Middle Ear Compartments

4

Contents

The middle ear cavity is anatomically not only a sole chamber, but a space with different compartments. The objective of this chapter is to present a detailed and exhaustive description of these compartments, their frontiers, their relationship, and their connections to improve the understanding of the pathophysiology of the inflammatory and cholesteatomatous middle ear diseases.

The middle ear cavity was divided into five compartments: the mesotympanum in the center, the epitympanum superiorly, the protympanum anteriorly, the hypotympanum inferiorly, and the retrotympanum posteriorly (Fig. 4.1).

In addition, this chapter, based on the description of the anatomy of the middle ear folds in Chap. 3, will describe several anatomo-functional units inside or even beyond the traditional division of the compartments.

The comprehensive knowledge of this detailed anatomy is the key of success in the management of middle ear disorders.

4.1 Embryology of Middle Ear Compartments

In the developing human, the tympanomastoid system appears in the 3rd week of life from an outpouching of the first pharyngeal pouch called the tubotympanic recess. The endodermal tissue of the dorsal end of this pouch becomes the Eustachian tube and the tympanic cavity [1].

By the 7th week, a concomitant growth of the second branchial arch constricts the midportion of

S. Mansour et al., *Comprehensive and Clinical Anatomy of the Middle Ear*,
DOI 10.1007/978-3-642-36967-4_4, © Springer-Verlag Berlin Heidelberg 2013

the tubotympanic recess, placing the primary tympanic cavity lateral to this constriction and the primordial Eustachian tube medial to this constriction [1]. The future development of the Eustachian tube is marked by lengthening, narrowing, and mesodermal chondrification establishing the fibrocartilaginous Eustachian tube (see Sect. 7.1).

The terminal end of the tubotympanic recess buds into four sacci: the saccus anticus, the saccus medius, the saccus superior, and the saccus posticus [1–3]. These sacci expand progressively to replace middle ear mesenchyme and mastoid mesenchyme (Fig. 4.2). The walls of the expanding sacci envelop the ossicular chain and line the walls of middle ear cavity; the interface between two sacci gives rise to several mesentery-like mucosal folds, transmitting blood vessels and ligaments to middle ear contents.

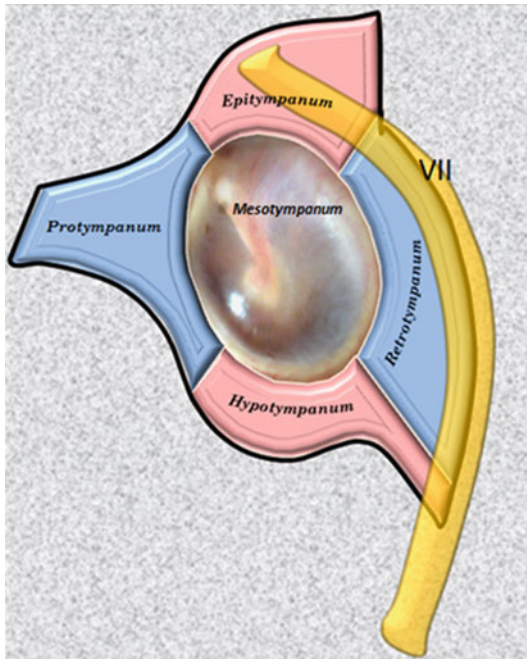

Fig. 4.1 Middle ear compartments; *VII* facial nerve

4.1.1 The Saccus Anticus

The saccus anticus is the smallest saccus. It extends upward anterior to the tensor tympani tendon to form the anterior epitympanic recess and the anterior pouch of von Tröltsch. At the level of the tensor tympani muscle canal, it fuses with the anterior saccule of the saccus medius to form an important mucosal fold, the tensor tympani fold. The tensor tympani fold separates the anterior epitympanic recess superiorly from the supratubal recess inferiorly [2] (Figs. 4.2 and 4.3).

