is about 1 cm long, and tapers down from the anterior wall of the middle ear to its junction with the cartilaginous part of the tube. This junction, the isthmus, is the narrowest part of the tube and lies just medial to the spine of the sphenoid. The cartilaginous part of the eustachian tube (2 cm long), runs forwards and medially at 45° and downwards at 30°, to open into the nasopharynx by way of a trumpet-shaped orifice attached to the back of the medial pterygoid plate just above the pharyngobasilar fascia. The eustachian tube cartilage is an important landmark in base of the skull anatomy. Along its lateral aspect, a straight line passes from the lateral pterygoid plate along the medial lip of the foramen ovale to the foramen spinosum and into the petrotympanic fissure (Bosley and Martinez, 1986).

The salpingopharyngeus muscle arises from the posterior margin of the tubal orifice and runs vertically down inside the pharynx to be inserted into the posterior border of the thyroid cartilage and the adjacent pharyngeal wall. It is supplied by way of the pharyngeal plexus by the pharyngeal branch of the vagus, and its contraction assists in the opening the tube.

The pharyngobasilar fascia is attached to the undersurface of the tube, and the two 'paratubal' muscles arise one on each side of it. The levator palati arises medially (within the pharynx) and the tensor palati arises laterally (outside the pharynx). Both muscles are partly attached to the tube, and so open it during the act of swallowing. The paratubal muscles are fully described in the section on the parapharyngeal space.

**Neurovascular area**

Posterior to the tubal area lies the neurovascular area, containing the structures of the carotid sheath and styloid apparatus, as well as the facial nerve.

**Carotid sheath**

The carotid sheath itself is not a membranous fascia, but a dense feltwork of areolar tissue that surrounds the internal carotid artery and vagus nerve; it is virtually absent over the internal jugular vein, however, which is thus able to expand greatly during periods of increased blood flow. The carotid sheath is attached to the skull base around the carotid foramen, and continues downwards as far as the aortic arch.
In the neck, the carotid sheath, together with the pretracheal fascia, is firmly attached anteriorly to the deep surface of sternomastoid. Posteriorly, it is not attached to the prevertebral fascia, but is free to slide over it. This means that pus tracking laterally from a parapharyngeal abscess passes behind the sheath and behind the sternomastoid, to point in the posterior triangle.

The *internal carotid artery* passes vertically upwards from the carotid bifurcation in the neck to enter the carotid foramen. It has no branches, but carries with it the carotid plexus of sympathetic nerves from the superior cervical ganglion.

The jugular foramen is divided by two transverse septa of fibrous dura (which may ossify) into three compartments. The anterior compartment is occupied by the ninth cranial nerve and the inferior petrosal sinus; the middle compartment is shared by the tenth and eleventh nerves; and the posterior compartment is filled by the emerging internal jugular vein. The ninth and eleventh nerves lie more laterally than the tenth in the foramen.

The *internal jugular vein* descends from the jugular bulb to lie behind the internal carotid artery on the lateral mass of the atlas; just below the base of the skull, it receives the inferior petrosal sinus. As it descends, it passes across on to the lateral side of the internal carotid artery, receiving tributaries from the pharyngeal plexus of veins, and crossed on its lateral side by the accessory nerve. Also on the lateral side of the vein lie the deep cervical lymph nodes.

The *glossopharyngeal nerve* (IX) lies lateral to the inferior petrosal sinus as it emerges from the anterior part of the jugular foramen. The nerve passes down on the lateral surface of the internal carotid artery and then gently curves forward around the lateral side of stylopharyngeus, medial to the external carotid artery towards the tongue.

The *vagus nerve* (X) emerges from its superior ganglion in the middle compartment of the jugular foramen and runs straight down in the back of the carotid sheath between the carotid artery and jugular vein. Just below the skull base, it is dilated into its inferior ganglion, where it receives a connection from the accessory nerve carrying fibres from the nucleus ambiguus.

The *accessory nerve* (XI) is just lateral to the vagus in the middle compartment of the jugular foramen. It immediately begins to curve away posteriorly across the lateral surface of the internal jugular vein, medial to the styloid process and posterior belly of the digastric, giving a branch to the sternomastoid before piercing the muscle to gain the posterior triangle.

