1 The Temporal Bone

Contents

Due to its multiple embryological origins and its adverse developmental aspects, the temporal bone is considered as one of the most complex anatomical structures of the human body. Since the middle ear lodges inside the temporal bone, this chapter will be mostly oriented, not to study the temporal bone as such, but to address it in a specific and restricted scope aiming to describe precisely the developmental and anatomical environment in which the middle ear achieves its final architecture.

The temporal bone houses various cranial nerves and inhabits different important vascular structures and many sensorineural organs in close contacts. Our target will be to demonstrate the richness of such critical structures along with their relationships around and inside the middle ear.

1.1 Embryology of the Temporal Bone

Temporal bone formation results from the fusion and growth of four bones: the squamous, the petrous, the tympanic bones, and the styloid bones. These bones interact to build up the final temporal bone.

Being a part of the skull, temporal bone development is an integral part in the process of skull development. Human skull is developed from three components:

1. *The cartilaginous neurocranium* or *chondrocranium* is the part of the skull formed by endochondral ossification; it constitutes the

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majority of the skull base (ethmoid bone and portions of the occipital, temporal, and sphenoid bones). Endochondral ossification takes place in a cartilaginous anlage; chondroblasts become hypertrophied and progressively change into osteoblasts, which elaborate the bony matrix. The corresponding area is the "ossification center."

2. *The membranous neurocranium or neuroskull* is the part of the skull formed by intramembranous ossification; it constitutes the vault of the skull (frontal, parietal portions of the temporal, occipital, and sphenoid bones). Intramembranous ossification happens when a cluster of mesenchymal cells in a membranous structure gives rise to osteoblasts, in the absence of any cartilaginous matrix.
3. *The viscerocranium or visceroskull* is the part of skull derived from the branchial arches and is suspended to the rest of the cranium [1]. It includes the facial bones.

These three components of the skull contribute actively in the formation of the temporal bone in the following way:

The deep part of the petrous bone is derived from the cartilaginous neurocranium, but the more superficial parts are derived from the membranous neurocranium. The squamous bone is derived from the membranous neurocranium, and the tympanic bone is a part of the visceral skull [2].

1.1.1 Cartilaginous Neurocranium

The majority of the skull base develops from the cartilaginous neurocranium. The formation of the human skull base is a complex process that begins during the fourth week of fetal development. Neural crest cells and paraxial mesoderm derived from occipital somites migrate to sit between the emerging brain and foregut. These cells migrate around and in front of the notochord to form condensations accumulating within the emerging cranial base. The chondrocranium begins to form when these cells condense into cartilage early in the seventh week; these cells are named parachordal cartilages and contribute to the creation of the basal plate.

These parachordal cartilages give rise to the body, greater and lesser wings of the sphenoid bones as well as the perpendicular plate of the ethmoid and the *crista galli*. These embryonic cartilages fuse around the existing cranial nerves and blood vessels to create the primordia of neural foramina [3].

1.1.1.1 The Cartilaginous Otic Capsule

Between the eighth and ninth week of gestation, the cartilaginous otic capsule appears as budge in the base of the cartilaginous cranium. It develops from the mesenchymal tissue that surrounds the otic vesicle. Later the otic capsule becomes surrounded by membranous layers (internal and external periosteal layers); these layers will become the extracapsular part of the petrous bone [3] (Fig. 1.1).

Shortly after this process, the lateral and superior boundaries of the otic capsule begin to appear with the earliest development of the mastoid process and tegmen tympani [4]. A cartilaginous flange grows from the lateral and superior part of the otic capsule and goes downwards and outwards superior to the tubotympanic recess and above the Meckel's cartilage to form the tegmen tympani and the lateral wall of the eustachian tube (ET) (Fig. 1.2) (see Sect. 2.4.1). Thus, the tympanic cavity and the bony part of the ET originate from the petrous bone. Furthermore, from the lateral and inferior part of the cartilaginous otic capsule, another flange grows below the tubotympanic recess to form the jugular plate and the floor of the tympanic cavity. Anteromedially, another periosteal layer grows to form the petrous apex (Fig. 1.2).

By the 16th week, the labyrinth reaches its adult size. Only at this time, the first part of the petrous bone starts to ossify by the endochondral ossification process. There are 14 different ossification centers in the otic capsule, which progressively fuse during the fetal period [4].

The ossification proceeds and continues in the remaining part of the petrous bone to gain its final aspect by about midterm. By the 23rd week of gestation, the rest of the ossification process of the extracapsular parts of the temporal bone continues by extension of the surrounding periosteum forming the mastoid process, the tegmen tympani, middle ear floor, and the walls of the Eustachian

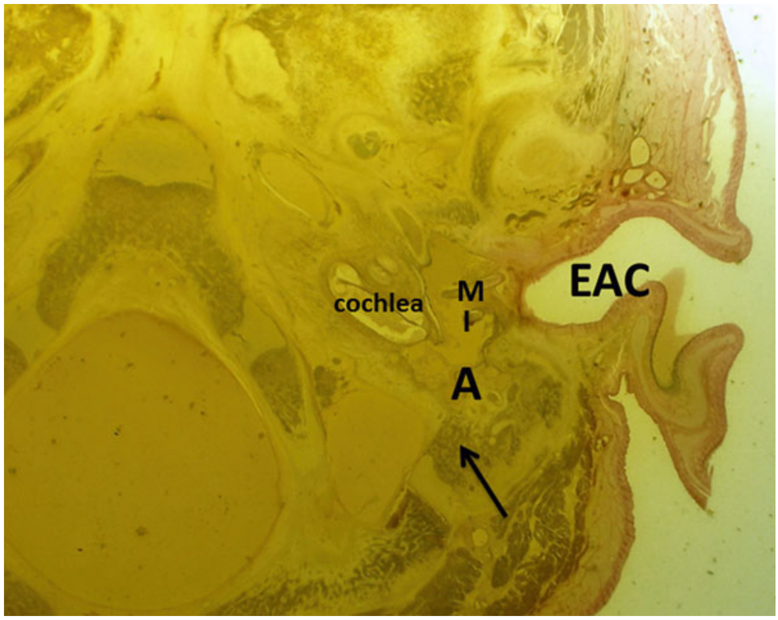

Fig. 1.1 The left temporal bone in a 6 months human fetus. The mastoid area contains external periosteal layer bone (*arrow*), will transform into mastoid bone. Notice that the mastoid antrum (*A*) and the cochlea are already developed. *M* malleus, *I* incus, *EAC* external auditory canal

