2 Middle Ear Cavity

Contents

The middle ear cavity is an irregular air-filled space hollowed out in the center of the temporal bone between the external auditory meatus laterally and the inner ear medially (Fig. 2.1). It lies at the intersection between two important axes: one latero-medial between the external and the internal auditory canals, the other one posteroanterior between the mastoid antrum and the Eustachian tube (see Fig. 1.8).

For descriptive purposes, the tympanic cavity may be considered as a box with four walls, a roof, and a floor. Because of the convexity of the medial and lateral walls, the middle ear cavity is constricted at its center. The width of the middle ear cavity is 2 mm at the center, 6 mm superiorly in the attic, and 4 mm inferiorly in the hypotympanum. In the sagittal plane, the middle ear cleft measures about 15 mm both in the vertical and horizontal directions (Fig. 2.2).

The middle ear cavity is surrounded by six walls: the lateral wall, the inferior wall called the floor or the jugular wall, the posterior called the mastoid wall, the superior wall also called the roof or the tegmen, the anterior wall called the carotid wall, and the medial wall called the cochlear wall.

2.1 Lateral Wall

The lateral wall is formed by the tympanic membrane, the bony tympanic ring and the attic outer wall (Fig. 2.2). This wall of the middle ear cavity,

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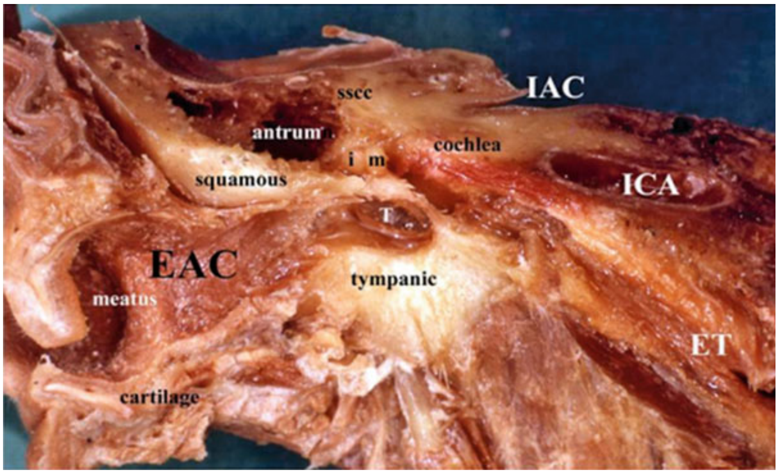

Fig. 2.1 Oblique cut of a right temporal bone. The middle ear cavity lies in the center of the temporal bone between the outer ear (*EAC*) and the inner ear. *T* the tympanic membrane, *i* incus; *m* malleus, *sscc* superior semicircular canal, *ET* Eustachian tube, *IAC* internal auditory canal, *ICA* internal carotid artery

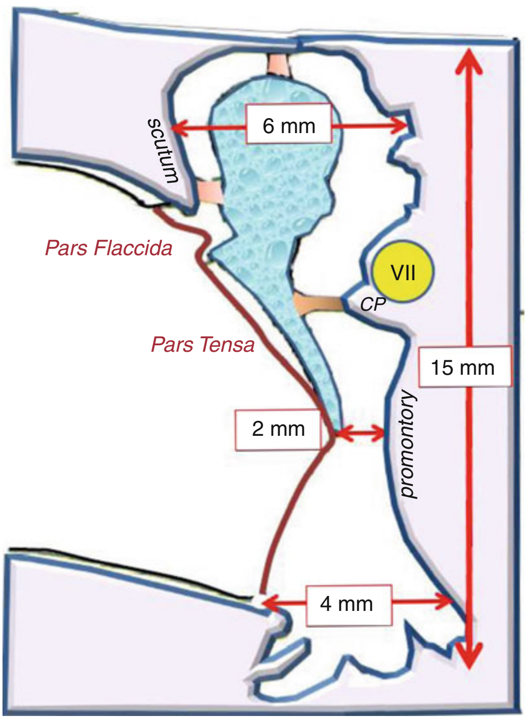

Fig. 2.2 Schematic drawing of the middle ear cavity showing its different dimensions. *VII* facial nerve, *CP* cochleariform process

especially the tympanic membrane, is the only wall accessible to clinical examination and is the site of most middle ear pathologies. In addition, the lateral wall represents the classic entry site to the middle ear during ear surgery.

2.1.1 Embryology of the Lateral Wall

The development of the tympanic bone and membrane starts as early as the fourth week of intrauterine life [1]. A funnel-shaped ectoblastic pouch grows inwards from the first branchial cleft until it reaches an endoblastic pouch growing laterally from the first branchial pouch, known as the tubotympanic recess. The contact between the ectoblastic and the endoblastic pouches is short-living.

By the fifth week of the fetal life and due to the growth of the cephalic extremity with its flexion-extension positions, the region of the future neck creates two types of forces: an expansive force and a depressive force. Under the expansive cephalic flexion, the mesenchyme interposes between the ectoblastic and the endoblastic pouches. At the seventh week this mesenchyme contributes to the formation of the fibrous stratum of the tympanic membrane and the handle of malleus (Fig. 2.3).

At the eighth week, the epithelial cells at the bottom of the ectoblastic pouch proliferate and form a compact epithelial plate reaching the endoblast. Later, this ectoblastic plate gives rise to the bony external auditory canal and the tympanic membrane at its end. When the tympanic membrane appears, it consists already of three layers and has an elliptical form with a horizontal diameter of approximately 2 mm.

At birth the tympanic membrane is in almost horizontal plane. As the tympanic ring changes its

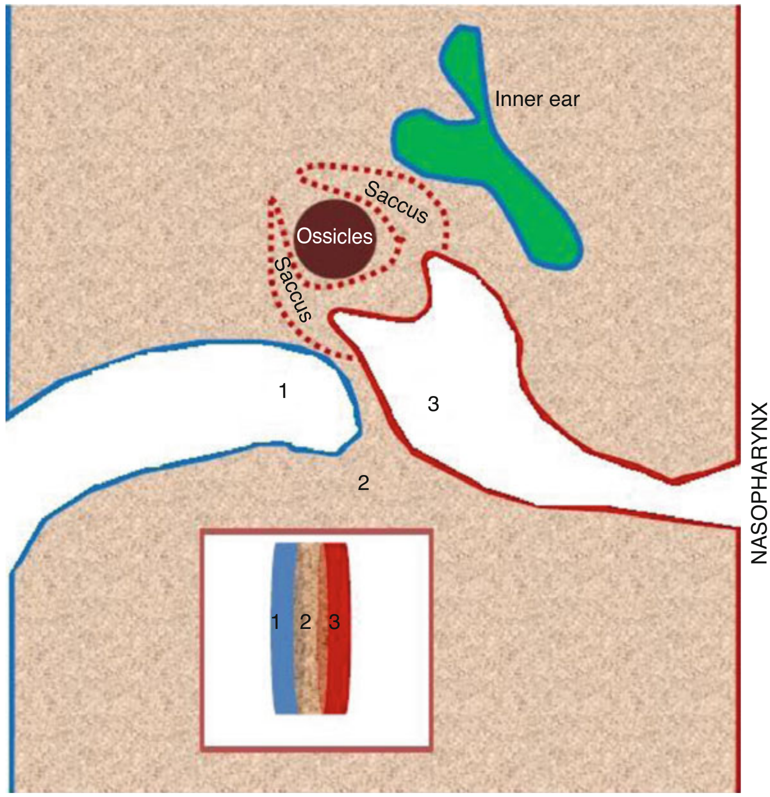

Fig. 2.3 Tympanic membrane formation. The tympanic membrane is formed from the three germ layers, ectoderm (*1*), mesoderm (*2*), and endoderm (*3*)

orientation, the caudal tympanic sulcus is pushed laterally and the tympanic membrane becomes more vertical (see Sect. 1.3). This explains the difficulty of exposure of the tympanic membrane in newborns during otoscopic examination or paracentesis.

> ***Clinical Pearl***
> **Congenital Cholesteatoma**
> Congenital cholesteatoma are residual squamous inclusion cysts that arise from epithelial rests in the middle ear. These epithelial rests are normally seen during fetal development and usually disappear by the third trimester. The failed involution of these epithelial rests leads to a congenital cholesteatoma [2, 3].

2.1.2 Lateral Wall Anatomy

The lateral wall of the tympanic cavity is partly bony and partly membranous. The central portion of the lateral wall is formed by the tympanic membrane and the incomplete tympanic ring to which the membrane is attached. Above the tympanic membrane there is a bony wall forming the attic outer wall.

2.1.2.1 The Attic Outer Wall

The attic outer wall, part of the squamous bone, is the bony lateral wall of the attic. It is a wedge-shaped plate of bone that separates the attic from the zygomatic mastoid cells laterally (Fig. 2.4).

The part of the attic outer wall lying below the plane tracing the roof of the external auditory canal is called the *scutum* (means shield in Latin).

The scutum is a thin sharp bony spur formed by the junction of the attic outer wall and the superior wall of the external auditory canal. The scutum forms part of the superior deep portion of the external meatus and gives attachment to the pars flaccida of the tympanic membrane, which is the lateral wall of the Prussak's space (Fig. 2.4).

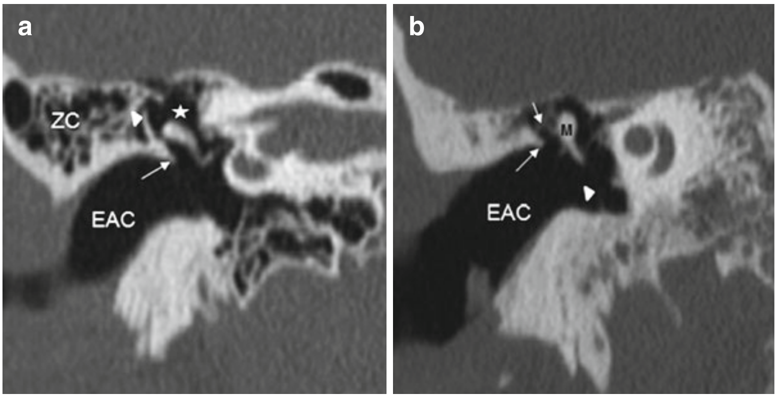

Fig. 2.4 (**a**) Coronal reconstruction of a computed tomography of a right ear, showing the scutum as a sharp bony spur (*white arrow*) and the attic outer wall (*white arrowhead*) that separates the attic (*) from the zygomatic cells (*ZC*). (**b**) Coronal computed tomography reconstruction of a right ear: erosion of the scutum (*long arrow*), due to a retraction pocket in the Prussak's space with keratin debris (*short arrow*). Thickened tympanic membrane (*arrowhead*); *M* malleus, *EAC* external auditory canal

> ***Clinical Impact***
> The scutum is the first bony structure to be eroded by an attical cholesteatoma secondary to a retraction pocket of the pars flaccida into the attic (Fig. 2.4b).

2.1.2.2 The Tympanic Ring

The tympanic ring is the most medial portion of the tympanic bone; it is C shaped and represents the frame in which inserts most of the tympanic membrane periphery. In the inner aspect of the tympanic ring, there is a gutter, the *tympanic sulcus*, which houses the *annulus* of the tympanic membrane.

The tympanic ring is deficient superiorly to form the *notch of Rivinus*. The pars flaccida inserts directly on this notch, and due to the absence of sulcus and the tympanic ring, the pars flaccida is lax rendering it more predisposed to a retraction (Fig. 2.5).

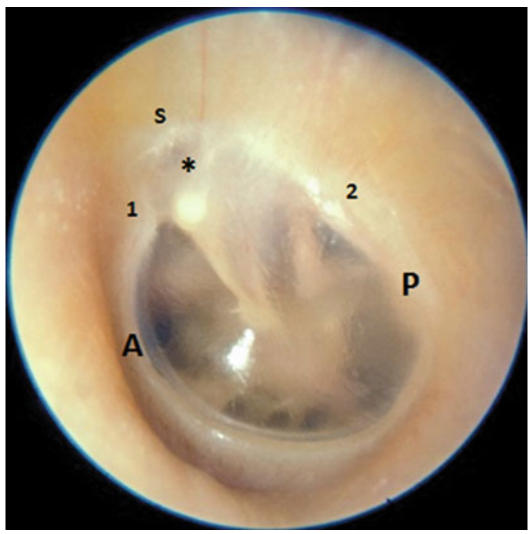

Fig. 2.5 Left tympanic membrane showing the notch of Rivinus (*) limited by the anterior (*1*) and posterior (*2*) tympanic spines. Notice the direct insertion of the tympanic membrane on the scutum (*s*) and the absence of annulus in this zone. Also notice the difference in size between the anterior part of the annulus (*A*) and the posterior part (*P*) of the annulus

The Tympanic Spines

At the junction of the tympanic ring and the attic outer wall, we can identify two spines – the anterior and the posterior tympanic spines (Fig. 2.5):

1. *Anterior tympanic spine:* is present at the anterosuperior end of the tympanic ring and represents the anterior limit of the notch of Rivinus
2. *Posterior tympanic spine:* is present at the posterosuperior end of the tympanic ring and represents the posterior limit of the notch of Rivinus

Tympanic Canaliculi

The medial surface of the tympanic ring near the tympanic spines presents three openings (Fig. 2.6):

- *The Petrotympanic Fissure* (*Glaserian Fissure*)
  The petrotympanic (Glaserian) fissure opens anteriorly just above the attachment of the

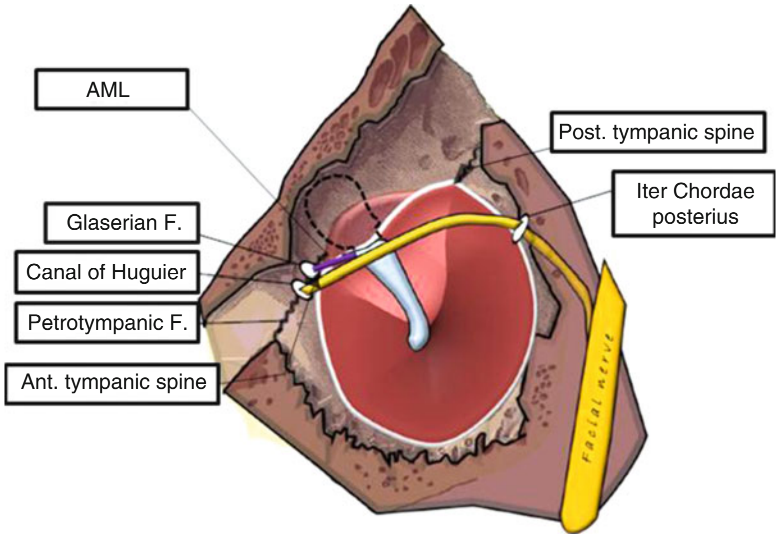

Fig. 2.6 Schematic drawing of the medial surface of a right tympanic membrane showing Glaserian fissure containing the anterior malleal ligament (*AML*), the more medial canal of Huguier giving exit for the chorda tympani to the infratemporal fossa. The chorda tympani enters the middle ear through the iter chordæ posterius

tympanic membrane. It is a slit about 2 mm long, which receives the anterior malleal ligament and transmits the anterior tympanic artery, a branch of the internal maxillary artery to the tympanic cavity (see Fig. 1.11).