The *hypoglossal nerve* (XII) emerges from the anterior condylar foramen, medial to the carotid sheath, and spirals in a lateral direction behind the vagus between the internal jugular vein and internal carotid artery (that is through the carotid sheath). It then swings forward lateral to the carotid arteries, deep to the styloid muscles and digastric, on its way to the tongue.
The cervical sympathetic trunk lies behind the carotid sheath in front of the prevertebral fascia, just medial to the vagus nerve. It ends superiorly at the superior cervical ganglion.

**Styloid apparatus**

From the tip of the styloid process, the stylohyoid ligament passes downwards and forwards to the lesser cornu of the hyoid bone. All these structures are derived from the second branchial arch cartilage. The stylomandibular ligament is not a distinct structure, but merely a condensation of the deep layer of the parotid fascia between the base of the styloid process and the angle of the mandible almost directly below it.

Three muscles diverge from the styloid process: the stylopharyngeus, the stylohyoid and the styloglossus. All three have a different nerve supply, but all three participate in the mechanism of swallowing.

The stylopharyngeus arises from the deep aspect of the base of the styloid process, slopes down across the lateral aspect of the internal carotid artery, and is inserted into the thyroid cartilage and side wall of the pharynx. It is supplied by the ninth nerve, and elevates the larynx and the pharynx.

The stylohyoid arises from the back of the base of the styloid process, and slopes downwards and forwards to be inserted by two slips (which pass on either side of the intermediate tendon of the digastric) into the base of the greater cornu of the hyoid. It passes lateral to the external carotid artery. It is supplied by the seventh nerve, and elevates and retracts the hyoid.

The styloglossus arises from the front of the styloid process and upper part of the stylohyoid ligament. It crosses lateral to the internal carotid artery and then swings forwards medial to the lingual nerve to reach its insertion into the side of the tongue. It is supplied by the twelfth nerve, and retracts the tongue.

The external carotid artery is closely adjacent to the muscles of the styloid apparatus. It runs up deep to the stylohyoid (and the digastric), but lies superficial to stylopharyngeus and styloglossus, on its way to enter the parotid gland. The retromandibular vein, on the other hand, runs down superficially to all elements of the styloid apparatus.

**Facial nerve (VII)**

The stylomastoid foramen transmits the facial nerve and the stylomastoid artery. As soon as it emerges from the foramen, the facial nerve gives off the posterior auricular nerve (supplying the occipital belly of occipitofrontalis) and a muscular branch (supplying posterior belly of digastric and stylohyoid). It then swings forward into the parotid gland, dividing as it does so into upper and lower divisions which then redivide to form the plexus of the plexus of the pes anserinus within the substance of the gland.
Auditory area

This small area anterolateral to the neurovascular area comprises the steeply sloping face of the tympanic bone, forming as it does the floor and anterior wall of the external auditory canal and middle ear.

At the anteromedial edge of the area lies the petrotympanic fissure of Glaser (already described in the section on the osteology of the temporal bone). This transmits the chorda tympani and anterior tympanic branch of the maxillary artery, and the corresponding veins which drain into the pterygoid plexus.

The *chorda tympani* emerges from the petrotympanic fissure and indents the spine of the sphenoid before joining the lingual nerve 2 cm below the skull base.

Articular area

This area, immediately in front of the auditory area, is the surface on which the head of the mandible articulates (by way of an intervening fibrocartilaginous disc). It is bordered by the attachment of the joint capsule, anteriorly just in front of the eminentia articularis, posteriorly to the squamotympanic fissure, and medially and laterally to the margins of the mandibular fossa.

Infratemporal fossa

The infratemporal fossa lies below the middle cranial fossa, between the ramus of the mandible and the lateral wall of the pharynx.

Its roof is the infratemporal area of the skull base, which is made up by the greater wing of the sphenoid with a small triangular contribution posteriorly from the squamous temporal bone. It has no anatomical floor and continues down into the neck. Anteriorly lies the posterior wall of the maxilla with the pterygomaxillary and inferior orbital fissures; posteriorly, it is bounded by the carotid sheath and styloid apparatus. The fossa is limited medially by the medial pterygoid muscle and interpterygoid fascia, and laterally by the mandible.

The contents of the fossa are the lateral and medial pterygoid muscles, the maxillary artery and its branches, the pterygoid venous plexus and maxillary veins, and the branches of the mandibular nerve.