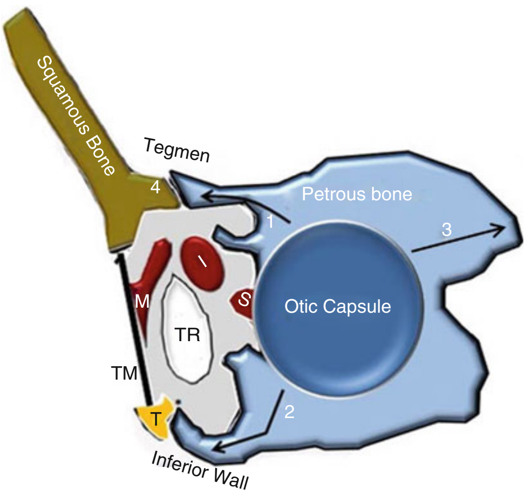

Fig. 1.2 Schematic drawing, frontal plane (34-week-old fetus). Schema showing the cartilaginous flanges running out from the otic capsule: (*1*) lateral and superior flange or the tegmental plate growing from the otic capsule superior to the tubotympanic recess (*TR*) to form part of the tegmen tympani and the walls of the Eustachian tube; (*2*) lateral and inferior cartilage flange, growing from the otic capsule to form the jugular plate and the floor of the tympanic cavity; (*3*) anteromedial flange growing from the otic capsule anteromedially to form the petrous apex. The inferior wall of the middle ear is built up by the inferior plate of the petrous bone (*2*) which runs laterally to join the tympanic bone (*T*); the plane of fusion constitutes the hypotympanic fissure(*). The tympanic bone (*T*) and the tympanic membrane (*TM*) form the lateral wall of the middle ear cavity. The tegmen tympani is formed by fusion of the tegmental process of the petrous bone (*2*) and the transverse plate of the squamous bone (*4*). *M* malleus, *I* incus, *S* stapes

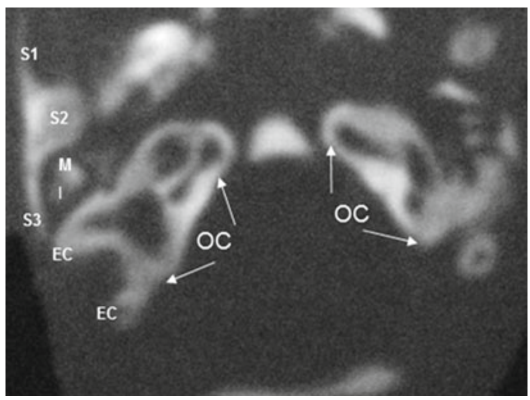

Fig. 1.3 Transversal CT scan of a 22-week-old fetus, showing ossification of the otic capsule (*OC*) and beginning of the ossification process in the extracapsular parts of the petrous bone (*EC*) extending to form the mastoid process. The inferior part of the squamous bone with its three parts: *S1* anterior part forming the zygomatic process, *S2* middle part forming the roof of the EAC and part of the tegmen, *S3* the posterior part forming the anterior part of the mastoid process. Also notice that the petrous bone and the squamous bone are not yet fused. *M* malleus, *I* incus

tube (Figs. 1.2 and 1.3). The floor of the middle ear ossifies between the 24th and 29th week from an extension of the jugular plate ossification center [5]. Ossification of the otic capsule is completed only shortly before birth [5].

A delay or a focal lack of the ossification process may explain the dehiscence of the superior semicircular canal [6, 7].

1.1.2 Membranous Neurocranium and the Squamous Bone

The squamous part of the temporal bone develops from intramembranous ossification; it is formed from one ossification center that appears during the eighth week of gestation [8]. The development of the upper and lower halves of the bone primordium differs:

The upper part is flat and thin and will become the vertical portion.

The lower part, due to the presence of the tympanic bone by the 16th week, bulges and grows rapidly into three directions (Fig. 1.2):

1. *The anterior part* extends anteriorly around the tympanic ring towards the zygomatic bone primordium. It is fixed to the anterosuperior part of the tympanic bone. It forms the zygomatic process of the squamous bone and is involved in the formation of the roof of the temporomandibular joint.
2. *The middle part* sinks medially above the tympanic ring to form the superior wall of the external auditory canal, the attic outer wall, and the lateral part of the tegmen tympani [9].
3. *The posterior part* extends posteriorly behind the tympanic ring to cover a major part of the base of the petrous bone. It forms the anterior portion of the mastoid process.

1.1.3 The Viscerocranium

1.1.3.1 The Styloid Process

The styloid process derives directly from the Reichert's cartilage of the second branchial arch. It develops from two parts:

- The proximal part or the base, also named the tympanohyale, is situated close to the tympanic bone. Its ossification center appears before birth and continues to grow until the age of 4 years. It fuses with the petromastoid component during the first year of life [10].
- The distal part, the stylohyale, starts its ossification only after birth. It fuses with the proximal part only after puberty.

1.1.3.2 The Tympanic Bone

The tympanic ring is a C-shaped bone that provides physical support to the tympanic membrane. It is formed by intramembranous ossification (Fig. 1.4).

At the eighth week of gestation, the tympanic ring appears as a condensation in the cephalic part of the mandibular part of the first branchial arch, which is situated ventral to the first pharyngeal cleft and lateral to Meckel's cartilage. This condensation will extend in a circumferential fashion around the first pharyngeal cleft resulting in the C-shaped structure [11]. Within 2 weeks,

Fig. 1.4 An intramembranous area of ossification (*arrow*) corresponding to the tympanic bone in an E17 mouse embryo (sagittal section, toluidine blue). The cartilaginous primordial of the malleus (*M*) and incus (*I*) are also visible. Tubotympanic recess (*TTR*). Toluidine blue staining at pH4

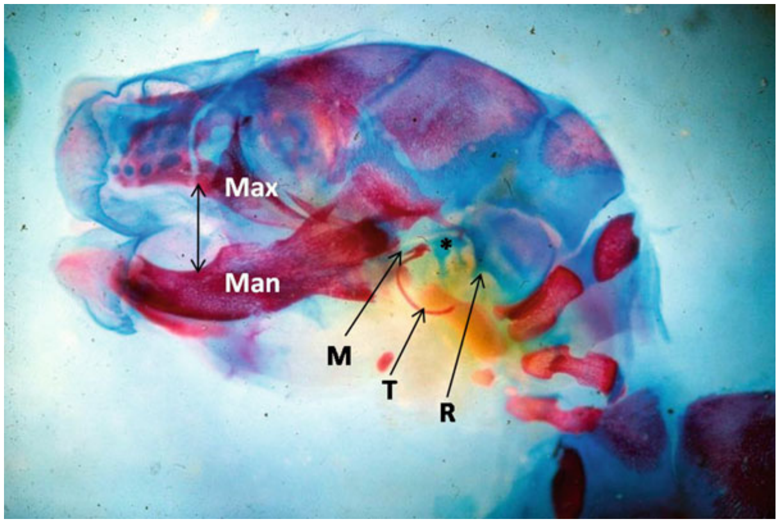

Fig. 1.5 Skeletal staining of a mouse E 16 embryo. In blue, the Meckel's (*M*) and Reichert's (*R*) cartilages appear in close relationship with the ossicles rudiment (*). In red, we can see maxillary (*Max*) and mandibular (*Man*) bones around the oral cavity (*double arrow*). The tympanic ring (*T*) is also red and ossifies following intramembranous process

the ossification is first detected in the part of the condensation adjacent to Meckel's cartilage; then it progresses through the rest of the condensation to form a fully developed tympanic ring that is well recognized by the 11th week of gestation (Fig. 1.5).