- *The Iter Chordæ Anterius* (*Canal of Huguier*)
  The canal of Huguier is a separate canaliculus placed in the medial end of the petrotympanic fissure; through it the chorda tympani nerve leaves the tympanic cavity towards the infratemporal fossa.
- *The Iter Chordæ Posterius*
  The iter chordæ posterius is situated medial to the posterior tympanic spine. It leads into a minute canal through which the chorda tympani nerve exits to enter the tympanic cavity. It lies immediately medial to the tympanic membrane at the level of the upper limit of the malleus handle.

The Tympanic Sulcus

The tympanic sulcus houses the annulus of the tympanic membrane. The lateral edge of the tympanic sulcus is higher than the medial edge.

The average depth of the sulcus is about 1 mm. However, this depth is not constant; it is maximal at 6 o'clock and decreases gradually as it goes up towards the tympanic spines where it disappears completely. The posterosuperior part of the sulcus is shallow and its depth is around 4 mm.

Clinical Implications

These changes in the depth of the sulcus reflect the stability of the insertion of the annulus; in the posterosuperior quadrant the annulus is not totally inserted into the sulcus and is merely supported (Fig. 2.7). This weak insertion of the posterosuperior quadrant of tympanic membrane to the tympanic ring makes it lax and predisposed to retraction [4].

2.1.2.3 The Tympanic Membrane

The tympanic membrane (TM) separates the external auditory meatus from the middle ear. It is a thin semitransparent membrane that is nearly circular in form and is approximately 8 mm wide, 9–10 mm high, and 0.1 mm thick.

The inferior part of the membrane lies more medially than the superior part; the TM forms an inclination of about 40° relative to the inferior wall of the auditory meatus (Figs. 2.1 and 2.8).

The handle of the malleus is firmly attached to the central part of the inner surface of the TM and draws it centrally; this zone of the TM is called the *umbo* (Fig. 2.10).

Shrapnell divided the TM into two parts, an upper small part called *pars flaccida* and a lower bigger part called the *pars tensa*.

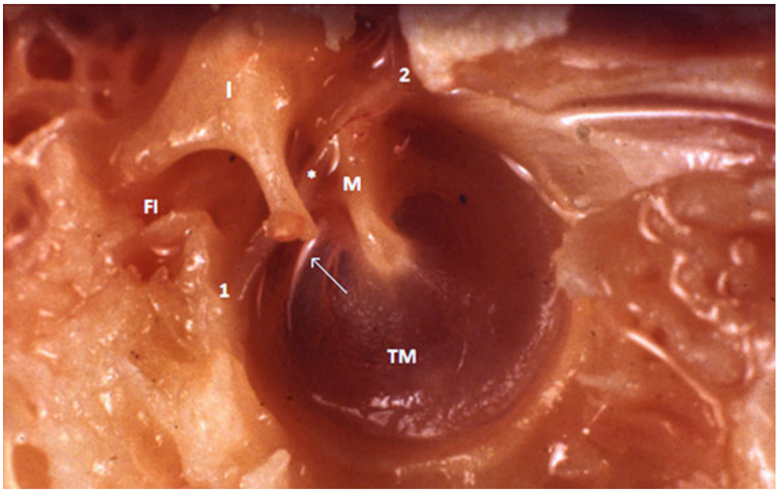

Fig. 2.7 A medial view of the lateral wall of a left middle ear showing the incomplete insertion of the posterosuperior part of the annulus (*white arrow*) in the tympanic sulcus. *1* iter chordæ posterius, *2* iter chordæ anterius, *FI* fossa incudis, *TM* tympanic membrane, *M* malleus, *I* incus, * chorda tympani

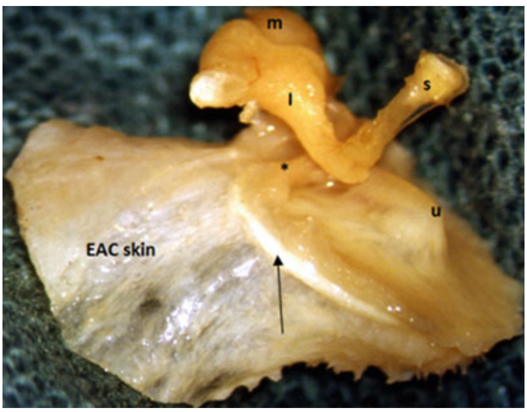

Fig. 2.8 Left ear tympanic membrane allograft showing the annulus (*black arrow*) and the posterior tympano-malleal fold (*). *I* incus, *m* malleus, *u* umbo, *s* stapes

The *pars tensa*, the largest part of the TM, is taut, thickened peripherally into the annulus which is inserted into the tympanic sulcus.

The *pars flaccida*, Shrapnell's membrane, is lax, occupies the notch of Rivinus, and is attached to the scutum [5].

The Tympanic Annulus

The tympanic annulus, or Gerlach's ligament is a horseshoe-like fibrocartilaginous structure that maintains the insertion of the tympanic membrane in the tympanic sulcus (Fig. 2.8). The annulus is absent superiorly at the level of the notch of Rivinus.

In cross section, the annulus shows a triangular form with a summit pointing towards the pars tensa and a base inserted on the tympanic sulcus [6].

At the level of the tympanic spines, the tympanic annulus prolongs centrally towards the lateral process of the malleus constituting two strands: the anterior and the posterior tympanomalleal strands. These two strands divide the tympanic membrane into the pars flaccida superiorly and the pars tensa inferiorly. Medially, these two strands rise up two slight ridges of mucous membrane on the inner side of the tympanic membrane called the *anterior* and *posterior tympano-malleolar folds* (Fig. 2.8).

The diameter of the annulus is not uniform. The maximal mean caliber of the annulus is at 6 o'clock level; from this point, the annulus gradually thins out in both directions until it reaches about 15 % of its maximal caliber at the anterior and posterior tympanic spines [4, 7] (Fig. 2.5).

> ***Surgical Application***
> During middle ear surgery, the annulus allows an operative dislocation of the tympanic membrane out of the sulcus without tearing it. The most difficult part of the annulus to dislodge is the anterior part because of its firm attachment to the sulcus.

Microscopic Structure of the Tympanic Membrane

The pars tensa and pars flaccida differ in structure despite the fact that both parts are made of three layers: a lateral epidermal layer, a medial mucosal layer, and a middle layer or lamina propria.

- *The epidermal layer*
  The epidermis of the TM and of the bony part of the external ear canal is a specialized type of skin; it does not contain any glands or hair follicles, and it has a potential of lateral migration not encountered in any epidermis elsewhere. Epithelial cells migrate centrifugally outwards from the center of the drum desquamating only when they reach the cartilaginous portion of the ear canal. This process accounts for the self-cleaning ability of the ear canal [8].
- *The Mucosal layer*
  The mucosal layer of the eardrum is a continuation of the mucosal lining of the middle ear cavity. It is a very thin monocellular layer of cells.
- *Lamina propria*
  This intermediate layer consists of fibrous tissue: The amount and the organization of this tissue is the main difference between the pars tensa and the pars flaccida of the TM.
  - *The pars tensa*
    The fibrous layer of the pars tensa is attached to the malleus handle and to the tympanic bone and consists of two layers of densely packed collagenous fibers; one is oriented radially and another one oriented circularly [9, 10].
    - *Radial fibrous layers* (*stratum radiatum*) are attached to the manubrium and radiate outward to the annulus.
    - *Circular fibrous layer* (*stratum circulare*) is medial to the radial layer and has its fibers arranged concentrically and insert on the manubrium.
  - The pars flaccida
    The lamina propria of the pars flaccida is composed of small amount of elastic and collagenous fibers with no special arrangement and gradually passes into the dermis of the meatal skin [11].

Blood Supply of the Tympanic Membrane

- *Inner surface of the tympanic membrane*
  The TM is supplied by a vascular circle formed by the *anterior tympanic artery* branch from the internal maxillary artery and from the stylomastoid branch of the posterior auricular artery (Fig. 2.9).
- *Outer surface of the tympanic membrane*
  The tympanic membrane is supplied by the arteria manubrii having origin from the deep auricular branch of the internal maxillary artery.

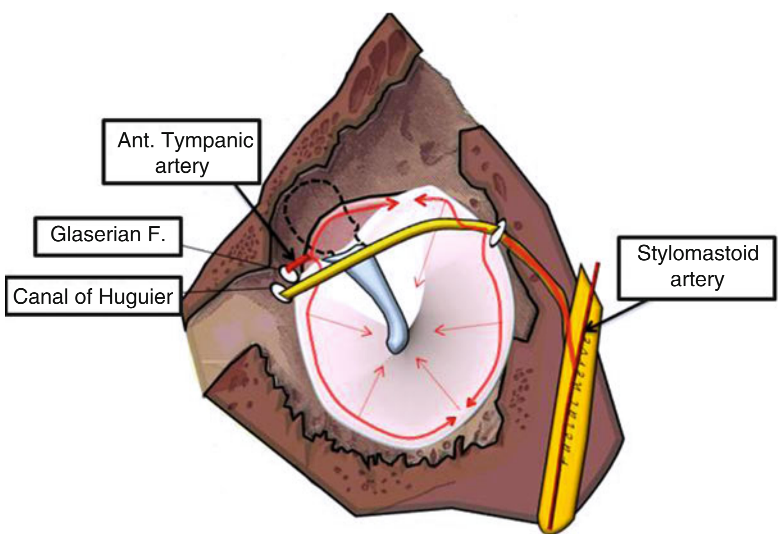

Fig. 2.9 Medial view of a left tympanic membrane showing tympanic membrane vascularization

Nerves of the Tympanic Membrane
The membrane receives its innervations from the auriculotemporal branch of the mandibular nerve (CN V3), the tympanic branch of the glossopharyngeal nerve (CN IX), and the auricular branch of the vagus (CN X).

Clinical Application
Tympanic Membrane Retraction Pockets

- *Pars flaccida retraction pockets*
  The pars flaccida is the most common area of TM retraction pockets because it is the weakest part of the TM. Two reasons stand behind this weakness:
  1. Sparse amount of unorganized fibres in its lamina propria
  2. Direct insertion of the skin of the pars flaccida on the scutum in the absence of the combination annulus-sulcus, which acts like a ligament stabilizing the insertion of the TM to the surrounding bone [12]
- *Pars tensa retraction pockets*
  Pars tensa retraction pockets are more common in its posterosuperior part. Three reasons stand behind this fact:
  1. This part of the TM is more vascularized and thus more vulnerable to inflammation, which leads to secretion of collagenase and destruction of collagen fibers. This renders this part of the TM atrophic and prone to retraction in case of middle ear negative pressure.
  2. The middle fibrous layer of the posterosuperior part lacks a well-developed circular fibrous layer.
  3. The weak annulus insertion on the tympanic ring because of a shallow sulcus at this level [4].

In contrary, the anterosuperior quadrant of the TM is less prone to retraction because of its strong insertion into the sulcus, the better arrangement of its circular fibers and the presence of the anterior malleal ligament acting as a support [4].

2.2 Inferior Wall (Jugular Wall)

2.2.1 Embryology of the Inferior Wall

The inferior wall of the middle ear develops between the 21st and the 31st gestational week, from the fusion of the tympanic bone and the petrosal bone. The fusion of these two bones, at 24th gestational week, closes the hypotympanum incompletely and leaves a persistent hypotympanic fissure, which houses the inferior tympanic canaliculus. The inferior tympanic canaliculus transmits the Jacobson's branch of the glossopharyngeal nerve and the inferior tympanic artery to the middle ear [13] (see Fig. 1.2) (see Sect. 1.1.1).