4.1.2 The Saccus Medius

The saccus medius forms the attic. It extends upward and divides into three saccules:

1. Anterior saccule: It develops upward to form the anterior compartment of the attic.
2. Medial saccule: The medial saccule forms the superior incudal space by its growth over

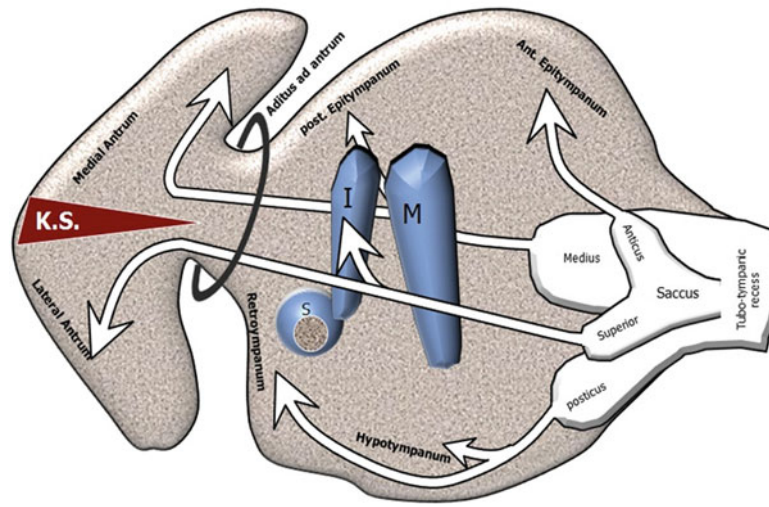

Fig. 4.2 Embryology of middle ear spaces. *I* incus, *M* malleus; S, stapes, *KS* Korner's septum

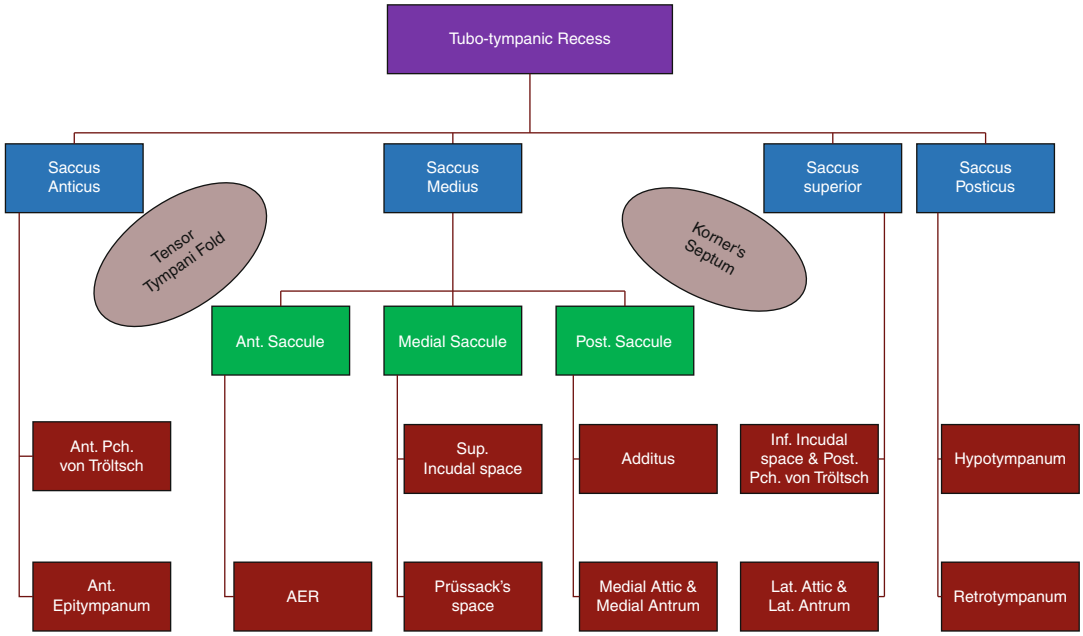

Fig. 4.3 Table illustrating the origin of the different spaces, recesses, and pouches of the middle ear

the incudomalleal bodies and the posterior incudal ligament. The medial saccule sends an offshoot forward to form the Prussak's space.