At 12th week, growth of the tympanic ring proceeds rapidly with a consequent increase in its overall size. The tympanic ring is never closed superiorly, giving rise to the incisura tympanica (*Rivinus notch*) where the pars flaccida of the tympanic membrane will make insertion.

Fusion of the tympanic ring with the other components of the temporal bone starts first at 31st week in the posterior part. The anteromedial segment of the tympanic bone does not join the temporal bone until 37th week. Its fixation to the temporal bone is complete at birth.

The tympanic bone is 9 mm in diameter at birth, almost its definitive size. At this time, it is ring shaped and is open superiorly [12–16].

The formation of the external auditory meatus and the formation of the manubrium are in close association with the tympanic ring formation [11]. The tympanic ring plays an instructive role for the external auditory canal development. Very likely aural atresia results from the failure of the tympanic ring to develop [17]. In addition, the formation of the tympanic ring is essential for the insertion of the manubrium of the malleus into the tympanic membrane [18]. Several experimental conditions leading to a lack of external auditory meatus formation also result in a severe underdevelopment of the manubrium with a normal aspect of the rest of the malleus. This fact is confirmed in cases of major aural atresia, showing an absence of the manubrium with otherwise normal looking of the rest of the malleus [18, 19].

1.2 Perinatal Changes of the Temporal Bone

By the time the fetus has reached the perinatal period, the squamous and tympanic bones have already fused together; but the resultant segment is still separated from the petrous segment [20]. Early in the perinatal period, these two segments begin to fuse. The fusion of the two segments takes place simultaneously at several locations, beginning with the medial surface of the squamous part to the lateral edge of the tegmental process of the petrous bone. This zone of fusion becomes the internal petrosquamous suture [7]. The fusion continues posteriorly between the petrous and squamous parts of the mastoid process; failure of complete fusion of the two parts leads to formation of a bony septum inside the mastoid process, called Korner's septum [21] (see Sect. 5.1.1). The external petrosquamous suture present on the outer surface of the mastoid process marks the plane of fusion between these two parts.

Finally, the inferior portion of the tympanic ring fuses medially to the inferior process of the petrous bone, thus forming the inferior wall of the tympanic cavity.

1.3 Postnatal Changes of the Temporal Bone

Expansion pressures and antagonist forces exerted by the cephalic neuroskull and the muscular visceroskull, in addition to the pneumatization process, are the main factors for the remodeling process and postnatal changes of the temporal bone.

Bone growth around the tympanic ring following its fusion to the petrous bone proceeds laterally around its circumference. This results in the development of the bony external auditory canal [22]. This lateral extension of the tympanic ring results from the growth of two tympanic tubercles, one from the anterior aspect of the ring and the second from the posterior aspect (Fig. 1.6). These projections grow laterally and then towards each other inferiorly to form the inferior wall of the external auditory canal. By doing so, these projections delimit two openings: the first is in the upper part, the notch of Rivinus, and the second is inferior, the foramen of Huschke [23].

Clinical Pearl
Normally the foramen of Huschke closes by the age of 5 years by additional bone growth. This foramen remains patent in about 7 % of adults; in such cases, the skin of the external auditory canal may invaginate into the residual foramen and migrate under the inferior wall of the external bony canal, leading to the formation of a canal cholesteatoma (Fig. 1.7).

Enclosure of the base of the styloid process occurs simultaneously with the lateral extension of the tympanic bone as well.

In addition, the tympanic ring changes its orientation relative to the rest of the cranium.

At birth, the tympanic ring lies beneath the skull in an almost horizontal plane. By the third month, because of the upward and lateral rotation of the petrous bone caused by a rapid enlargement of the forebrain, the tympanic ring appears on the inferolateral aspect of the skull; few months later, it attains its final near vertical orientation [21].

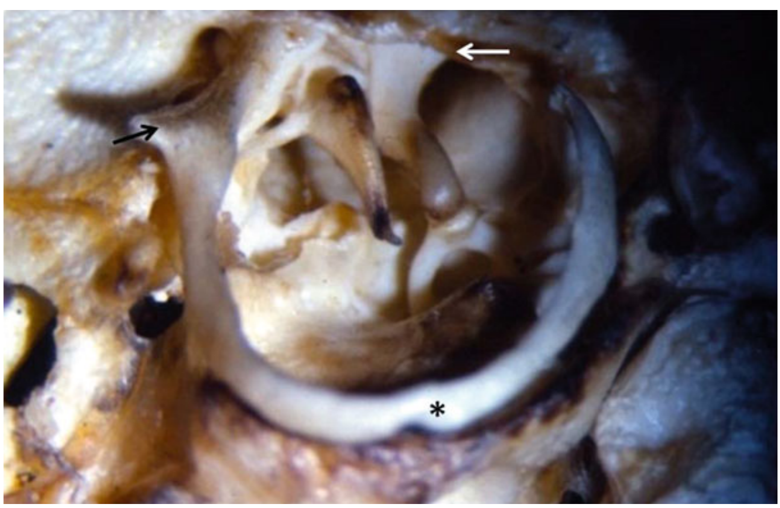

Fig. 1.6 Neonate skull with tympanic annular bone (*) with its anterior tubercle (*white arrow*) and posterior tubercle (*black arrow*). The external auditory meatus is short and ossicles are completely visible

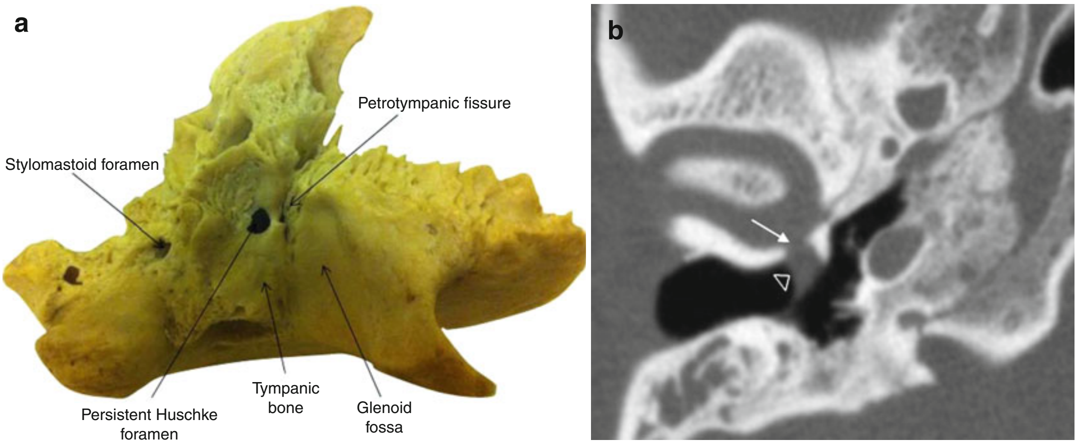

Fig. 1.7 Persistent foramen of Huschke. (**a**) Cadaveric temporal bone, inferior surface, showing a persistent foramen of Huschke. (**b**) Transversal computed tomography of the external auditory canal of a right ear, showing a persistent foramen of Huschke (*white arrow*) with a secondary cholesteatoma (*arrowhead*)

> ***Clinical Pearl***
> Accompanying the change of orientation of the tympanic bone, changes also occur in tympanic membrane orientation. At birth the tympanic membrane is in almost horizontal plane; this explains the difficulty of exposure of the tympanic membrane in newborns during otoscopic examination or paracentesis. As the tympanic ring changes its orientation, the caudal tympanic sulcus is pushed laterally and the tympanic membrane becomes more vertical.