2.2.1.1 Development of the Jugular Bulb After Birth

The jugular bulb, absent at birth, is a dynamic structure which develops after the age of 2 years and reaches its definite size in adulthood. Children younger than 2 years old do not demonstrate the bulbous enlargement typical of the jugular bulb. The upward forces and the hemodynamic changes that accompany prone position lead to the bulbous enlargement typical of the adult jugular bulb. An erect posture, as opposed to the "fetal" or lying-down positions maintained in utero and in neonates, results in an ascending negative pulse wave originating from the heart and traversing upward to strike the jugular sinus at the jugular foramen. This phenomenon is responsible of the expansion of the jugular bulb [14].

Because the left brachiocephalic vein is relatively longer than the right one, it may dissipate the energy of the venous pulsation generated from the heart and consequently explain the development of a larger jugular bulb on the right side.

The absence of the jugular bulb at birth and its development in early infancy suggest that jugular bulb abnormalities are acquired rather than congenital and thus may progress with time to expand into the adjacent structures.

The venous blood flow dynamics may ultimately determine the variations in final size and position of the jugular bulb [14].

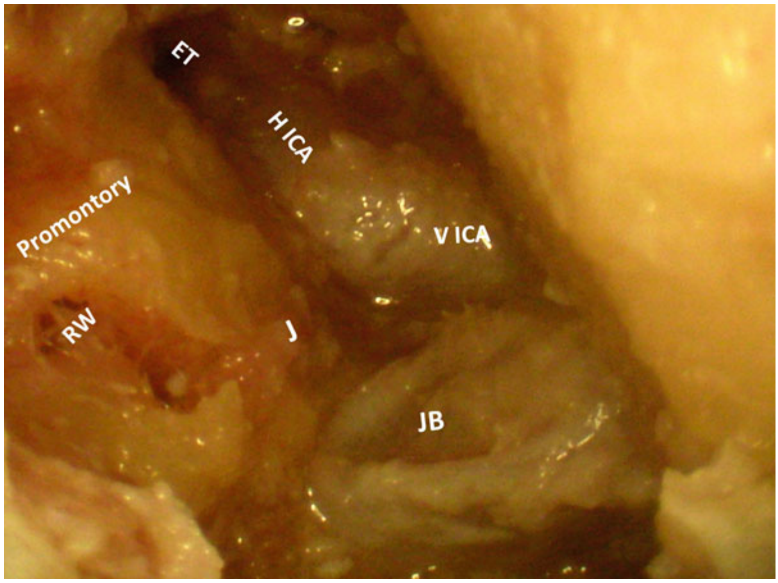

Fig. 2.10 Right ear after transcanal hypotympanotomy and dissection of the vertical portion of internal carotid artery (*VICA*) and the jugular bulb (*JB*), notice the emergence of the Jacobson's nerve (*J*) between the VICA and the JB and its relation to the round window (*RW*); also notice the relation of the horizontal portion of the internal carotid artery (*HICA*) and the Eustachian tube (*ET*); the HICA lies in the medial wall of the Eustachian tube

2.2.2 The Inferior Wall Anatomy

The floor of the middle ear cavity is narrow and consists of a thin plate of bone that separates the middle ear from the jugular bulb posteriorly and the internal carotid artery anteriorly. Between the carotid artery and the jugular bulb near the medial wall, there is a small canal, the inferior tympanic canaliculus, which transmits the Jacobson's nerve, branch of the glossopharyngeal nerve (CN IX), and the inferior tympanic artery (Fig. 2.10).

The surface of this wall may show irregularities due to the overlying pneumatized cells. In the posterior part of the floor is the root of the styloid process which gives rise to a bony eminence, the styloid eminence.

2.2.2.1 The Jugular Bulb

The jugular bulb connects the sigmoid sinus to the internal jugular vein.

It lies in the jugular fossa, an oval hollowed area at the internal and inferior surface of the petrous pyramid. The jugular bulb inhabits the posterior and largest compartment of the jugular foramen. The IX, X, and XI cranial nerves pass the skull base with this venous system.

The jugular bulb communicates with the cavernous sinus through the inferior petrosal sinus.

The jugular bulb dome lies at the floor of the middle ear cavity below the labyrinth and medial to the mastoid segment of the facial nerve.

It is variably positioned in relation to the hypotympanum, and its distance from the facial nerve laterally and the labyrinth superiorly is variable (Fig. 2.11). The distance from the jugular bulb to the posterior semicircular canal superiorly ranges from 0 to 10 mm (mean, 4 mm). The distance from the jugular bulb to the facial nerve laterally ranges from 0 to 12 mm (mean, 7 mm) [15].

Surgical Application

Retrofacial Approach to the Middle Ear

Retrofacial approach to the middle ear is done by drilling the area between the facial nerve laterally, the jugular bulb inferiorly and medially, and the ampulla of the posterior semicircular canal superiorly. This approach can provide a good access to the hypotympanum and the related structures without transposing the facial nerve or taking down the posterior external auditory canal wall. In cases with a high and lateral jugular bulb, this approach could not be done easily [15] (Fig. 2.12).

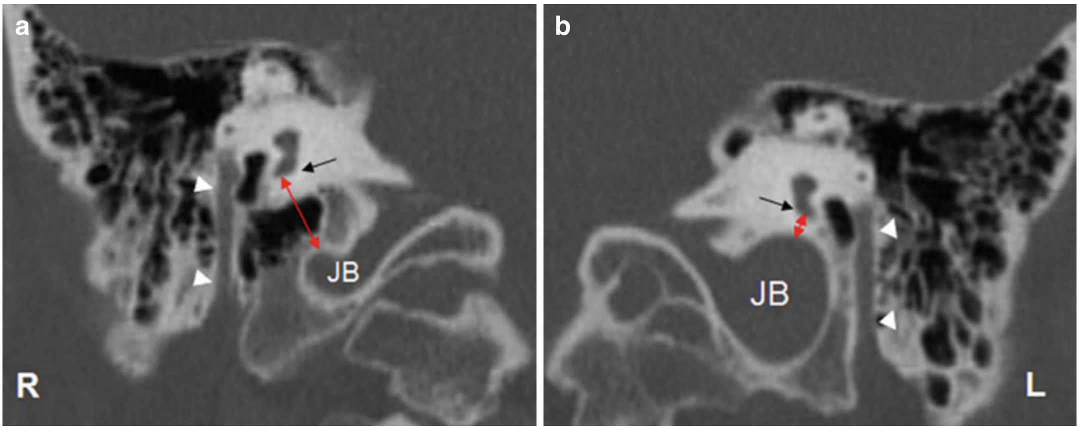

Fig. 2.11 Coronal computed tomographic reconstruction on the mastoid segment of the facial nerve (*arrowheads*) on both ears and the relation to the jugular bulb (*JB*) and the posterior semicircular canal (PSCC) (*black arrow*): (**a**) On the right side (*R*), small jugular bulb (*JB*) with a large distance (*red arrow*) to the PSCC. (**b**) On the left side (*L*), huge JB with a short distance (*red arrow*) to the PSCC

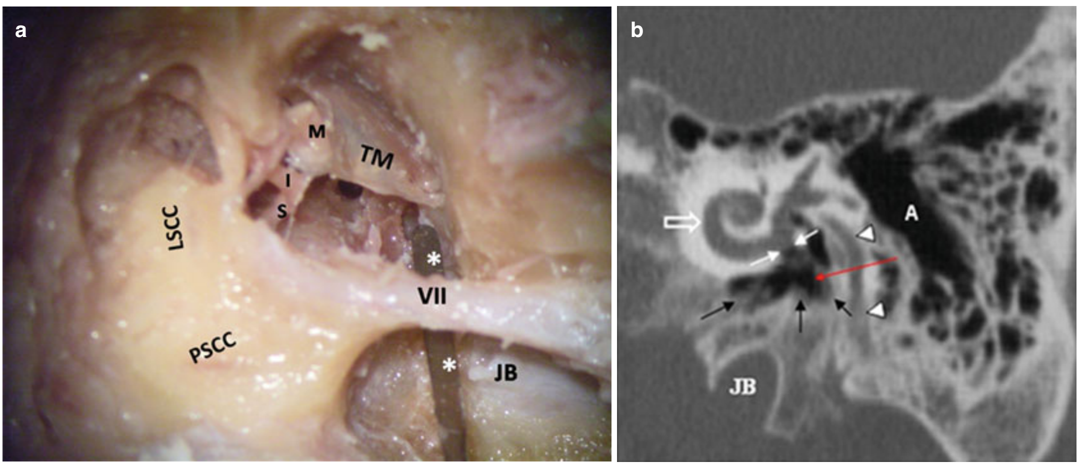

Fig. 2.12 (**a**) Retrofacial approach in a left ear hypotympanum. (*) surgical instrument; *VII* mastoid segment of the facial nerve, *JB* jugular bulb, *TM* tympanic membrane, *M* malleus, *I* incus, *S* stapes, *LSCC* lateral semicircular canal, *PSCC* posterior semicircular canal. (**b**) Sagittal oblique reconstruction of a computed tomography showing the retrofacial hypotympanotomy approach (*red arrow*). Mastoid segment of the VII nerve (*arrowheads*), hypotympanic air cells (*black arrows*), round window membrane (between the *white arrows*), basal turn of the cochlea (*empty arrow*). *A* antrum, *JB* jugular bulb

Clinical Application

Jugular Bulb Anomalies

A high jugular bulb (HJB) is a condition in which the jugular bulb dome rides above the tympanic annulus. A HJB has an intact sigmoid plate which separates it from the middle ear cavity. If the sigmoid plate is deficient, the bulb protrudes into the middle ear cavity; this situation is called a dehiscent jugular bulb (JBD) (Fig. 2.13).

A HJB or JBD manifests as a pulsatile tinnitus and appears like a posteroinferior retrotympanic blue mass on otoscopic examination. Injury of a JBD during tympanomeatal flap elevation results in profuse bleeding [16, 17].

The incidence of high JB ranges from 5 to 20 % and that of JBD ranges from 1 to 10 % [17].

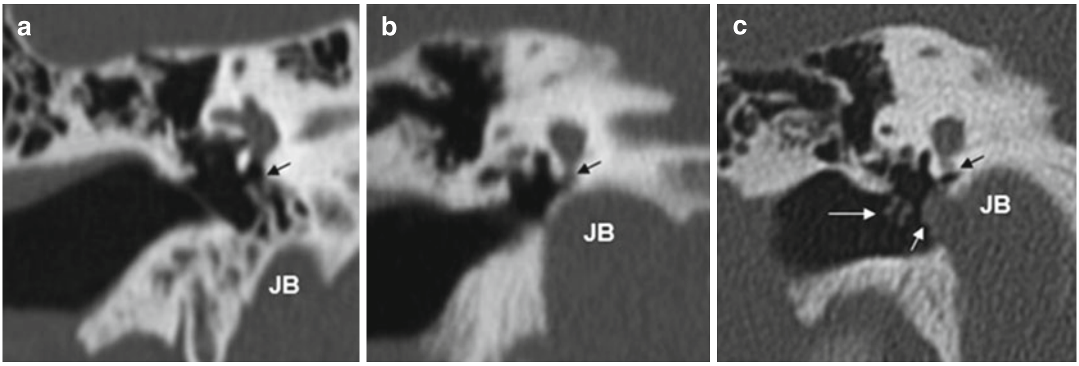

Fig. 2.13 (**a**) Coronal computed tomographic view on a right ear with a normal jugular bulb (*JB*), round window recess (*black arrow*). (**b**) High riding JB obliterating the round window recess (*black arrow*). (**c**) JB diverticula (*small white arrow*), reaching the round window recess (*black arrow*). Notice the transtympanic tube in place (*long white arrow*)

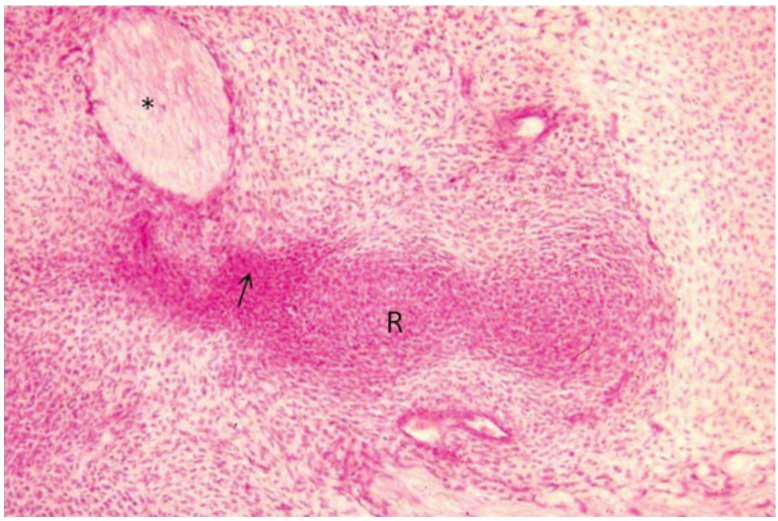

Fig. 2.14 15.5-mm human embryo coronal section showing the laterohyale (*arrow*) covering facial nerve rudiment (*), in connection with the Reichert's cartilage (*R*). Hematoxylin-eosin staining

2.3 Posterior Wall

2.3.1 Embryology of the Posterior Wall

The posterior wall develops from the Reichert's cartilage. The facial nerve develops in a groove on the otic capsule. By the 20th week, the facial canal is better defined by fibrous tissue laterally as the otic capsule ossifies medially. Reichert's cartilage persists as a cartilage bar interposed between the otic capsule and the facial nerve medially and the tympanic annulus laterally [18]. Ossification starts in this cartilage bar and continues in the mesenchyme both medial and lateral to this cartilage bar, forming the facial canal and the posterior wall of the middle ear cavity. The cartilage remnant of Reichert's bar frequently persists to the time of birth, ossifying separately from the surrounding mesenchyme. The first cartilaginous wall of the facial canal is the laterohyale connected primitively with the interhyale, rudiment of the stapedial tendon (Fig. 2.14).