3. Posterior saccule: The posterior saccule extends posteriorly between the long process of the incus and the stapes to form the medial portion of the mastoid antrum which is derived from the petrous part of the temporal bone [2] (Figs. 4.2 and 4.3).

4.1.3 The Saccus Superior

The saccus superior forms the posterior pouch of von Tröltsch and the inferior incudal space. It extends posteriorly and laterally between the handle of the malleus and the long process of the incus to form the posterior pouch of von Tröltsch, the inferior incudal space, and the lateral part of the antrum which derives from the squamous part of the temporal bone.

The plane of fusion between the posterior saccule of the saccus medius, which forms the medial part of mastoid air cells system, and the saccus superior, which forms the lateral part of mastoid air cells system, usually breaks down. If the breakdown fails, a bony septum persists between the two parts, called the Korner's septum [2] (Figs. 4.2 and 4.3).

4.1.4 The Saccus Posticus

The saccus posticus extends along the hypotympanum and rises up posteriorly to form the round window niche, the oval window niche, the facial recess, and the sinus tympani.

The sinus tympani has a variable size and depth posteriorly; this variation is dependent on the degree of extension of the saccus posticus under the stapedial tendon during fetal development [2] (Figs. 4.2 and 4.3).

4.2 Anatomy of the Protympanum

The protympanum is the middle ear compartment that lies anterior to a frontal plane drawn through the anterior margin of the tympanic annulus (Fig. 4.1). This space is widely open posteriorly into the mesotympanum; it leads anteriorly into the Eustachian tube. We included into the protympanum the whole bony portion of the Eustachian tube which is 1 cm long in adults.

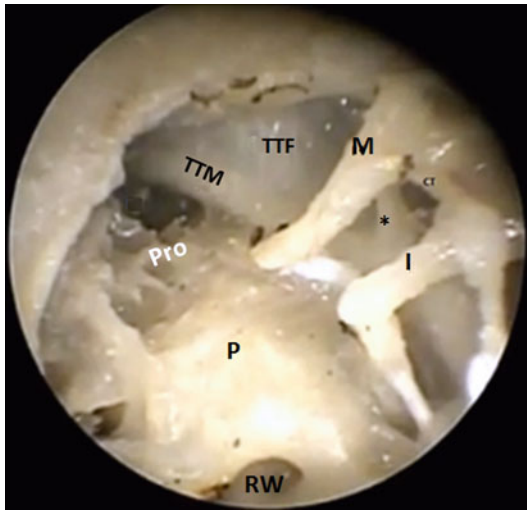

Fig. 4.4 Endoscopic view of a left cadaveric middle ear showing the protympanum (*Pro*) which is limited superiorly by the canal of the tensor tympani muscle (*TTM*) and the tensor tympani fold (*TTF*). (*) cochleariform process, *M* malleus, *I* incus, *P* promontory, *RW* round window, *CT* chorda tympani

4.2.1 Walls of the Protympanum

The lateral wall of the protympanum consists of a thin plate of the tympanic bone called the lateral lamina; this plate separates the protympanum from the mandibular fossa. The medial wall consists of the cochlea posteriorly and the carotid canal anteriorly. The roof is composed of the bony semicanal for the tensor tympani muscle and the tensor tympani fold separating the protympanum from the anterior attic (Fig. 4.4).

4.2.2 The Supratubal Recess (STR)

The supratubal recess is the superior extension of the protympanum. It corresponds to the space lying between the superior border of the tympanic orifice of the Eustachian tube and the tensor tympani fold. It lies below the anterior attic from which it is separated by the tensor tympani fold (TTF).

The size of the supratubal recess depends on the anatomy of the TTF (see Sect. 3.6.2.10). The TTF forms the roof of the protympanum and has variable orientations depending on the level of its anterior insertion. For instance, a horizontal TTF results in a small or even absent supratubal recess and a vertical TTF gives place to a large supratubal recess [4–6] (see Fig. 3.38).