The styloid process does not make its appearance until after birth. It becomes attached to the tympanic bone during its lateral extension. The progression by which the styloid process grows and ossifies is variable, explaining the variable size and shape of the styloid process in adult skulls [24].

The squamous part of the temporal bone grows rapidly along with the cranial vault during the first 4 years of life and continues at a much slower pace until adulthood [7, 20].

The mastoid process is flat at birth. The stylomastoid foramen is superficial with the facial nerve lying on the lateral surface behind the tympanic bone. Due to pneumatization process in the mastoid process, its lateral portion grows downwards and forwards so that the stylomastoid foramen is pushed medially onto the undersurface of the temporal bone (see Sect. 5.1.2).

1.4 Anatomy of the Temporal Bone

The temporal bone, a paired and symmetrical bone, participates in the formation of the base and of the calvarium of the skull. It is formed from the fusion of four different embryological bones: the petrous bone, the squamous bone, the tympanic bone, and the styloid bone.

The temporal bone is a complex anatomical region that is hollowed by cavities and canals that house the audiovestibular structures and permits the passage of nervous, vascular, and muscular elements. The auditory system is disposed on two axes:

- Anteroposterior air axis consisting of the mastoid antrum, the middle ear cavity, and Eustachian tube
- Latero-medial sensorial axis consisting of the external and internal auditory canals

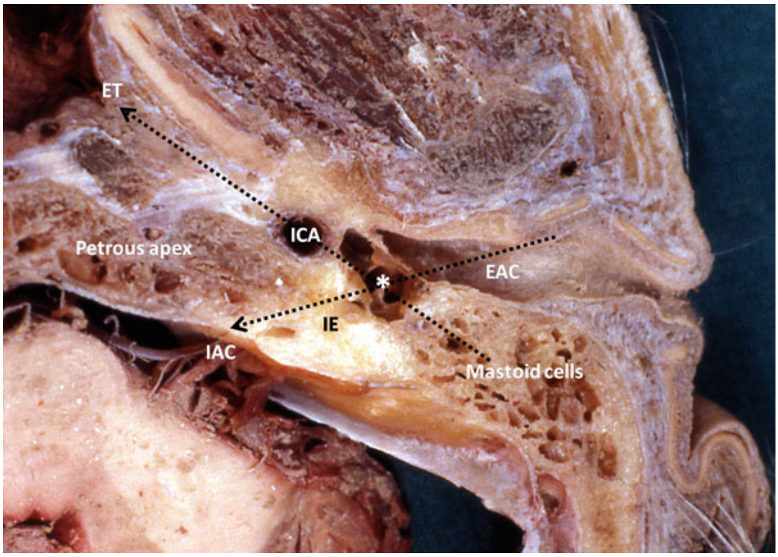

Fig. 1.8 Transverse cut through a left temporal bone showing the middle ear cavity (*) hollowed out in the center of the temporal bone between the external auditory canal (*EAC*) and the inner ear (*IE*). The middle ear lies at the intersection of two axes (*black dotted arrows*), external - internal auditory canal axis and mastoid - Eustachian tube (*ET*) axis. *ICA* internal carotid artery

These two axes intersect at the level of the middle ear cavity (Fig. 1.8).

The temporal bone connects with five other cranial bones: the frontal, parietal, sphenoid, occipital, and zygomatic bone.

1.4.1 The Petrous Bone

Petrous comes from the Latin word "petra" meaning rock; it is the hardest bone of the human skull. It houses the inner ear, the internal carotid artery, the Fallopian canal, and the major part of the middle ear. It results from the ossification of the otic capsule and its flanges.

The petrous bone is shaped like a pyramid that project anteromedially forming a 45° angle with the transverse axis. This pyramid has a posterolateral base (the mastoid) and an anteromedial summit (the petrous apex). It is wedged between the basiocciput and the greater wing of the sphenoid. Its anterosuperior surface is endocranial and participates in the formation of middle cranial fossa floor.

Its posterosuperior surface is also endocranial and forms the anterolateral wall of the posterior cranial fossa. Its inferior surface is exocranial and corresponds to the posteromedial part of the mastoid process.

1.4.2 The Squamous Bone

The squamous bone constitutes the major part of the lateral surface of the temporal bone; it presents a vertical and a horizontal part:

- *The vertical part* is a flat and a thin plate of bone that extends upward to form part of the lateral wall of the middle cranial fossa.
- *The horizontal part* is prolonged anteriorly as the zygomatic process, which originates from two roots: a sagittal posteroexternal root that overhangs the external auditory canal forming its superior part and a transversal anterointernal root that forms the condyle of the temporomandibular joint.

1.4.3 The Tympanic Bone

The tympanic portion of the temporal bone is a gutter-shaped plate of bone. It is situated below the squamous bone between the glenoid fossa anteriorly and the mastoid process posteriorly. The inferior surface of the tympanic bone presents a plate of bone called the vaginal process, which surrounds the styloid process and merges with the petrous bone near the carotid canal.

The tympanic bone forms the anterior, inferior, and posterior walls of the bony external auditory canal. Its attachment to the mastoid and the squamous delineates two suture lines: the tympanosquamous suture anterosuperiorly and the tympanomastoid suture posteroinferiorly. Medially, the tympanic bone articulates with the petrous bone to form the petrotympanic fissure.

The junction between the tympanic bone and the squamous bone superiorly corresponds to the notch of Rivinus.

Medially, the tympanic bone presents a narrow furrow: the tympanic sulcus to which the tympanic membrane annulus is inserted.

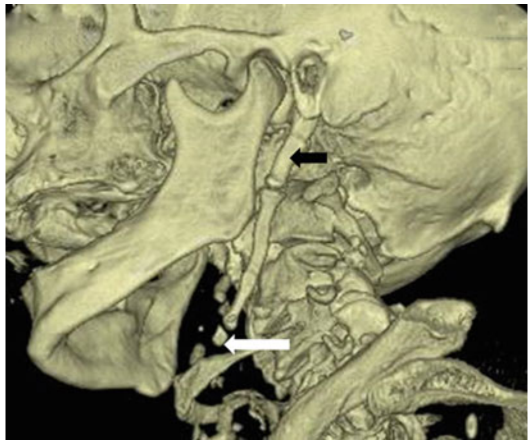

Fig. 1.9 Computed tomography with 3D reformation showing complete ossification of the stylohyoid ligament from the styloid process (*upper arrow*) to its insertion on the hyoid bone (*lower arrow*)

1.4.4 The Styloid Bone

The styloid process is a long, slender, and pointed bone of variable length averaging from 20 to 25 mm. It lies anteromedial to the stylomastoid foramen.