2.3.2 Posterior Wall Anatomy

The posterior wall is the highest wall of the middle ear and measures about 14 mm. It is formed essentially by the petrous bone. The posterior

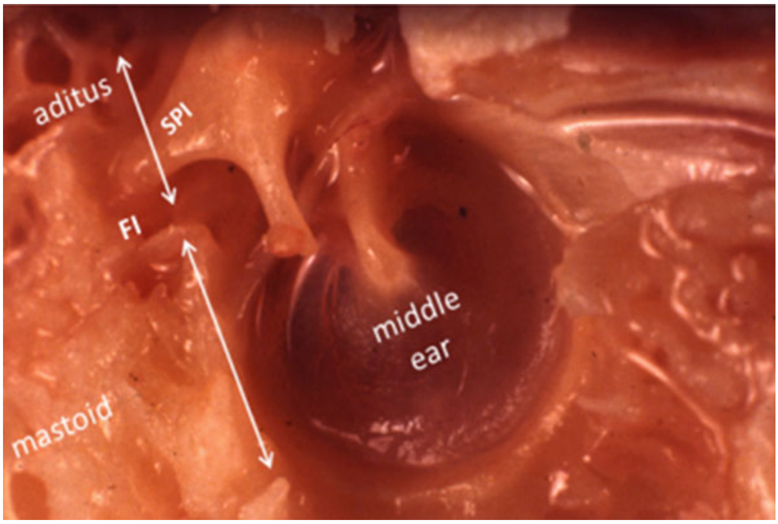

Fig. 2.15 A medial view of a left middle ear showing the posterior wall composed of an inferior closed part separating the middle ear from the mastoid and a superior open part, the aditus ad antrum, which connects the middle ear to the mastoid. Notice that the floor of the aditus houses the fossa incudis (*FI*), which lodges the short process of the incus (*SPI*)

wall separates the middle ear from the mastoid air cells, except at the area of the aditus ad antrum, where it is deficient and permits communication between the attic and the mastoid antrum.

The posterior wall can be divided into two distinct parts: the upper third which corresponds to the *aditus ad antrum* and represents the posterior limit of the epitympanum and the lower two thirds which correspond to the posterior wall of the retrotympanum.

The two parts are separated by the incudal buttress which is a compact bone that runs from the tympanic ring laterally to the lateral semicircular canal medially. It houses the *incudal fossa* in its superior surface which lodges the short process of the incus (Fig. 2.15).

2.3.2.1 The Upper Part: The Aditus Ad Antrum

The aditus ad antrum connects the epitympanum of the middle ear to the mastoid antrum posteriorly. The aditus is of a triangular shape with dimensions of 4×4×4 mm height, length, and width (see Sect. 5.2.3 and Fig. 5.17).

2.3.2.2 The Lower Part: The Posterior Wall of the Tympanum

The posterior wall of the tympanum is a complete bony wall and bridges the bony annulus tympanicus to the bony labyrinth. It is the extension of the styloid eminence upward to the pyramidal eminence and to the level of the fossa incudis. It houses the vertical segment of the facial nerve.

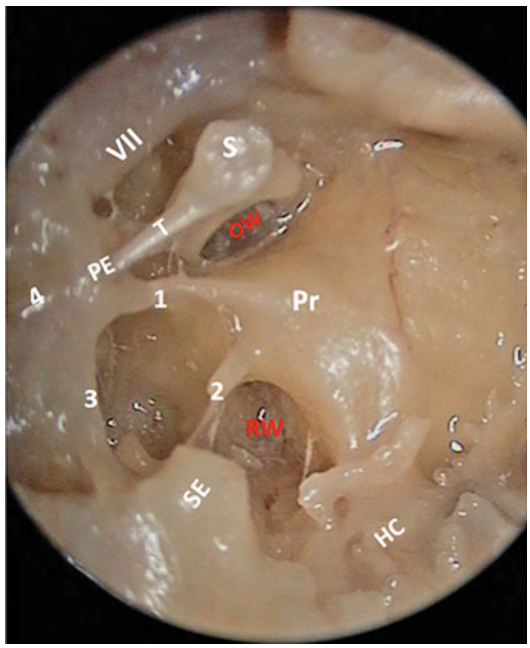

Fig. 2.16 Endoscopic view of a right middle ear showing the different ridges of the posterior wall. *1* ponticulus, *2* subiculum, *3* pyramidal ridge, *4* chordal ridge, *PE* pyramidal eminence, *SE* styloid eminence, *OW* oval window, *RW* round window, *S* stapes, *T* stapedial tendon, *Pr* promontory, *HC* hypotympanic cells, *VII* facial nerve

This wall is wider above than below and presents three eminences directed anteriorly, five bony ridges, and four sinuses delimiting the retrotympanum spaces (Fig. 2.16).

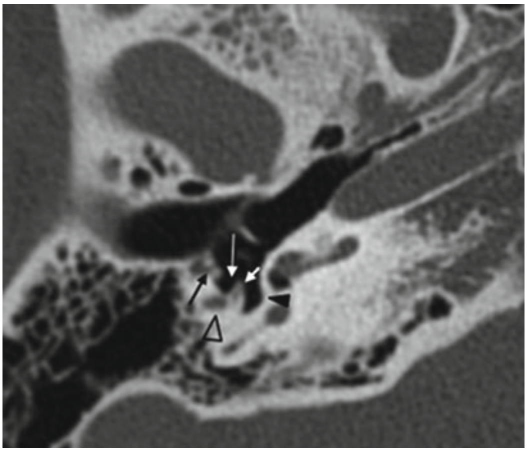

Fig. 2.17 Transversal computed tomography of the posterior wall of the cavity. From lateral to medial: chordal eminence (*black arrow*), facial recess (*long white arrow*), facial nerve (*empty arrowhead*), pyramidal eminence (*short white arrow*), sinus tympani (*black arrowhead*)

Posterior Wall Eminences

The posterior wall presents three bony eminences: the pyramidal, chordal, and styloid eminences. These three eminences altogether form what is called the *styloid complex,* which is a derivative of the superior portion of the second branchial arch.

- *The pyramidal eminence*
  The pyramidal eminence is situated at the center of the posterior wall immediately behind the oval window; it is about 2 mm height. Its base is fused with the canal of the facial nerve. It lodges the body of the stapedial muscle and its apex gives passage to the stapedial tendon. The pyramidal eminence communicates with the facial bony canal by a minute aperture which transmits the stapedial branch of the facial nerve (Fig. 2.17).
- *The chordal eminence*
  The chordal eminence is situated lateral to the pyramidal eminence and 1 mm medial to the tympanic membrane. The chordal eminence shows a foramen: the *iter chordæ posterius* through which the chorda tympani nerve gains access to the middle ear cavity (Fig. 2.17).
- *The styloid eminence*
  The styloid eminence or Politzer eminence is a recognized smoothed elevation at the inferior part of the posterior wall; it represents the base of the styloid process.

> During transcanal hypotympanotomy, the styloid eminence represents a very important landmark for the facial nerve; the styloid eminence is always anterior to the facial nerve and represents the posterior limit of safe drilling in the posterior part of the hypotympanum.

Posterior Wall Ridges

We can identify in the posterior wall five bony ridges which connect the eminences with each other and with the promontory.

- *The chordal ridge of Proctor*
  The chordal ridge runs laterally and transversally from the pyramidal eminence to fuse with the chordal eminence.
- *The pyramidal ridge*
  The pyramidal ridge is very prominent. It runs inferiorly from the base of the pyramidal eminence to the styloid eminence. It could be absent.
- *The styloid ridge*
  The styloid ridge connects the styloid prominence to the chordal eminence.
- *The ponticulus*
  The ponticulus is a central structure in the retrotympanum. It is a bony ridge extending from the pyramidal process to the promontory. There are two different variants of the ponticulus:
  – Complete ponticulus: when the ponticulus is completely formed and extends from the pyramidal process to the promontory area. In this case the ponticulus represents the superior frontier of the sinus tympani and separates it from the posterior sinus.
  – Incomplete ponticulus: in this case the ponticulus does not connect with the pyramidal process making the sinus tympani and the posterior sinus one confluent sinus.
- *The subiculum*
  The subiculum is a smooth bony projection that is situated posterior to the promontory and extends inferiorly from the posterior lip of the round window niche towards the styloid eminence. Therefore, it intervenes between the sinus tympani superiorly and the round window inferiorly.

Posterior Wall Spaces

The posterior wall bony eminences and ridges divide the posterior wall into four different spaces that are completely separated from the mastoid cavity (see Sect. 4.4).

2.4 Superior Wall (The Tegmen)

The superior wall of the middle ear cavity is a plate of bone that separates the middle ear cavity from the overlying middle cranial fossa dura and temporal lobe of cerebrum. The integrity of the tegmen is essential to avoid spread of infection from the middle ear to the intracranial cavity, as well as to prevent herniation of the brain into the middle ear.

2.4.1 Superior Wall Development

The superior wall forms from the fusion of two horizontal plates, a small lateral plate (*horizontal process*) derived from the squamous bone and a large medial plate (*tegmental process*) derived from the otic capsule of the petrous bone. The lateral plate shows membranous ossification, whereas the medial one shows endochondral ossification (see Fig. 1.2) (see Sect. 1.1.1).

At the line of fusion of both plates, a bony log is formed and is called the tignum transversum that is the major supporting element of the tegmen. The tignum transversum extends anteriorly to the Glaserian fissure and then beaks medially to form the so-called cog [19].

Delayed or incomplete ossification of the tegmen may lead to tegmen defects observed in childhood or early, with possible meningocele or spontaneous CSF fistula (Fig. 2.18).

> ***Clinical Implications***
> **Middle Ear Meningoencephalocele**
> Middle ear meningoencephalocele is a herniation of brain tissue through a bony defect into the middle ear. Middle cranial fossa meningoencephaloceles are the most common, and this is related to tegmen tympani dehiscence under the weight of the temporal brain lobe and CSF pulsations effect [20, 21]. The most frequent bony defect in the tegmen tympani is in the region next to the geniculate ganglion [22] (see Fig. 2.18).
>
> Posterior cranial fossa meningoencephalocele into the middle ear is rare.

2.4.2 Superior Wall Anatomy

The tegmen is a thin bony plate that forms the roof of the middle ear cavity and separates it from the overlying temporal lobe. The part of the tegmen overlying the Eustachian tube is called *tegmen tubari*, the part overlying the tympanic cavity is called the *tegmen tympani,* and that overlying the mastoid antrum is called the *tegmen antri*.

The superior surface of the tegmen forms part of middle cranial fossa floor and is covered by the dura; the inferior surface of the tegmen is lined

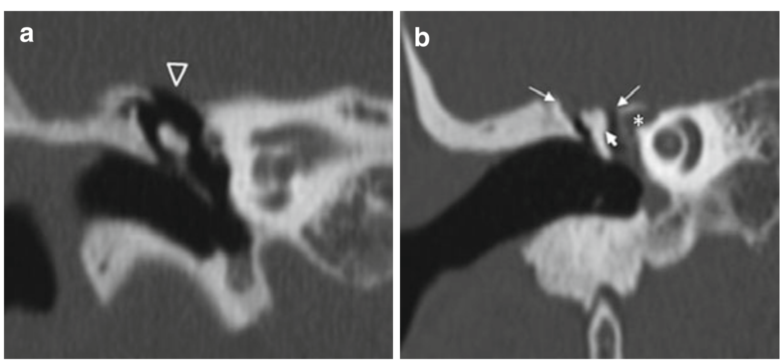

Fig. 2.18 Coronal computed tomography of the right ear showing in (**a**) congenital dehiscence of the tegmen (*arrowhead*); (**b**) herniation of endocranial tissue of the middle fossa through a congenital dehiscence of the tegmen (*between the long arrows*), laterally to the geniculate ganglion (*), reaching the ossicles (*short arrow*)

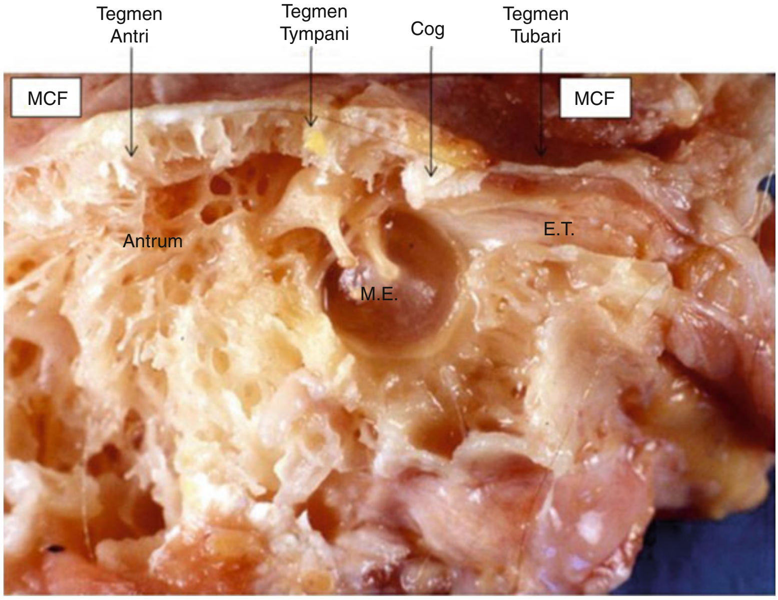

Fig. 2.19 A sagittal cut of the temporal bone, showing the superior wall of a left middle ear (*ME*). *MCF* middle cranial fossa, *ET* Eustachian tube

by middle ear mucosa. The tegmen separates the cerebrospinal fluid superiorly from the air of the middle ear inferiorly [23] (Fig. 2.19).