*Lateral pterygoid muscle*

This muscle arises from two heads: the upper head from the whole infratemporal surface of the skull, and the lower head from the outer surface of the lateral pterygoid plate. The heads converge posteriorly into a tendon which is inserted into the pterygoid pit at the medial end of the mandibular condyle. It is supplied by the fifth nerve (mandibular division), and acts in opening the mouth by pulling the condyle forwards onto the eminentia articularis.
Medial pterygoid muscle

The medial pterygoid arises from the medial surface of the lateral pterygoid plate and the fossa between the two plates; a small slip joins from the tuberosity of the maxilla and tubercle of the palatine bone. It passes outwards, down and back at 45° to its insertion into the angle of the mandible. It is supplied by the fifth nerve (mandibular division), and acts to close the mouth and move the mandible towards the opposite side in chewing.

Maxillary artery

The external carotid artery has two terminal branches, the superficial temporal and the maxillary. The maxillary artery enters the infratemporal fossa between the sphenomandibular ligament and the neck of the mandible, and passes forward either lateral or medial to the lateral pterygoid muscle. If it takes the medial course, the artery then turns laterally again to emerge between the two heads of the muscle. It leaves the infratemporal fossa through the pterygomaxillary fissure to enter the pterygopalatine fossa.

The artery is traditionally described in three parts: before, on and beyond the lateral pterygoid muscle, with five branches coming from each part. From the first and third parts, the five branches all enter foramina in bones; from the second part, none of the branches go through bony foramina (Last, 1973).

The first part gives off the inferior alveolar, middle meningeal, accessory meningeal, deep auricular and anterior tympanic arteries. The inferior alveolar artery passes down to join the inferior alveolar nerve and enter the mandibular foramen. The middle meningeal artery passes straight up through the foramen spinosum, while the accessory meningeal artery goes through the foramen ovale. The deep auricular artery passes up to supply the external auditory canal, and the anterior tympanic artery enters the petrotympanic fissure on its way to the middle ear (Davies, 1967).

The second part of the maxillary artery gives off five branches to the soft tissues: the lateral and medial pterygoid muscles, the temporalis muscle, the lingual and long buccal nerves.

The third part of the artery divides into the pterygopalatine fossa and will not be described further here.

The pterygoid plexus and maxillary veins

The pterygoid plexus of veins lies within and on the lateral surface of the lateral pterygoid muscle, and receives tributaries corresponding to the branches of the maxillary artery. The plexus drains into two short, large maxillary veins which pass horizontally backwards deep to the neck of the mandible to join the superficial temporal vein and form the retromandibular vein.

The pterygoid plexus has three important communicating veins. The inferior ophthalmic vein pass to it through the inferior orbital fissure; a connecting vein passes
vertically down from the cavernous sinus by way of the foramen ovale or, when present, the foramen of Vesalius; and the deep facial vein runs forward beneath the zygoma to join the anterior facial vein. These connections can allow infection from the face to spread by way of the pterygoid plexus to produce a cavernous sinus thrombosis.

**The mandibular nerve**

The mandibular nerve drops down through the foramen ovale and, after a short course just deep to the upper head of the lateral pterygoid muscle, the main trunk divides into anterior and posterior divisions. Before it does so, the main trunk gives off the sensory nervus spinosus (which re-enters the middle fossa through the foramen spinosum), and the motor nerve to the medial pterygoid, which also supplies the tensor palati and tensor tympani.

The anterior division is motor except for the long buccal nerve. The latter passes between the heads of the lateral pterygoid to swing forwards and downwards on the deep surface of the temporalis muscle, and then pierces the buccinator to supply the mucous membrane of the cheek. The motor branches supply the temporalis, masseter (by a branch which emerges through the mandibular notch) and the lateral pterygoid.

The posterior division is sensory except for the mylohyoid nerve. The auriculotemporal nerve springs from two roots which pass either side of the middle meningeal artery, and passes backwards between the sphenomandibular ligament and neck of the mandible. The inferior alveolar nerve swings downwards on the surface of the medial pterygoid muscle, passes between the sphenomandibular ligament and neck of the mandible, and gives off the mylohyoid nerve before entering the mandibular foramen. The lingual nerve is joined by the chorda tympani 2 cm below the base of the skull and passes downwards and forwards on the medial pterygoid, grooving the mandible before entering the mouth.