The tip of the styloid bone is located between the external and internal carotid arteries, lateral to the pharyngeal wall, and immediately behind the tonsillar fossa.

Three muscles and two ligaments are attached to the styloid process: the stylopharyngeus muscle, the stylohyoid muscle, and the styloglossus muscle. The stylohyoid ligament extends from the tip of the styloid process to the lesser horn of the hyoid bone and the stylomandibular ligament, which starts under the attachment of the styloglossus muscle and ends on the mandibular angle [10, 22, 25–27].

> ***Clinical Pearl***
> The ossification process of the styloid ligament may involve the whole length of the ligament, giving rise to a bony prolongation between the skull and the hyoid bone; this may manifest clinically by odynophagia, Eagle's syndrome (Fig. 1.9).

1.4.5 Temporal Bone Fissures

Four intrinsic fissures form at the fusion lines of the four bones forming the temporal bone.

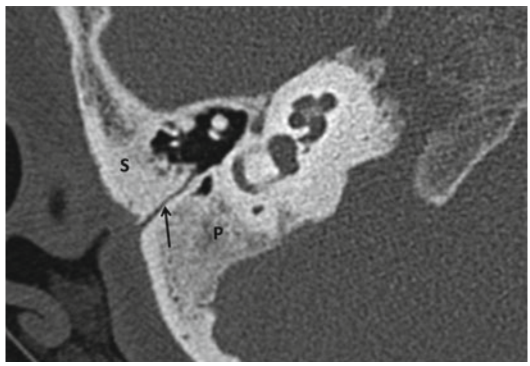

Fig. 1.10 Transversal computed tomography of the right temporal bone of a child with hereditary cleidocranial dysostosis: prominent petrosquamous suture (*black arrow*) that could be misinterpreted as a temporal bone fracture. *S* squamous bone, *P* petrous bone

1.4.5.1 The Petrosquamous Fissure

The petrosquamous fissure or suture connects the petrous bone and the squamous bone and opens directly into the mastoid antrum. It is a narrow fissure and continuous with the petrotympanic fissure.

The external petrosquamous fissure, which links the squamous and the petrous parts of the mastoid process, is sometimes visible on the outer surface of the mastoid process (Fig. 1.10). The internal petrosquamous fissure is located in the tegmen tympani and joins its squamous and petrous portions.

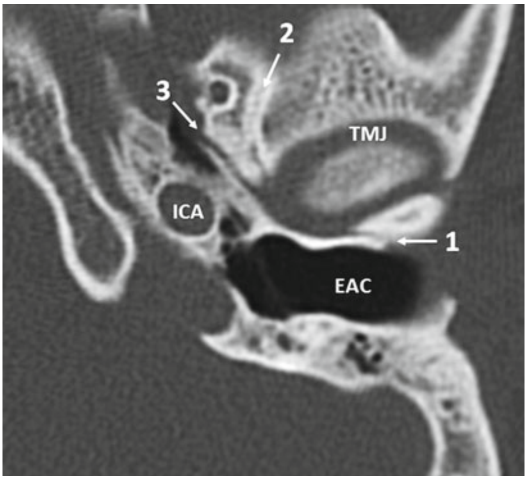

Fig. 1.11 Transversal computed tomography of a left ear, showing the three different sutures appearing with an *Y* shape. They form together the Glaserian fissure. *1* the tympanosquamous fissure, *2* the anterior petrosquamous fissure, *3* the petrotympanic fissure. *ICA* internal carotid artery, *EAC* external auditory canal, *TMJ* temporomandibular joint

1.4.5.2 Tympanomastoid Fissure

The tympanomastoid fissure or suture anchors the tympanic bone to the mastoid process.

This suture is situated in the posteroinferior part of the external auditory canal (see Fig. 1.12).

The auricular branch of the vagus nerve, Arnold nerve, emerges through the tympanomastoid suture to innervate part of the external auditory canal skin.

1.4.5.3 Tympanosquamous Fissure

The tympanosquamous fissure connects the tympanic bone to the squamous bone.

The tympanosquamous fissure is seen in the anterosuperior part of the external auditory canal and continues medially into the petrotympanic and petrosquamous fissures (see Figs. 1.11 and 1.12).

1.4.5.4 The Petrotympanic Fissure

The petrotympanic fissure or Glaserian fissure is situated between the medial aspect of the tympanic bone and the mandibular fossa. It transmits the chorda tympani, the anterior tympanic artery, and the anterior malleal ligament (Fig. 1.11).

> ***Clinical Pearl***
> In the context of trauma, these normal fissures, especially if evident, may be misinterpreted as temporal bone fractures (Figs. 1.10 and 1.11).
>
> The petrosquamous fissure may remain open until the age of 20 years, providing a route for a spread of infection from the middle ear to the intracranial cavity.

1.4.6 Temporal Bone Surfaces

The temporal bone exhibits four surfaces: the lateral, posterior, superior, and inferior surface.

1.4.6.1 The Lateral Surface (Fig. 1.12)

The squama constitutes the major part of the lateral surface of the temporal bone and extends upward as a flat bone to cover part of the temporal lobe of the cerebrum.

The lateral surface of the squama shows a vertical groove for the middle temporal artery and serves as an area of attachment for the temporalis muscle.

The medial surface of squama is grooved for the branches of the middle meningeal artery. Inferior to the squama, the external auditory canal is located. The tympanic bone forms the anterior, inferior, and posterior walls of the bony external auditory canal. The hiatus between the tympanic bone and the squamous bone corresponds to the *notch of Rivinus*. Anterior to the external auditory canal is the temporomandibular joint; a thin bony shell separates them from each other.

Several important landmarks mark the lateral surface of the temporal bone:

- *The mastoid process* refers to the bony process located on the posteroinferior border of the lateral surface of the temporal bone. Two distinct bones contribute to the formation of the mastoid process: the anterosuperior portion is formed by squamous bone and the petrous bone forms the posteroinferior portion. These processes serve laterally for the attachment of the sternocleidomastoid muscle and medially to the posterior belly of the digastric muscle (see Sect. 5.2).