The tegmen tympani is formed from two unequal bony plates. The largest medial portion develops from the tegmental plate of the petrous bone, and the smaller lateral portion develops from the horizontal plate of the squamous bone (Fig. 2.20).

The suture line between these two plates is known as the internal petrosquamous suture.

In newborns, this suture is not ossified and is filled with connective tissue; it does not close until adulthood [24]. In adults, the dura of the middle cranial fossa is tightly adherent to this suture; sharp dissection may be required for elevation of the dura at this level during middle cranial fossa approach.

In the middle ear surface of the petrosquamous fissure serves as a point of attachment to the superior malleal and superior incudal ligaments.

In the anterior attic, the tegmen is formed completely by the tegmental plate of the petrous bone. In the posterior attic and in the antrum, the horizontal plate of the squamous bone contributes to the formation of the tegmen tympani [22] (Fig. 2.20).

At the level of fusion between the tegmental plate and anterior limit of the horizontal plate, the cog appears (Fig. 2.20). The cog is a 0.5-mm long transversal hard and dense bony crest situated 1–2 mm anterior to the malleus head and heading vertically towards the cochleariform process. Its medial part may eventually prolong to reach the cochleariform process [25, 26].

2.4.2.1 Supportive Mechanisms of the Tegmen

As described above, the tignum transversum is the major supporting element of the tegmen. In addition to the tignum transversum, the carrying capacity of the tegmen depends on the lateral and medial processes of the tignum as well. The tignum transversum and the medial and lateral processes establish a structure similar to the nervation of a leaf. This aspect of a nervation assures an evenly distributed mechanical support for the thin and eventually perforated plate of the tegmen. Thus, the resistivity of a thin tegmen against the weight of the temporal lobe and cerebrospinal pulsations is determined more by the complete structure of the described network of the bone rather than by the thickness of the plate [19] (Fig. 2.21).

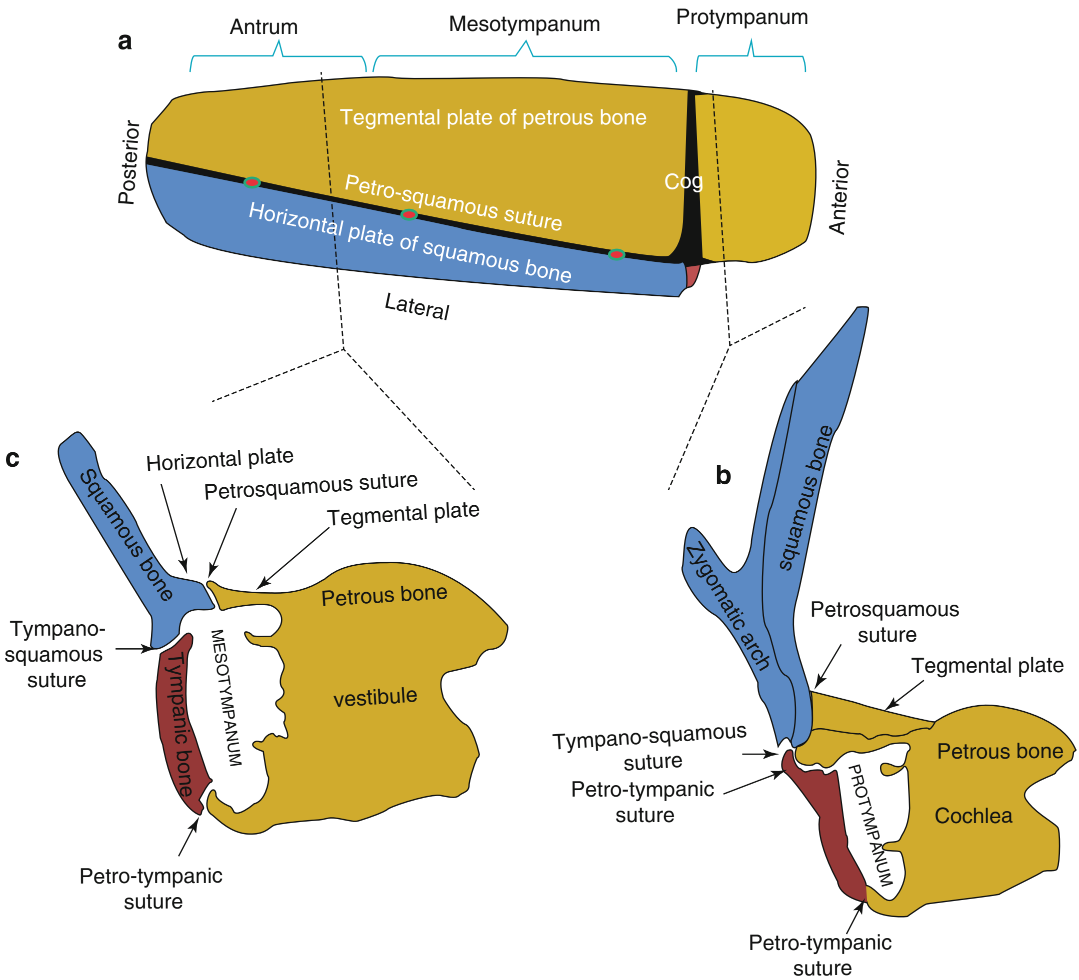

Fig. 2.20 (**a**) Superior view of the tegmen from the middle cranial fossa demonstrates the setup of the tegmen tympani formed by two distinct bony plates of the temporal bone, with the horizontal process of the squamous part laterally and the tegmental process of the petrous part medially. Both plates meet at the petrosquamous fissure. (**b**) Section made through the protympanum shows that the roof of the protympanum is built up only by the tegmental process. (**c**) Section made through the mesotympanum showing that the squamous part contributes to the formation of the tegmen tympani in this area

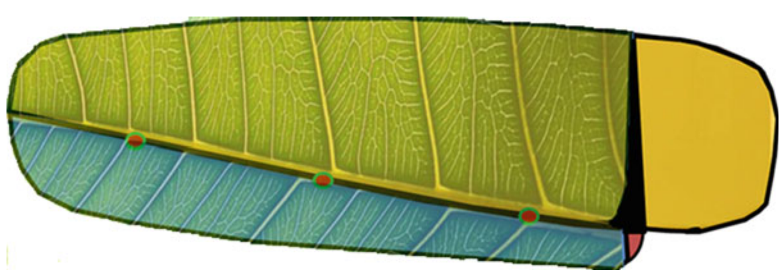

Fig. 2.21 The carrying capacity of the tegmen depends on the tignum transversum (*black line*) and its associated lateral and medial processes; these together establish structures similar to the nervation of a leaf

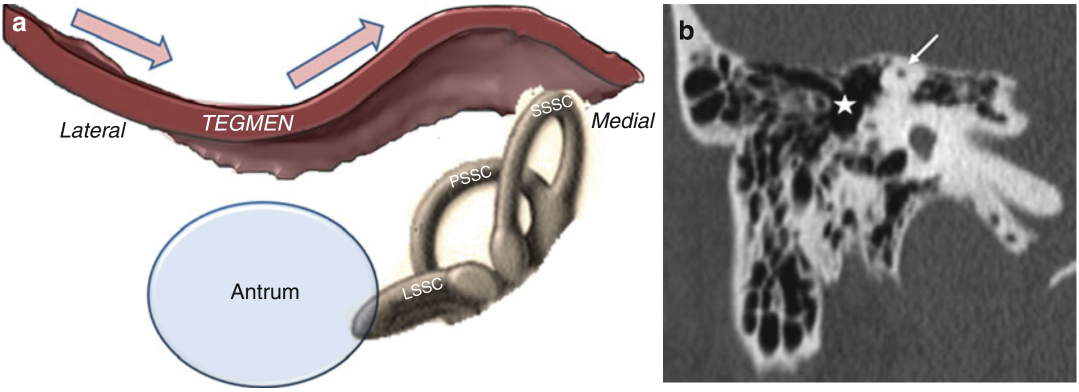

Fig. 2.22 (**a**) 3D image of the tegmen in the coronal plane. The tegmen slopes down above the antrum and then goes up to cover the superior semicircular canal. *SSSC* superior semicircular canal, *PSSC* posterior semicircular canal, *LSCC* lateral semicircular canal. (**b**) Computed tomography of a right ear showing the shape variation of the tegmen relatively to the antrum (*) and the superior arch of the SCCC (*white arrow*)

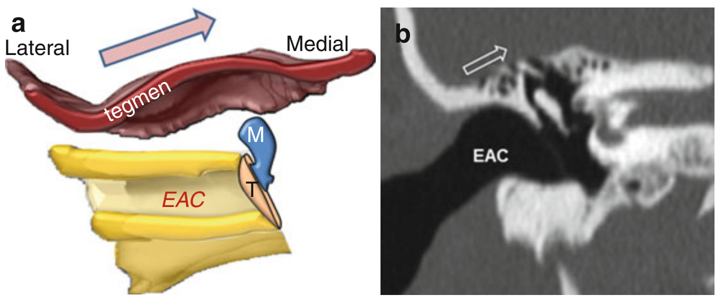

Fig. 2.23 (**a**) 3D Image in the coronal plane showing the relationship between the tegmen and the bony external ear canal. Notice that the tegmen rises up as we move medially (*arrow*). *EAC* external auditory canal, *T* tympanic membrane, *M* malleus. (**b**) Coronal computed tomography of a right ear showing the slope of the tegmen (*arrow*) upwards in relation to the superior wall of the external auditory canal (*EAC*) in lateral-to-medial direction

2.4.2.2 Surgical Anatomy of the Tegmen

Mastoid surgery and atticotomy require complete conservation of the tegmental plate.

Since the tegmen shows a variable shape and inclination and because the dura and the arachnoid are closely adherent to the bone in the middle fossa region, iatrogenic injuries by drilling could lead to cerebrospinal fluid leak, pneumocephalus, brain herniation, or cerebral abscess. Thus, a thorough knowledge of the tegmen slopes as well as its relationship with the external auditory canal is essential for a safe and successful attico-mastoid surgery. The tegmen is not a simple horizontal plane, but it is an irregular plate of bone with ondulating slopes.

There are two distinct slopes in the configuration of the tegmen: one is from lateral to medial and a second one is from posterior to anterior direction.

Lateral-to-Medial Slope

In the lateral-to-medial direction, the tegmen presents an inferiorly directed hang before heading up to its highest point above the superior semicircular canal (Fig. 2.22). This shape of hanging down laterally and rising up medially exists throughout the whole course of the tegmen as in its posterior or in its anterior part [27].

Over the external auditory canal (Fig. 2.23), the majority of the population has a narrower distance laterally than medially [27].

Posterior-to-Anterior Slope

In the sagittal plane the tegmen makes also a slope in a posterior to anterior direction and becomes close to the superior part of the external auditory canal [27]. The tegmen is higher posteriorly by about 1–10 mm than anteriorly (Fig. 2.24).

> ***Surgical Application***
>
> During mastoid dissection anteriorly it is recommended to start first inferiorly, then progress back around superiorly. Therefore, while approaching the superior wall of the external auditory canal and knowing that the dura hangs down laterally, the surgeons' drill must work from medial to lateral to avoid lowering or injuring the canal wall or hitting the dura. The tegmen can be easily damaged laterally where the dura is low lying. Also this lateral overhang can obscure the disease tissues hidden medially.
>
> In addition, if the medial level of the dura is wrongly expected to be at the same lower lateral level, the drilling may wrongly progress much lower medially and could traumatize the lateral semicircular canal or facial canal [27].
>
> The sagittal plane is especially relevant when extending the drilling from the antrum to the attic region anteriorly: the tegmen slopes inferiorly as the drilling progresses anteriorly. One should expect a much lower dura anteriorly at the level of root of the zygoma; this is of most concern during anterior epitympanic recess approach (Fig. 2.23).
>
> The space available to work between the EAC wall and the dural plate in canal wall-up attico-mastoidectomy is smaller than posteriorly. Basically this finding confirms that the root of zygoma is a surgically challenging area, especially when approaching the anterior attic with conservation of the ossicular chain in place. In this procedure care must be taken not to penetrate the external canal wall nor to injure the dura in a canal wall-up technique.