The otic ganglion lies close to the mandibular nerve just below the foramen ovale, between the nerve and the tensor palati muscle. It relays secretomotor fibres for the parotid gland, which it receives by way of the lesser superficial petrosal nerve and transmits to the auriculotemporal nerve. The lesser superficial petrosal nerve leaves the middle fossa through the foramen ovale, or sometimes through its own foramen, the foramen innominatum.

**The sphenomandibular ligament**

The sphenomandibular ligament is a fibrous band joining the spine of the sphenoid to the lingula of the mandibular foramen. It is derived from the first branchial arch (Meckel's) cartilage. Anteriorly, it blends into the interpterygoid fascia, which separates the lateral and medial pterygoid muscles, stretching forward as a sheet to be attached to the posterior edge of the lateral pterygoid plate.

**Parotid space**

The space enclosed within the capsule of the parotid gland lies partly superficial to the mandible, and extends through the retromandibular space behind the infratemporal fossa to abut against the parapharyngeal space. The parotid space is described in Chapter 9.
Parapharyngeal space

Prestyloid compartment

This compartment contains the two palati muscles, and two arteries, the ascending palatine and ascending pharyngeal.

The tensor palati muscle arises from the skull base in a line from the scaphoid fossa along the edge of the greater wing to the spine of the sphenoid, and is also attached to the lateral side of the eustachian tube. It tapers down to a tendon which takes a right-angled turn around the hamulus to enter the pharynx, where it broadens into a flat aponeurosis; this triangular sheet blends with its counterpart on the opposite side and is attached to the posterior edge of the hard palate (the crest of the palatine bone). It is supplied by the fifth nerve by way of the nerve to the medial pterygoid. The action of this muscle is to tense the palate so that other muscles can raise and lower it.

The levator palati muscle arises from the petrous apex anterolateral to the carotid foramen and from the medial end of the tubal cartilage, and is inserted into the upper surface of the palatal aponeurosis. Supplied by the tenth nerve by way of the pharyngeal plexus, it acts to raise the soft palate and close off the nasopharynx.

The ascending palatine artery, a branch of the facial artery, ascends close to the pharyngeal wall to supply the soft palate and tonsil.

The ascending pharyngeal artery, a branch of the external carotid artery, ascends a little more posteriorly along the superior constrictor to supply the pharynx, the middle ear and the meninges. Often it is a major feeding vessel to a glomus tumour.

Retrostyloid compartment

This corresponds to the neurovascular space, and contains the carotid sheath (see previous section).

Structures within the skull base

The internal carotid artery curves forwards in the petrous bone from the carotid foramen, and then curves upwards into the upper part of the foramen lacerum in the middle fossa, emerging at the apex of the petrous bone and immediately entering the cavernous sinus. It lies in front of the cochlea and middle ear cavity, separated from the middle ear and eustachian tube by a thin plate of bone which may be dehiscent. It gives off some small intrapetrous branches, including the carotico-tympanic artery, which may enlarge as feeding vessels for a glomus tumour.

The jugular bulb is the point at which the sigmoid sinus feeds into the upper end of the internal jugular vein. It usually lies below the posterior part of the floor of the middle ear, although its bony covering may be dehiscent, with only mucosa separating it from the middle ear cavity. However, its position is extremely variable and it may intrude right up into the
middle ear ('high jugular bulb') (Graham, 1977). The inferior petrosal sinus joins the jugular bulb at the skull base; it emerges from the skull in the anterior part of the jugular foramen and crosses either lateral or medial to the ninth, tenth and eleventh nerves to enter the bulb. It is variable and may consist of three or more channels (Goldenberg, 1984).

The internal carotid artery diverges from the jugular bulb beneath the middle ear, leaving a wedge of bone between the two vessels which is clearly shown on lateral hypocycloidal polytomography. Erosion of this ‘keel’ of bone is an early finding in patients with a glomus jugulare tumour.

The paths of the ninth, tenth and eleventh cranial nerves in the jugular foramen, and of the twelfth nerve at this level, have already been described (see subsection on the carotid sheath).

The greater superficial petrosal nerve enters the foramen lacerum from the middle fossa and is joined there by the deep petrosal nerve, which is a branch of the sympathetic carotid plexus. The two nerves unite to form the nerve of the pterygoid canal (vidian nerve) which leaves the foramen lacerum in the pterygoid canal and runs forward to the pterygopalatine ganglion.