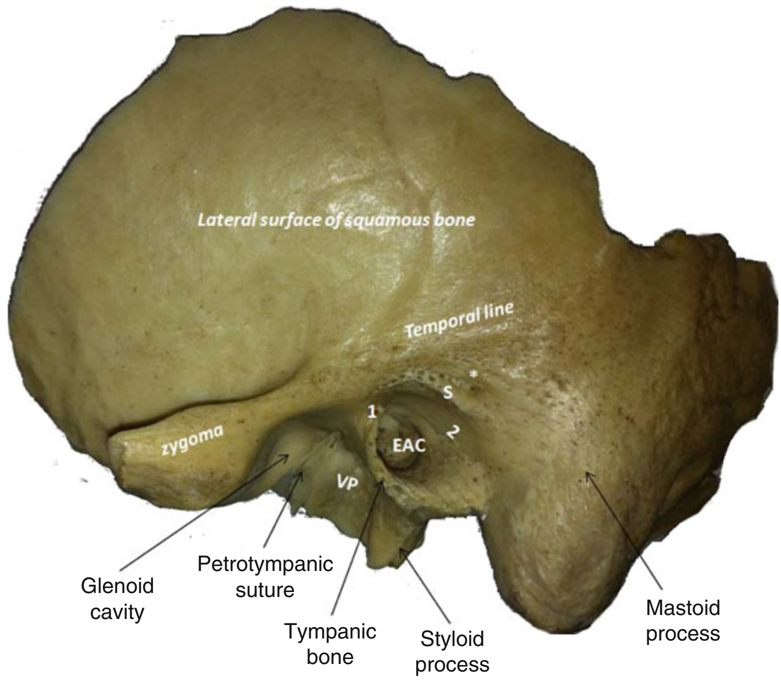

Fig. 1.12 Lateral surface of a left temporal bone. *1* tympanosquamous fissure, *2* tympanomastoid fissure, *EAC* external auditory canal, *S* Henle's spine, * suprameatal triangle, *VP* vaginal process

- *The zygomatic process* originates above the external auditory canal. It leaves the squama and projects anteriorly to unite the zygomatic bone. On the inferior surface of the zygomatic process is the mandibular or glenoid fossa, which accommodates the condyle of the mandible. The anterior limit of the glenoid fossa is demarcated by the articular eminence; the post-glenoid process demarcates its posterior limit. The glenoid fossa communicates with the middle ear through the petrotympanic fissure.
- *The temporal line or supramastoid crest*: posterior to the external auditory canal the zygomatic process prolongs as a faint line or the supramastoid crest. This crest serves for the attachment of the temporal muscle. It is an important landmark for the level of middle cranial fossa dura.
- *Suprameatal Mac-Ewen's triangle*: located between the posterosuperior wall of the external auditory canal and the temporal line. This triangle corresponds medially to the antrum.
- *Henle's spine*: it is a bony spine implanted on the posterosuperior edge of the external auditory canal; it corresponds to the attic medially.
- *The scutum* is a sharp bony spur formed at the junction of the lateral wall of the middle ear cavity and the superior wall of the external auditory canal which is part of the squamous bone.

1.4.6.2 Posterior Surface

The posterior surface of the temporal bone is formed exclusively by the petrous part. It represents the anterolateral wall of the posterior cranial fossa. This surface is limited superiorly by the sulcus for the superior petrosal venous sinus, which separates the superior and the posterior surfaces of the petrous bone. Laterally it presents the sigmoid sinus sulcus and the internal orifice of the emissary vein canal.

The most important feature of the posterior surface is the internal auditory meatus, which lies in the center of this surface midway between the apex and the anterior border of the sigmoid sinus sulcus. An important structure situated at the lateral part of this surface is the endolymphatic sac; this sac lies medial to

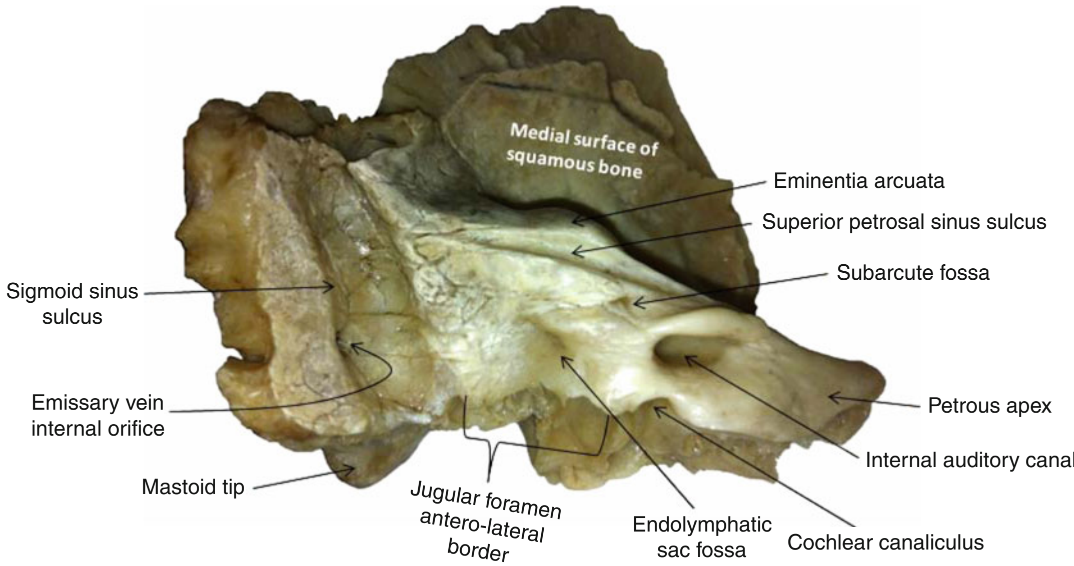

Fig. 1.13 Posterior surface of a left temporal bone

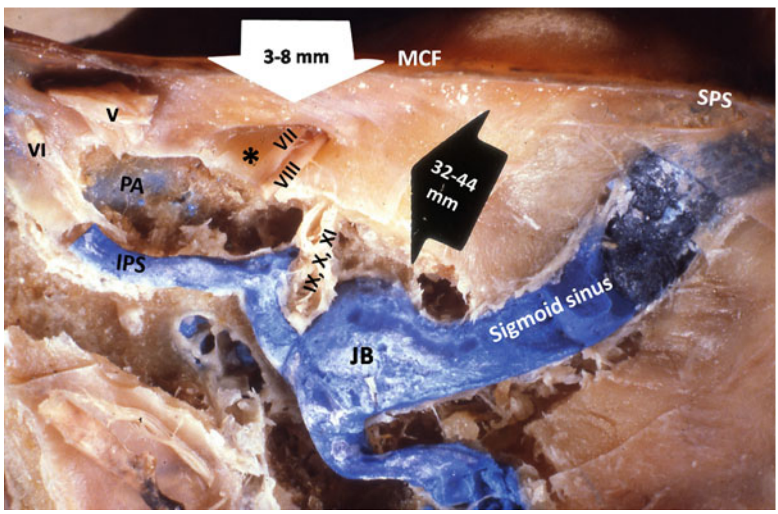

Fig. 1.14 Posterior surface of a right temporal bone showing the relation of the internal auditory canal (*) with the sigmoid sinus (*black arrow*), the middle cranial fossa (*MCF*) (*white arrow*), and the jugular bulb (*JB*). *SPS* superior petrosal sinus, *IPS* inferior petrosal sinus, *PA* petrous apex, *V* fifth CN, *VI* sixth cranial nerve in Dorello's canal, *IX, X, XI* ninth, tenth, and eleventh CN

the level of the posterior semicircular canal (Fig. 1.13).

The average dimensions of the internal auditory canal are 1 cm horizontally and 0.5 cm vertically. The mean distance from the highest border of the jugular bulb to the inferior border of the internal auditory canal is about 0.5 cm [28] (Fig. 1.14). The mean distance from the lateral border of the internal auditory canal to the endolymphatic sac is about 1 cm [29].