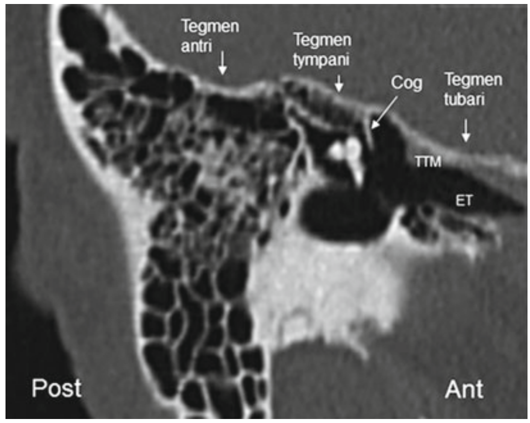

Fig. 2.24 Sagittal reconstruction of a computed tomography of a temporal bone showing the different parts of the tegmen and the cog. Note that the tegmen slopes downwards from posterior to anterior. *TTM* tensor tympani muscle, *ET* Eustachian tube

2.5 Anterior Wall (Carotid Wall)

The anterior wall separates the middle ear cavity from the petrous carotid artery canal. It houses the tympanic orifice of the Eustachian tube.

2.5.1 Anterior Wall Development

The development of the anterior wall and the protympanum is in close relationship to that of the carotid canal and the auditory tube. The anterior wall arises completely from the petrous bone.

After the development of the otic capsule at the 16th week of gestation, multiple plates extend laterally from the otic capsule around the developing tubotympanic recess and ICA to build up almost the entire protympanum (Fig. 2.25). The tympanic bone forms the posterior border of the lateral wall of the protympanum [28]. In the protympanum, the bone appears in the 18th week.

The developmental junction between the petrous and tympanic bones is marked by the petrotympanic fissure, or Glaserian fissure, which continues laterally into the tympanosquamous fissure.

2.5.1.1 Development of the Carotid Canal

The development of the carotid canal has a close relationship with the internal carotid artery (ICA)

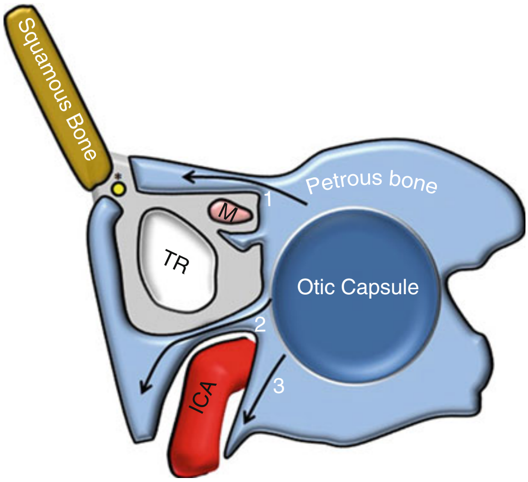

Fig. 2.25 Schematic drawing of the developing protympanum and its surroundings in the frontal plane (34-week-old fetus). The walls of the protympanum are built up by several processes of the petrous bone: the tegmental plate (*1*) forming the roof, the superior lamina of the carotid canal (*2*) and the inferior lamina of carotid canal (*3*) forming the inferomedial wall. The medial wall of the protympanum is created by the promontory itself. *M* tensor tympani muscle, *TR* tubotympanic recess, *ICA* internal carotid artery, * chorda tympani

development. In the early embryonic period, the ICA lies on the anterior part of the cartilaginous otic capsule; ossification of the otic capsule that starts in the 18th week produces two plates around the ICA, the superior and the inferior plate. At birth, the plates of the carotid canal have enclosed the ICA in a bony channel in the medial wall of the protympanum [28] (Fig. 2.25).

If the ICA is not directly beside the otic capsule, the bony canal of the ICA will be absent [29].

Consequently ICA dehiscence encountered in children is the result of incomplete fusion of the superior and inferior bony plates of the carotid canal. Furthermore, agenesis of the internal carotid artery is associated to an absence of the carotid canal [30] (see Sect. 3.5.1.2).

2.5.2 Anterior Wall Anatomy

The anterior wall of the tympanic cavity is very narrow because the medial and lateral walls of the middle ear cavity converge anteriorly in an acute angle. The anterior wall is formed entirely from the petrous bone and can be divided into three portions: the lower, the middle, and the upper portion (Fig. 2.26).

2.5.2.1 The Lower Portion

The lower portion of the anterior wall is the largest portion and represents the anterior wall of the hypotympanum. It is a thin plate of bone that separates the middle ear cavity from the vertical segment of the petrous carotid artery. This bony plate has two tiny openings for the

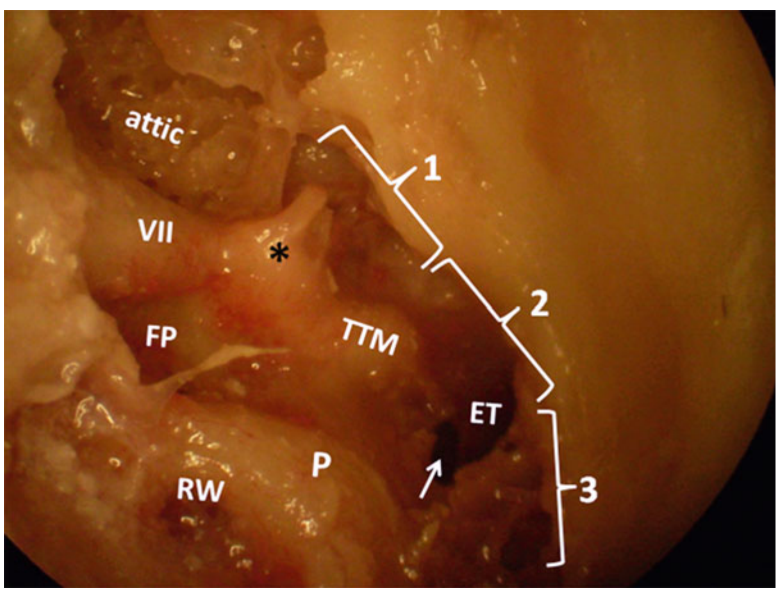

Fig. 2.26 Anterior wall of a right middle ear. *1* upper third, *2* middle third, *3* inferior third; notice the internal carotid artery dehiscence (*white arrow*) in the medial wall of the Eustachian tube (*ET*); *TTM* tensor tympani muscle canal, * cochleariform process, *VII* tympanic portion of the facial nerve, *FP* footplate, *RW* round window, *P* promontory

caroticotympanic nerves: the upper opening transmits the superior caroticotympanic nerve and the inferior opening transmits the inferior caroticotympanic nerve. These nerves have origin from the pericarotid sympathetic chain; they transmit sympathetic fibers coming from the superior cervical ganglia to the tympanic plexus of the middle ear.

2.5.2.2 The Middle Portion

The middle portion of the anterior wall corresponds to the protympanum. The middle portion has two tunnels placed one below the other: the upper tunnel transmits the tensor tympani muscle, and the lower tunnel corresponds to the bony portion of the Eustachian tube. A thin horizontal plate of bone, the septum canalis musculotubari, separates these two tunnels from each other.

- The semicanal for the tensor tympani (semicanalis m. tensoris tympani) is cylindrical and lies beneath the tegmen tympani. It extends to join the cochleariform process.
- The septum canalis musculotubarii passes posteriorly below the tensor tympani semicanal; it expands above the anterior end of the oval window and terminates by curving laterally forming a pulley, the cochleariform process, over which the tendon of the tensor tympani muscle passes [31].
- The bony portion of the Eustachian tube: is situated below the septum canalis (see Sect. 7.2.1).

2.5.2.3 The Upper Portion

The upper portion of the anterior wall corresponds to the root of the zygoma which represents the anterior wall of the epitympanum.

2.5.2.4 The Carotid Artery and the Anterior Wall

The carotid artery enters the temporal bone through the carotid foramen. It ascends vertically in the anterior wall of the hypotympanum and in the medial wall of the bony Eustachian tube at the area just beneath the cochlea (the vertical segment); then it turns anteromedially at almost a right angle towards the petrous apex, forming the horizontal segment anteroinferiorly to the cochlea (Figs. 2.10 and 2.27).

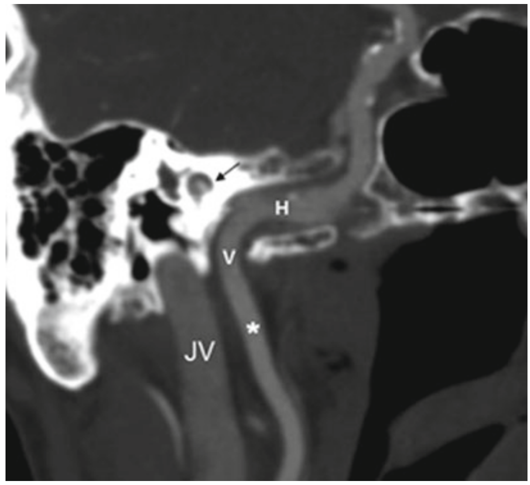

Fig. 2.27 CT Angio-scan of the supra-aortic right vessels, with a sagittal oblique reconstruction, showing the trajectory of the internal carotid artery (*) with its vertical (*V*) and horizontal (*H*) segment. Note the relationship to the basal turn of the cochlea (*black arrow*). *JV* jugular vein

The Vertical Segment of the Petrous Carotid Canal

The vertical segment of the petrous carotid canal is 5.0–12.5 mm in height and 4.0–7.5 mm in diameter.

The vertical segment is separated from the middle ear cavity by a thin plate of bone of about 0.25 mm. There is no difference in thickness between pediatric and adult subjects. A dehiscence of carotid canal is observed in about 5 % of temporal bones, usually located at the medial wall of the bony portion of Eustachian tube (Fig. 2.26).

The tympanic bone is anterolateral to the vertical segment [32]. The distance from the anterior margin of the tympanic annulus to the nearest point of carotid canal is about 5 mm [33].

The Horizontal Segment of the Petrous Carotid Canal

The horizontal segment of the petrous carotid canal is directed anteromedially by a path of 14.5–24 mm long and 4.5–7.0 mm in diameter [32]. The average distance between the carotid canal and the cochlea is about 1 mm near the basal turn, 2 mm near the middle turn, and 6 mm near the apical turn [34].

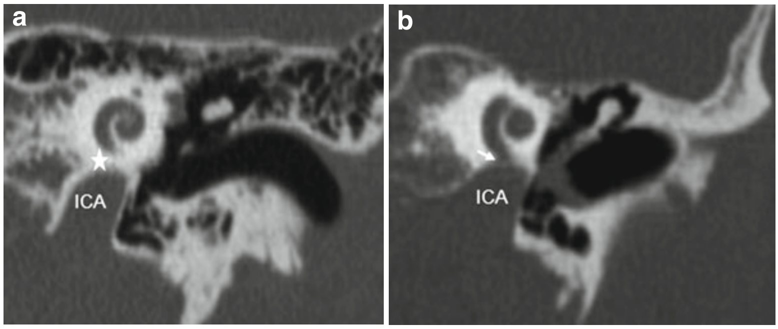

Fig. 2.28 Coronal reconstruction of a computed tomography of a left ear with (**a**) normal bony separation (*) between the cochlea and the internal carotid artery (*ICA*); (**b**) a dehiscent internal carotid artery (*white arrow*) into the basal turn of the cochlea

Surgical Implication

Rarely, there is partial absence of septation between the cochlea and the carotid canal. In these cases, preoperative imaging of the temporal bone shows the anatomical relationship between the cochlea and petrous carotid canal and may help prevent inadvertent penetration of the carotid canal during cochlear implant surgery (Fig. 2.28).

2.6 Medial Wall (Cochlear Wall)

The medial wall is formed mainly by the cochlear promontory in addition to several important structures: the tympanic segment of the facial nerve, the oval and the round windows, the tensor tympani canal, the cochleariform process, and the lateral semicircular canal.

2.6.1 Embryology of the Medial Wall Structures

2.6.1.1 Facial Nerve VII, Tympanic Segment (See Chap. 6)

The horizontal segment of the facial nerve is recognized by the sixth week when it passes between the developing membranous labyrinth and the primitive stapes [35]. By the eighth week, soon after the stapes blastema reaches the otic capsule, a sulcus forms within the lateral margin of the cartilaginous otic capsule, initiating the formation of the horizontal facial nerve canal; this groove forms by the tenth week. If this canal is deep and well formed, the facial nerve will be "locked in" to its normal anatomic position against the otic capsule [35]. The facial nerve groove will begin to enclose the facial nerve in the 4th gestational month. Ossification of the canal is completed during or shortly after the first year of life [36].

2.6.1.2 Oval Window

The oval window is derived from the lateral surface of the otic capsule. Its development is related directly to the development of second branchial arch structures and most importantly the stapes and the facial nerve. As early as the fifth week, the blastemal mass of the stapes becomes recognizable as a ring-shaped structure around the stapedial artery. This rudimentary stapes grows medially, then contacts and indents the developing otic capsule at the future oval window during the seventh week. The mesenchyme in this depression fuses with the stapedial ring to form the stapes footplate [37, 38]. Once the base of the stapes has fully developed, dedifferentiation of the oval window cartilage occurs, and a rim of fibrous tissue forms to produce the annular ligament [36].

Clinical Implications

Oval Window Atresia

When the primitive stapes fails to fuse with the primitive vestibule, the oval window cannot develop, resulting in its congenital absence. One widely accepted explanation for the congenital absence of the oval window proposes that during the fifth and sixth weeks of gestation, the developing facial nerve becomes anteriorly displaced and interposed between the otic capsule and the stapes blastema. As a result, the contact between the stapes and the otic capsule is prevented; thus, the development of the oval window is not initiated [35, 39, 40]. An abnormal appearance of the stapes is often associated with congenital absence of the oval window.