The tympanic branch of the ninth nerve (Jacobson’s nerve) leaves the glossopharyngeal nerve at the petrous ganglion and passes through a canaliculus in the keel of petrous bone between the jugular and carotid foramina to supply the middle ear (tympanic plexus).

The auricular branch of the tenth nerve (Arnold’s nerve) passes behind the internal jugular vein and enters the mastoid canaliculus on the lateral wall of the jugular foramen, from which it emerges by way of the tympanomastoid fissure to supply the skin of part of the external auditory meatus.

The anatomy of the ear within the petrous temporal bone is described in Chapter 1.

**Muscles superficial to the lateral skull base**

Four muscles lying laterally, superficial to the base of the skull, are important in achieving surgical exposure of the area, and are, therefore, briefly described in the following.

The masseter muscle arises from the zygomatic arch and is inserted into a wide area on the lateral aspect of the mandible from the angle forwards along the lower border, and upwards over the lower part of the ascending ramus. It is supplied by the fifth nerve by way of the masseteric branch from the anterior division of the mandibular nerve, and its action is to close the jaws.

The temporalis muscle arises from the temporal fossa on the side of the skull, and from this large origin it converges in the shape of a fan to be inserted into the coronoid process of the mandible, mainly on its inner surface. It is supplied by the fifth nerve by way of the deep temporal branches of the anterior division of the mandibular nerve. It acts to close the jaws, and its posterior fibres also retract the mandible.
The **sternomastoid muscle** arises from two heads: from the manubrium and clavicle. It is inserted into a curved line extending from the tip of the mastoid process to the superior nuchal line of the occiput. It is supplied by the eleventh nerve and its main action is to protract the head (moving it forwards while keeping it vertical with a horizontal gaze).

The **digastric muscle** arises from the digastric notch on the medial surface of the mastoid process. This posterior belly narrows into an intermediate tendon which passes through a fibrous sling on the hyoid near the lesser cornu, and then expands into the anterior belly which runs beneath the mylohyoid to its insertion into the digastric fossa on the lower edge of the mandible. The posterior belly is supplied by the seventh nerve (nerve to digastric) and the anterior belly by the fifth nerve (mylohyoid nerve). Its action is to depress and retract the chin.

**Anatomical principles of the lateral surgical approach to the skull base**

Several different surgical approaches have been employed in order to reach lesions in the rather inaccessible region of the skull base (Sasaki, McCabe and Kirchner, 1984). However, it is the lateral approach that has recently become established as the approach of choice for most surgeons who work in this area (Goldenberg, 1984).

The main difficulty in creating adequate exposure has been the long, tortuous course of the facial nerve, which prevents direct access. However, the technique of anterior transposition of the nerve demonstrated by Fisch (1977) has provided the access necessary for control of the internal carotid artery and internal jugular vein, and so has permitted satisfactory exploration of the skull base from the lateral approach. Fisch has developed three variants of this lateral approach, which he loosely terms the ‘infratemporal fossa approach’ (Fisch, 1984).

The type A approach provides access to the temporal bone right up to the petrous apex. The type B involves a more anterior approach which allows dissection to proceed across the petrous apex to the basiocciput and clivus. The type C approach takes the exposure even further forward, allowing the surgeon to remove lesions in the nasopharynx and parasellar region.

**Type A approach**

This technique is employed primarily for the removal of glomus jugulare tumours, and involves the now classic manoeuvre of anterior facial nerve transposition.

A long postaural incision is extended down into the neck, and if necessary up into the temporal region. The dissection begins in the neck with identification of the great auricular nerve where it lies on the surface of the sternomastoid; it is preserved for later use as a facial nerve graft, if needed. The accessory nerve is identified where it emerges from the posterior border of the sternomastoid, and the carotid sheath is then exposed. Control tapes are passed round the external and internal carotid arteries, and the ascending pharyngeal and occipital arteries are identified; the latter are usually major feeding vessels for the tumour and may, therefore, need ligation.
The internal jugular vein is ligated and divided at the level of the carotid bifurcation, elevated and dissected up towards the jugular foramen.