Surgical Implications
During retrosigmoid approach for hearing preservation surgery in vestibular schwannoma, drilling of the posterior lip of the internal auditory canal may be necessary in order to remove the intrameatal portion of the tumor. This step carries a risk of injuring the posterior semicircular canal or a high riding jugular bulb.

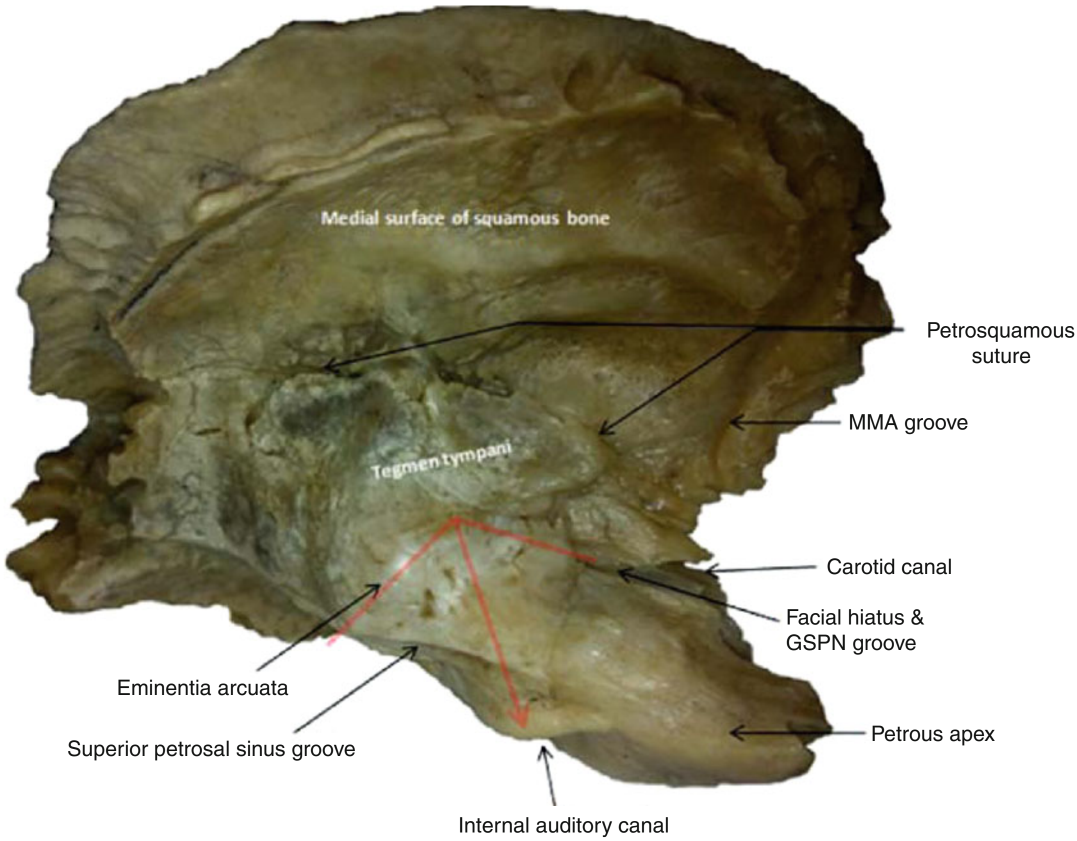

Fig. 1.15 Superior view of a left temporal bone. The red lines represent the relation of the internal auditory canal with respect to the eminencia arcuata and the greater superficial petrosal nerve (*GSPN*), middle meningeal artery (*MMA*)

Based on these measurements mentioned above, 0.5 cm of bone can be safely drilled away from the posterior lip of the canal without injuring any structure.

1.4.6.3 Superior Surface (Fig. 1.15)

The superior surface of the temporal bone forms part of the middle cranial fossa floor; it is limited posteromedially by the superior petrosal sinus sulcus.

The superior surface presents from lateral to medial several structures that serve as important surgical landmarks during middle cranial fossa approach.

Tegmen Tympani

The most lateral part of this surface contains the tegmen tympani, which separates the middle cranial fossa from the middle ear. It is formed partly from the caudal portion of the squamous bone, which extends medially to join the petrous bone. The petrous bone forms the major part of the tegmen. The fusion line of the two bones forms the petrosquamous fissure.

Eminentia Arcuata

The Eminentia arcuata is an important surgical landmark. It lies on the posterior part of the superior surface, near the superior petrosal sinus, about 20–25 mm from the inner tablet of the cranium [30, 31]. It corresponds to the wall of the superior semicircular canal. Usually the posterior aspect of the eminentia arcuata is rotated lateral to the posterior crus of the superior semicircular canal, but the anterior aspect of the eminentia arcuata is located over the anterior crus of this canal [30, 32].

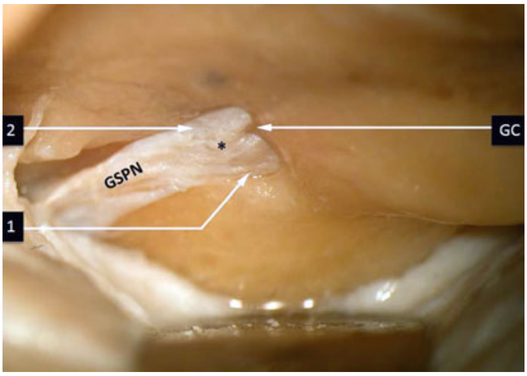

Fig. 1.16 Middle cranial fossa view of a right-side facial nerve. View after drilling off the bone covering the geniculate ganglion (*). G.C., geniculate crest; (*1*) labyrinthine segment of facial nerve; (*2*) tympanic segment of facial nerve (Courtesy of Tardivet [36])

Greater Superficial Petrosal Nerve and Geniculate Ganglion (Fig. 1.16)

The superior surface is marked also by the facial hiatus and the groove of the greater superficial petrosal nerve, which runs from the geniculate ganglion to the middle cranial fossa. The distance from the geniculate ganglion and the inner tablet of the cranium is of 2.7 mm. Two plates of bone form the bony roof of the geniculate ganglion and the proximal part of the greater superficial petrosal nerve bony canal: a medial plate, which is a periosteal derivative of the petrous bone, and a lateral plate, which is a membranous derivative from the squamous bone.