In addition, a congenital absence of the oval window could be associated with different anomalies of the tympanic segment of the facial nerve canal such as a low-lying facial nerve relative to the oval window or a canal situated within or below the expected location of the oval window or a dehiscent large facial nerve [41].

Failure of development of the annular ligament results in congenital fixation of the stapes footplate.

2.6.1.3 Fissula Ante Fenestram

The fissula ante fenestram is part of the perilymphatic labyrinth and it is unique to humans. The fissula is first apparent in the ninth week (embryo of 34 mm) [42], as a strip of precartilage in the lateral wall of the cartilaginous otic capsule immediately anterior to the oval window. During the next 3 weeks, this extension of periotic tissue stretches as a connective tissue ribbon from the vestibule to the middle ear. The fissula continues to grow until mid-fetal life about 21st week, at which time the ossification of the otic capsule is almost completed (Fig. 2.29). The cartilage border that separates the connective tissue of the fissula from the bone of the otic capsule is gradually replaced by intrachondral bone.

Because of the metamorphosis of the lining cartilage rests, the fissula is thought to be the area of histological instability. Later in life the new bone-forming process may be enhanced and expand to become an active focus of otosclerosis [43].

2.6.1.4 Round Window

The round window area appears during the 11th week. By this time ossification has started in the otic capsule. During the ossification of the otic capsule, the round window niche is surrounded by a thickened ring of cartilage which isolates the round window mesenchyme from the ossifying otic capsule and prevents the ossification of the round window opening. Further differentiation of the cartilage ring forms the round window niche, and the round window membrane appears inside the niche with an epithelial layer of mucous membrane. Mesenchymal tissue left unabsorbed in the round window niche may form a separate outer membrane, closing off the actual niche.

When the cartilage ring does not develop, osseous obliteration will occur and lead to congenital round window atresia [44].

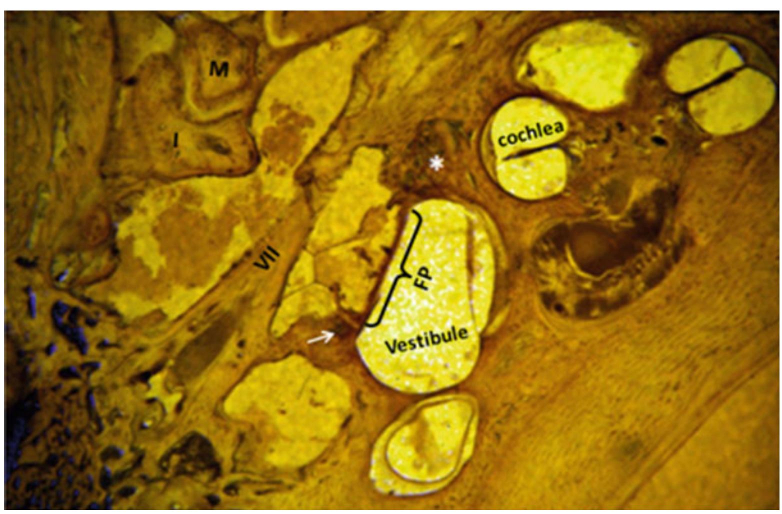

Fig. 2.29 Transverse cut of a left temporal bone of a 28-week-old embryo showing the fissula ante fenestram (*) in front of the footplate (*FP*) and the fissula post fenestram posterior to the footplate (*white arrow*). *VII* facial nerve, *I* incus, *M* malleus

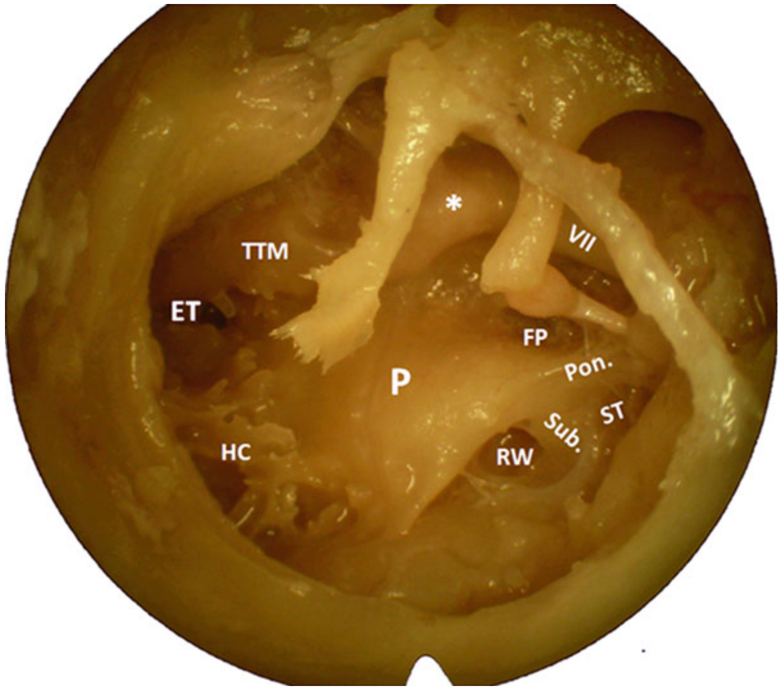

Fig. 2.30 Endoscopic view of a left middle ear. *VII* tympanic facial nerve, * cochleariform process, *TTM* tensor tympani muscle, *RW* round window, *ET* Eustachian tube, *FP* footplate, *P* promontory, *HC* hypotympanic cells, *ST* sinus tympani, *Pon* ponticulus, *Sub* subiculum

The ossification of the walls of the round window niche starts at the 16th week and is established by both membranous and endochondral ossification. However, related to the different degrees of this double ossification types, there will be a great variability in the phenotypes of the round window niche. Depending on the state of development of the upper and anterior walls of the niche, the plane of the opening of the round window niche can be horizontal, dorsal, or lateral.

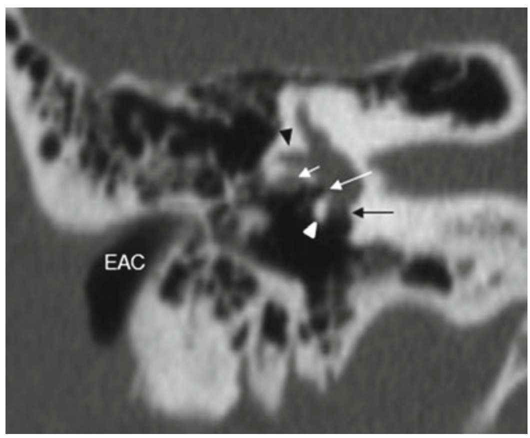

Fig. 2.31 Coronal computed tomographic reconstruction of a right ear. The medial wall of the middle ear cavity from upward to downwards: the lateral semicircular canal (*black arrowhead*), the tympanic facial nerve (*short white arrow*), the oval window (*long white arrow*), the round window (*black arrow*), promontory (*white arrowhead*), *EAC* external auditory canal

2.6.2 Medial Wall Anatomy

The medial wall of the tympanic cavity separates the middle ear cleft from the adjacent inner ear. The canal of the tensor tympani muscle anteriorly and the tympanic Fallopian canal posteriorly are two landmarks that divide the medial wall into upper third part and lower two third part. The upper third forms the medial wall of the epitympanum and is demarcated posteriorly by the lateral semicircular canal (LSCC). The lower two-thirds form the medial wall of the mesotympanum and include the cochlear promontory on the center, the oval window posterosuperiorly, and the round window posteroinferiorly (Figs. 2.30 and 2.31).

2.6.2.1 Tensor Tympanic Muscle Bony Canal and the Cochleariform Process

The semicanal of the tensor tympani muscle (semicanalis m. tensoris tympani) is cylindrical and extends from the protympanum on to the labyrinthine wall of the tympanic cavity and ends immediately in front of the oval window niche.

The medial wall of the tympanic cavity is marked by a slightly curved bone protruding laterally called the cochleariform process which is situated anterosuperior to the oval window and just inferior to the tympanic segment of the facial nerve. It represents the posterior end of the bony canal of the TTM. This curved projection of bone is concave anteriorly, and it houses the tendon of the tensor tympani muscle. The tendon turns laterally and attaches at the medial aspect of the handle of the malleus.

> ***Surgical Pearl***
> The cochleariform process is a highly important anatomical and surgical landmark to identify the facial nerve and the oval window in invasive pathologies (Fig. 2.32).

2.6.2.2 Facial Nerve Canal

The prominence of facial nerve canal is an important anatomical structure present in the upper part of the medial wall of the mesotympanum. This nerve canal runs obliquely above the promontory and above the oval window in an anteroposterior direction from above the cochleariform process anteriorly down below and medial to the dome of the lateral semicircular canal. It presents its second genu at the turning point between the horizontal tympanic portion and the vertically descending mastoid portion in the posterior wall of the tympanic cavity.

In the medial wall the bony canal of VII could be dehiscent to leave the VII only covered with a submucosa or even prolapsing lying over the oval window (see Chap. 6). This situation is highly at risk during middle ear surgery. Even infections of the middle ear mucosa can cause facial nerve palsy in patients with an exposed facial nerve (Figs. 2.31 and 2.32).

2.6.2.3 Lateral Semicircular Canal

The region above the level of the facial nerve canal forms the medial wall of the attic. The dome of the lateral semicircular canal extends a little lateral to the facial canal and is the most

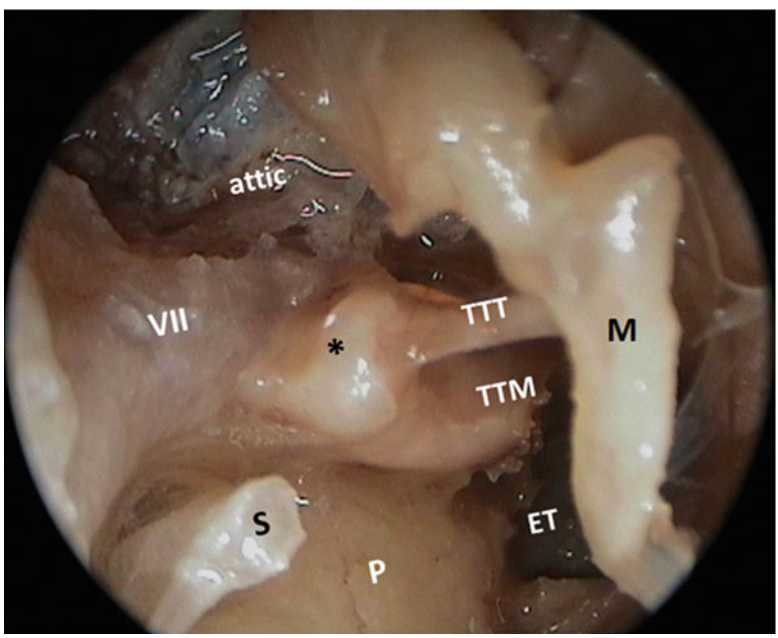

Fig. 2.32 Endoscopic view of a right middle ear through a posterior tympanotomy showing the tympanic segment of the facial nerve (*VII*) and its relationship with the cochleariform process (*) and stapes (*S*). *TTM* tensor tympani muscle, *TTT* tensor tympani tendon, *P* promontory, *ET* Eustachian tube, *M* malleus

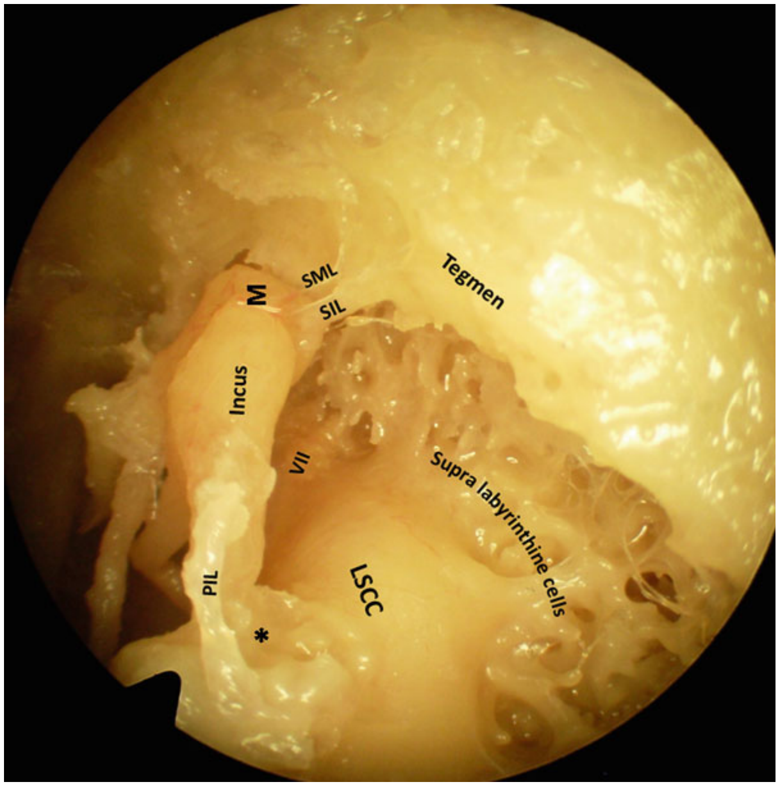

Fig. 2.33 Medial wall of the attic. *LSCC* lateral semicircular canal, *VII* facial nerve, *M* malleus, *PIL* posterior incudal ligament, *SIL* superior incudal ligament, *SML* superior malleal ligament, * incudal fossa

prominent structure of the posterior portion of the epitympanum (Figs. 2.31 and 2.33).