The hypoglossal nerve is identified as it crosses lateral to the external carotid artery. The sternomastoid is divided at its insertion into the mastoid tip, preserving and tracing out the accessory nerve as the muscle is turned down. The internal jugular vein can then be dissected right up to the skull base, where cranial nerves IX, X, XI and XII are identified at the jugular foramen, and the internal carotid artery is exposed as it enters the carotid canal.

The intratemporal part of the operation can not commence, as a widely bevelled cortical mastoidectomy with transection of the cartilaginous external auditory canal, which is closed by suture as a blind-ending sac. The vertical portion of the facial nerve is identified, and the posterior bony canal wall is taken down with removal of the mastoid tip. The tympanic membrane, malleus and incus are removed, and the tympanic bone in the anterior hypotympanum is drilled away to expose the lateral aspect of the jugular bulb. The facial nerve is mobilized from the geniculate ganglion to its division in the parotid, and is then transposed anteriorly into a new fallopian canal created in the anterior attic. The sigmoid sinus can then be exposed with the drill from the sinodural angle downwards and anteriorly to the jugular bulb; the sinus is then either packed or ligated superiorly.

The next step is obliteration of the eustachian tube at the isthmus. In the case of a large tumour extending forwards into the carotid canal, the internal carotid artery must next be identified at the medial wall of the protympanum, and its intratemporal portion exposed by further removal of tympanic bone. Fisch then breaks off the styloid process and introduces a special infratemporal fossa retractor to displace the ascending ramus of the mandible forward, and permit separation of the anterior pole of the tumour from the internal carotid artery. The caroticotympanic artery usually feeds the tumour and requires coagulation.

The superior and posterior tumour poles are then separated from the otic capsule and posterior fossa dura. Separation from posterior fossa dura is achieved by opening the ligated sigmoid sinus and following its lumen down to the tumour.

Finally, the inferior pole of the tumour is approached at the jugular foramen and separated from cranial nerves IX, X, XII and XII. The whole jugular bulb can then be removed together with the tumour. There is brisk haemorrhage from the inferior petrosal sinus, which is packed and obliterated.

Large glomus jugulare tumours with intradural extension demand a neurosurgical approach to remove the intradural portion of the lesion once the extradural part has been excised.

**Type B approach**

For exposure of the clivus to remove a chordoma or petrous apex cholesteatoma, the type A approach is extended forward into the infratemporal fossa. Anterior facial nerve transposition may not be necessary, but its frontal branch must be dissected free from the parotid as far forward as the lateral rim of the orbit, permitting it to be displaced inferiorly.
The zygomatic arch is divided at each end. The temporalis muscle is then raised off the squamous temporal bone and reflected downwards together with the zygomatic arch and attached masseter. The bone of the glenoid fossa is drilled away to expose the temporomandibular joint, and this allows the mandibular condyle to be displaced inferiorly using the Fisch infratemporal fossa retractor. Some surgeons prefer to divide the ascending ramus of the mandible in order further to improve access.

The horizontal segment of the intratemporal portion of the internal carotid artery is exposed by drilling away the tympanic bone lateral and anterior to it. The cartilaginous eustachian tube is detached, and drilling may then proceed through the petrous apex to the foramen lacerum.

The middle meningeal artery is identified, coagulated and divided where it enters the foramen spinosum just anteromedial to the spine of the sphenoid. The mandibular nerve is identified next as it exits through the foramen ovale; this is readily done by following the posterior edge of the lateral pterygoid plate up to the skull base, where it leads directly to the foramen.

For extensive lesions of the basiocciput, it may be necessary to section the mandibular nerve and drill away the pterygoid tubercle. The tensor palati and cartilaginous eustachian tube are displaced inferiorly to complete the exposure.

**Type C approach**

This approach can be employed for very anteriorly placed lesions in the nasopharyngeal, parasellar, retromaxillary and paratubal regions. A subtotal petrosectomy is carried out as for the type A and type B approaches, but anterior transposition of the facial nerve is not required.

The surgery is completed as for a type B approach, and then continues with detachment of the upper head of the lateral pterygoid to expose the lateral pterygoid plate. Both pterygoid plates are removed and the maxillary nerve is sectioned at the foramen rotundum. The internal carotid artery can then be followed upwards as far as the cavernous sinus. Next, the pterygopalatine fossa is entered and, after division of the vidian nerve, the maxillary sinus, nasopharynx and sphenoid sinus may be exposed.