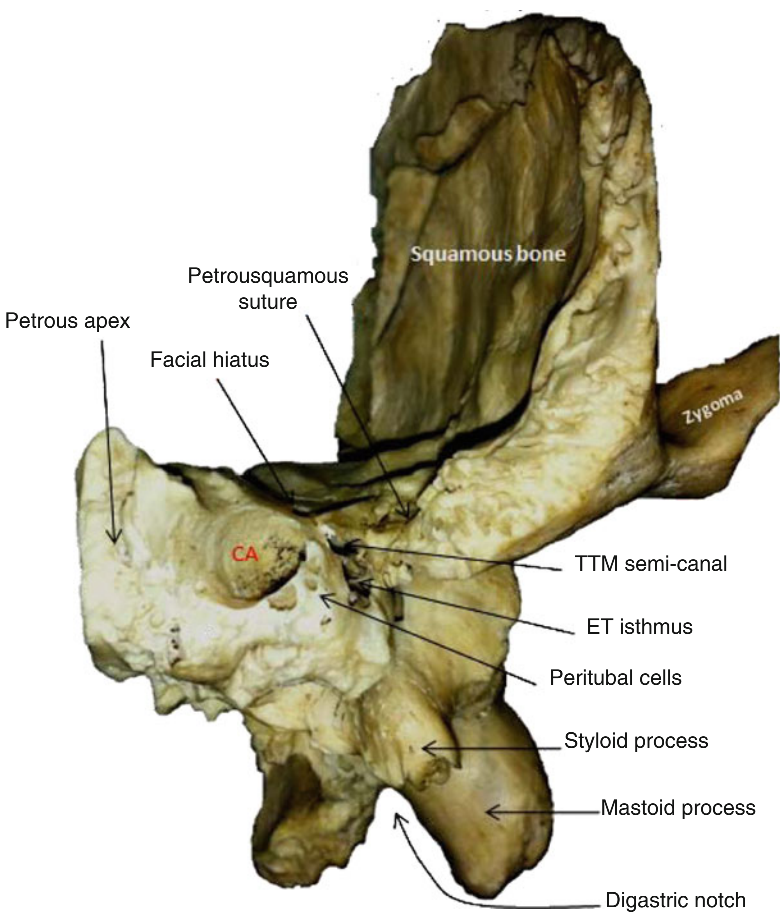

Fig. 1.17 Anteromedial view of a left petrous bone showing the petrous apex and the exit orifice of the carotid canal (*CA*) from the temporal bone anterolateral to the petrous apex. Notice the position of the ET isthmus and the tensor tympani muscle (*TTM*) semicanal lateral to the carotid canal

Surgical Implication
The geniculate ganglion could be dehiscent in 15–20 % of cases. In these cases, the risk of injuring the facial nerve during middle cranial fossa approach is very high while elevating of the dura mater from the superior surface of the temporal bone [30, 33, 34].

In middle cranial fossa approach, the internal auditory meatus is within 3–8 mm distant from the superior border of the petrous bone. The bisection of the angle formed by the greater superior petrosal nerve and the eminence arcuate marks the position of the internal auditory meatus (Fig. 1.14).

The Petrous Apex

The petrous apex is situated in the angular interval between the posterior border of the sphenoid and the basilar part of the occipital bone. The main portion of the apex lies anterior to the cochlea. Through the *apex*, the internal carotid artery exits the petrous bone to the foramen lacerum, which is found between the apex and the sphenoid bone (Fig. 1.17).

1.4.6.4 Inferior Surface (Fig. 1.18)

The inferior surface of the temporal bone represents posterolaterally the inferior part of the mastoid and the digastric notch. Anterior to the digastric notch and posterior to the styloid process is the stylomastoid foramen, from which the facial nerve leaves the temporal bone. Medial to the digastric notch is a shallow groove for the occipital artery.

More anteriorly lies the inferior surface of the tympanic bone, which forms the posterior boundary of the mandibular fossa and expands inferiorly to form the vaginal process.

Anteromedial to the stylomastoid foramen and styloid process is the jugular foramen; it is formed by the petrous bone anterolaterally and the occipital bone posteromedially.

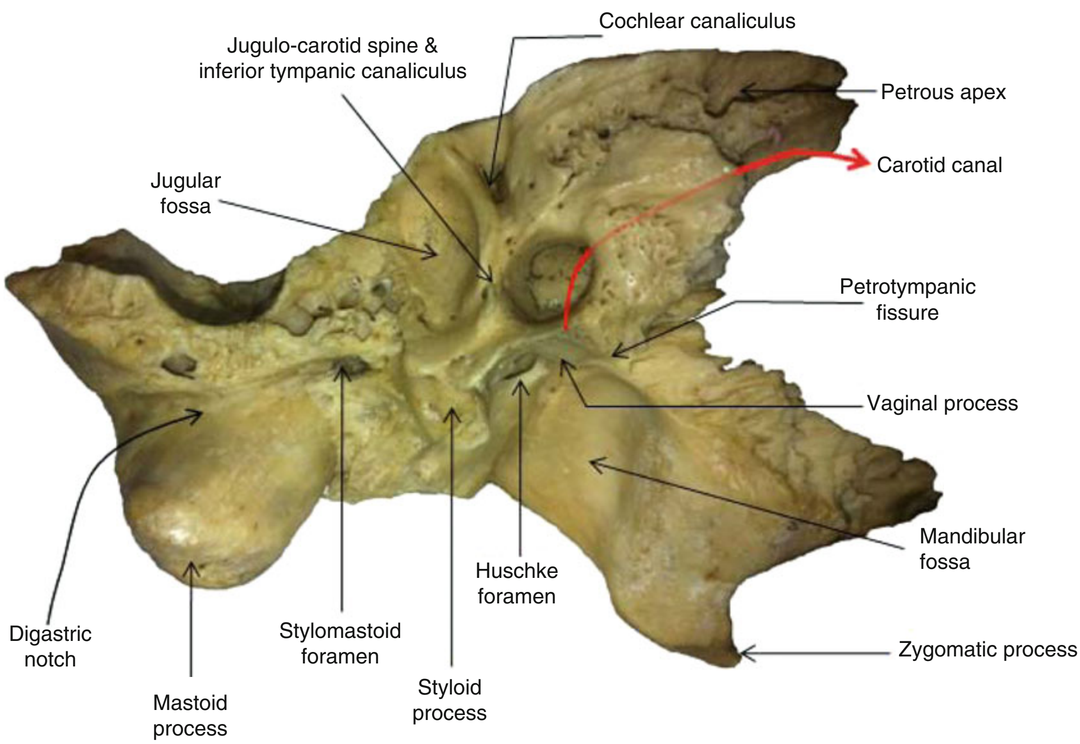

Fig. 1.18 Inferior view of a left temporal bone. The *red arrow* passes through the carotid canal

The jugular foramen is separated by the jugular spine and a fibrous band into two fibro-osseous compartments:

- Pars vascularis: posterolateral vascular compartment, which is larger and receives the internal jugular vein, vagus nerve (CN X) with Arnold's branch, the spinal nerve (CN XI), and posterior meningeal artery
- Pars nervosa: anteromedial nervous compartment, which is smaller and receives the glossopharyngeal nerve (CN IX) with its Jacobson's branch and the inferior petrosal sinus [35]

Posterior to the jugular fossa lies the small canal of Arnold's nerve.

Medial to the jugular fossa, there is the groove of the inferior petrosal sinus and the opening of the cochlear aqueduct.

The foramen of the internal carotid artery lies anterior to the jugular foramen and is separated from its anterior border by the jugulo-carotid spine through which we find a canal for the passage of Jacobson's nerve (IX) to the tympanic cavity.

Medially, near the petrous apex, the inferior surface presents the site of insertion of the levator veli palatini and the cartilaginous portion of the Eustachian tube.

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