2.6.2.4 The Cochlear Promontory

The promontory is a prominent eminence occupying most of the central portion of the medial wall of the middle ear and lodges between the oval and round windows. This projection represents the underlying basal turn of the cochlea (Fig. 2.34a).

The promontory surface is grooved to accommodate the branches of the tympanic plexus (Jacobson's nerve), which enters the temporal bone through the tympanic canaliculus, just anterior to the jugular foramen.

Surgical Pearl

The basal turn of the human cochlea is a bony canal. The least covered portion is located behind the apex of the promontory. The lower half of the basal turn of the cochlea can be approached from the facial recess or external auditory canal during cochlear implantation. The second and third turn of the cochlea are also approachable from the tympanic cavity; nevertheless, to be able to reveal the second and third turns fully, the tensor tympani muscle and the semicanal must be completely removed (Fig. 2.34).

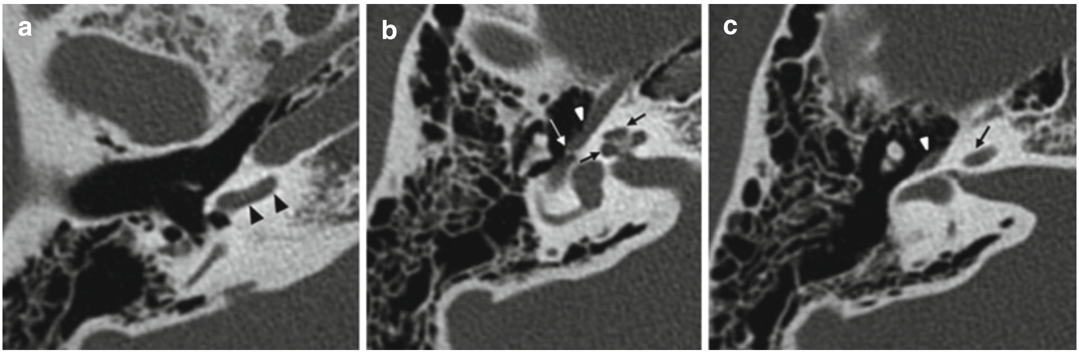

Fig. 2.34 Transversal computed tomography of a right ear. The medial wall of the middle ear in relation to (**a**) the basal turn of the cochlea (*arrowheads*). (**b**) The second turn of the cochlea (*black arrows*), the tensor tympani muscle (*white arrowhead*), the cochleariform process (*white arrow*). (**c**) The highest level of the cochlea (*arrow*), facial nerve (*arrowhead*)

2.6.2.5 The Oval Window Niche

The oval window niche (fenestra vestibuli) is located in the medial wall of the posterior part of the mesotympanum behind and above the promontory inferior to the facial nerve canal.

The oval window niche is limited anteriorly and superiorly by the cochleariform process and posteriorly by the ponticulus, sinus tympani, and pyramidal eminence. It is situated in a depression called the fossula vestibuli where its depth depends on the facial nerve position and the variable prominence of the promontory (Fig. 2.30).

It is a kidney-shaped opening leading to the vestibule of the inner ear. The long diameter of the oval window is horizontal and its convex border is directed upward. It is closed by the footplate of the stapes which is rounded by the annular ligament. The dimensions of the oval window average 3.25 mm long and 1.75 mm wide.

Fissula Ante Fenestram

The fissula ante fenestram is considered as an appendage of the perilymphatic labyrinth; it is a strip of periotic connective tissue extending from the vestibule just anterior to the oval window through an irregular still-like space in the bony otic capsule to join the mucoperiosteum of the tympanic cavity below the pulley of the tensor tympani muscle. Usually it is obliterated by fibrous tissue and immature cartilage (Fig. 2.35).

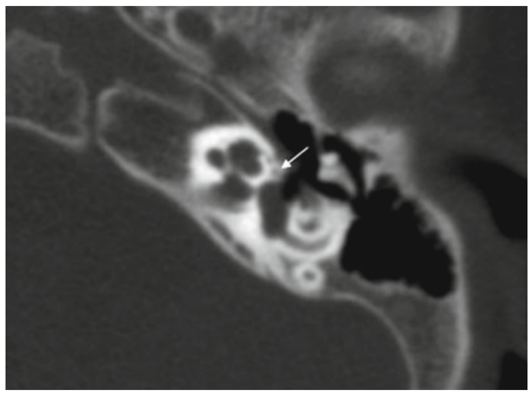

Fig. 2.35 Transversal computed tomography showing the normal appearance of the fissula ante fenestram (*white arrow*) in a child

Fissula Post Fenestram

This is an evagination of the periotic tissue into the otic capsule just posterior to the oval window at a point about one third of the way between the window and the non-ampullated end of the lateral semicircular canal.

> ***Clinical Application***
> In cases of otosclerosis, the oval window can be the site of different degrees of invasion, ranging from a typical focal anteroinferior thickening to a complete obliteration (Fig. 2.36).

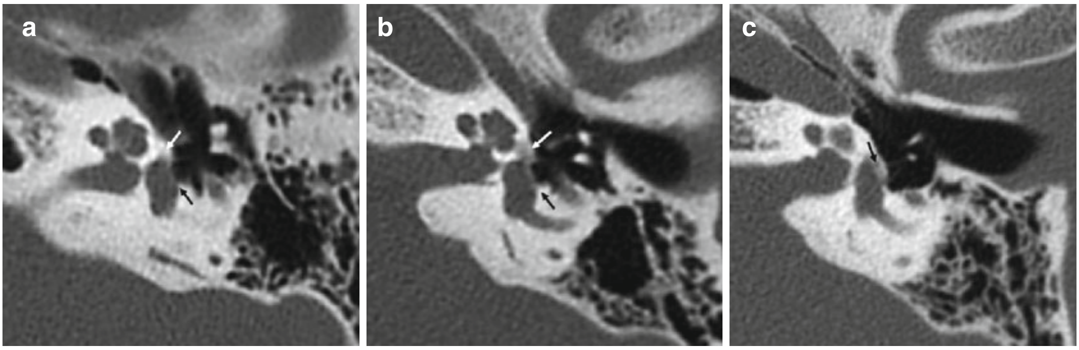

Fig. 2.36 Transversal computed tomography of left ears: (**a**) normal thin aspect of the footplate (*black arrow*), very small prevestibular otospongiotic focus (*white arrow*); (**b**) moderate otosclerotic footplate thickening (*black arrow*) with a large prevestibular focus (*white arrow*); (**c**) obliterating footplate otosclerosis (*black arrow*)

2.6.2.6 The Round Window

The round window is the second opening of the labyrinth to the middle ear. The round window niche is located in the posteroinferior aspect of the promontory in the medial wall of the tympanic cavity. The round window niche is closed by the round window membrane.

The round window niche is never more than 2 mm from the inferior margin of the oval window and is separated from the promontory by the subiculum. The round window niche varies in depth up to approximately 1 mm and is usually triangular in shape, having anterior, posterosuperior and posteroinferior walls [45–50] (Figs. 2.30 and 2.31).

The posterosuperior and posteroinferior walls meet posteriorly leading to the sinus tympani (Fig. 2.30). The anterior and posteroinferior margin of the round window overlies a crest (*crista fenestra*), which projects a mean distance of 0.2 mm; it must be drilled away during cochlear implantation to insure a good exposure and to allow the electrode to pass tangentially along the basal turn of the cochlea [49].

> ***Surgical Application***
> The ampulla of the posterior semicircular canal is the closest vestibular structure to the round window. The nerve supplying this ampulla, *singular nerve*, lies close to the round window niche. The round window forms a landmark for the position of the singular nerve. The singular canal that contains the nerve lies immediately inferior to the posterior attachment of the round window membrane.

Near the round window, the cochlear aqueduct connects the scala tympani (perilymph) with the subarachnoid space CSF.

Large hypotympanic cells of the hypotympanum border inferiorly the round window niche. These prominent cells must not to be mistaken as the round window niche, especially during cochlear implant surgery.

> ***Clinical Implication***
> The round window is the second most common site of otosclerosis. Round window involvement varies from mild involvement of the edge to a complete obliteration of the niche. Round window involvement could be diagnosed and staged by HRCT scan with thin cuts and classified from RW1 to RW5 [50] (Fig. 2.37).

Round Window Membrane

The round window membrane lies in the round window niche obscured to a variable degree by a bony overhang, which extends over the membrane anteriorly and superiorly for a distance of up to 1 mm [49, 50]. The round window membrane is placed at a right angle to the plane of the footplate.

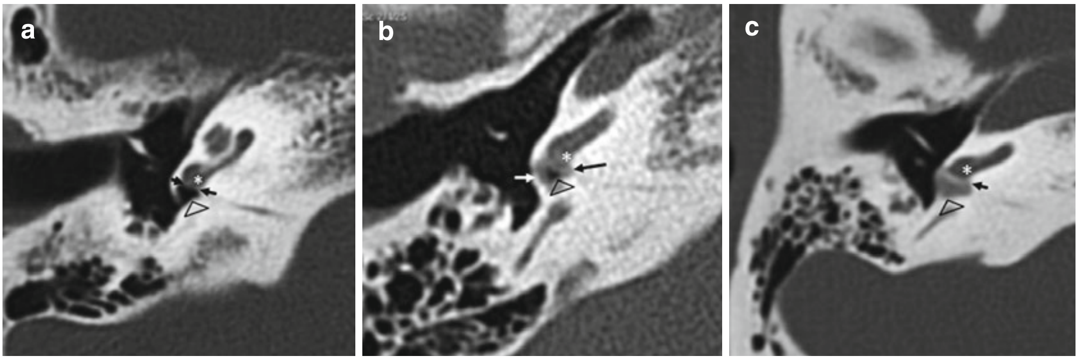

Fig. 2.37 Computed tomography in the transversal plan of right ears showing (**a**) normal round window membrane (*between the small black arrows*), very thin limit between the air filled round window recess (*arrowhead*) and the endolymph in the scala tympani of the basal turn of the cochlea (*) (**b**) otosclerotic foci on the promontory (*white arrow*) and of the round window (*black arrow*), presence of air in round window recess (*arrowhead*), but separated from the scala tympani (*) by the otosclerotic focus: RW3 (**c**) Condensation of the round window membrane (*black arrow*), scala tympani (*), complete obliteration of the round window recess (*arrowhead*): RW4

Clinical Application

The promontory covers completely the round window membrane which is oriented inferiorly and posteriorly. Therefore, in a transcanal approach, it is impossible to see the membrane per se directly. The correct assessment of a diseased round window membrane such as in otosclerosis with its different stages or an invasive tympanosclerosis is only possible with thin-cut computed tomography [50]. In addition a good access to the membrane requires surgical removal of the superior overhang of the niche. Moreover, some strands draped over the RW niche, remnants of embryonic connective tissue, render the RW membrane difficult to be seen (Fig. 2.38).

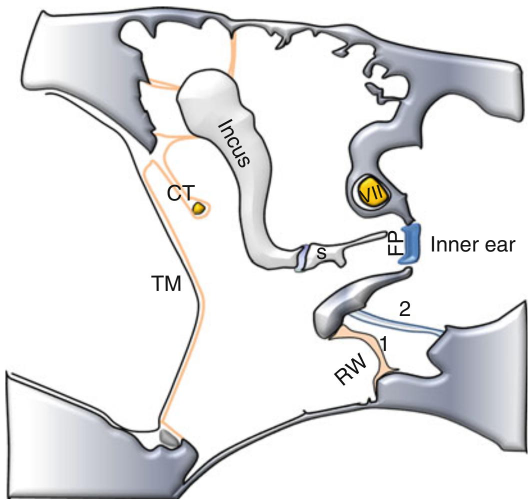

Fig. 2.38 Schematic drawing showing the round window (*RW*) with its false membrane (*1*) and true membrane (*2*). *S* stapes, *TM* tympanic membrane, *FP* footplate, *CT* chorda tympani

The mean horizontal diameter of the round window membrane is 1.35 mm and the vertical diameter 1.79 mm [46–50]. The membrane does not lie at the end of the scala tympani but forms part of its floor. The hook region of the basal turn of the cochlea is a cul-de-sac lying posterior to the round window.

The thickness of the normal human RWM is 60–70 μm [51]. The ultrastructure of the RWM consists of an outer epithelium of low cuboidal cells lining the middle ear, an inner epithelium of squamous cells bordering the inner ear, and a layer of connective tissue between the epithelial layers. The connective tissue layer consists of fibroblasts, collagen, and elastic fibers.

The membrane has several functions [52]: It releases mechanical energy to the labyrinthine fluids, permitting movement of the inner ear fluids associated with the movements of the stapedial footplate; thus, patency of the niche is essential for efficient acoustic transmission; it can serve as an alternative route for sound energy to enter the cochlea.

Clinical Application
Passage through the membrane is possible for small molecules by passive diffusion and for larger molecules probably by endocytosis [53, 54]. The round window membrane acts as the main gateway for local therapy of inner ear diseases. Drugs (such as dexamethasone and gentamicin) or bacterial exotoxins (in case of acute and chronic otitis media) present in the middle ear may pass through the round window membrane to reach the inner ear [55].

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