4.3 Anatomy of the Hypotympanum

The hypotympanum is a crescent-shaped space located at the bottom of the middle ear. It lies below a horizontal plane starting from the inferior margin of the fibrous annulus to the inferior margin of cochlear promontory; it is surrounded by five walls.

4.3.1 Walls of the Hypotympanum

- *The anterior wall* is formed by the carotid canal medially and by a dense bone laterally.
- *The posterior wall* is formed by the inferior part of the styloid complex and the vertical segment of the facial nerve canal. Frequently, the posterior wall is pneumatized by air cells (retrofacial air cells) which extend from the mastoid antrum to the hypotympanum medial to the facial nerve. The posterior wall corresponds to a vertical plane from the posterior semicircular canal to the junction of the sigmoid sinus with the jugular bulb.
- *The outer wall* is formed by the tympanic bone.
- *The medial wall* is formed by the lower part of the promontory and a part of the petrous bone which extends under the promontory. This wall is usually pneumatized; its air cell system may extend beneath the cochlea to reach the petrous apex air cells. Rarely the medial wall is compact (Fig. 4.5).
- *The inferior wall* corresponds to a thin bony plate separating the hypotympanum from the jugular bulb (Fig. 4.5). In cases of a high jugular bulb, the hypotympanum is significantly reduced, or it could even be missing.

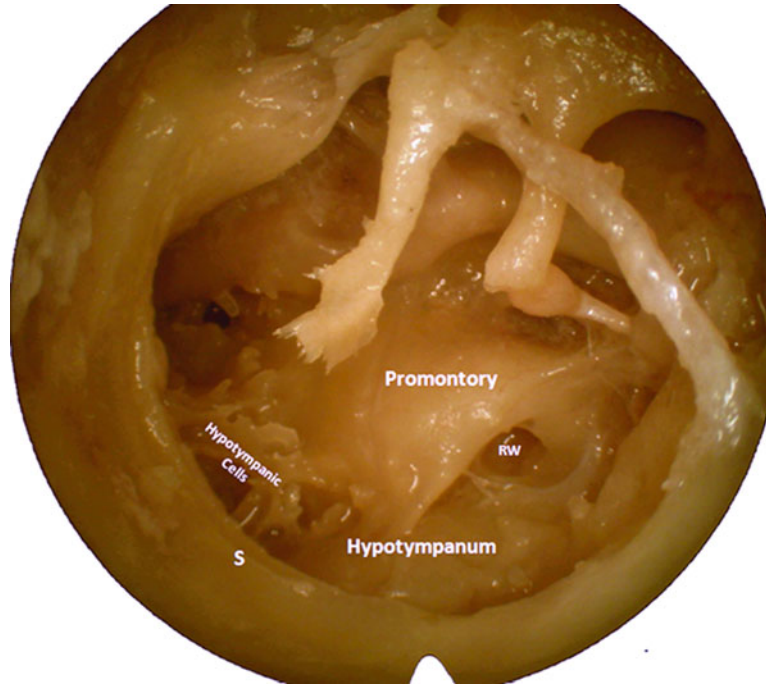

Fig. 4.5 Endoscopic view of a left ear showing the hypotympanum and some hypotympanic cells. Notice that the hypotympanum lies below the level of the tympanic sulcus (*S*). In this case, the inferior wall of the hypotympanum is smooth and consists of a thin plate of bone separating the middle ear from the jugular bulb. *RW* round window

4.3.2 Air Cells in the Hypotympanum

The air cells of the hypotympanum are divided into:

4.3.2.1 Hypotympanic Air Cells

The hypotympanic air cells, present in the medial and inferior wall of the hypotympanum, may extend below the labyrinth to reach the petrous apex cells (infralabyrinthine tract) (Fig. 4.6 and see Fig. 2.12b).

Surgical Applications

Infracochlear Approach

Through a transcanal hypotympanotomy, removal of the bone and the cells of the medial wall of the hypotympanum, between the carotid artery anteriorly and the jugular bulb posteriorly, offers a direct surgical approach for the drainage of the petrous apex [7–9].

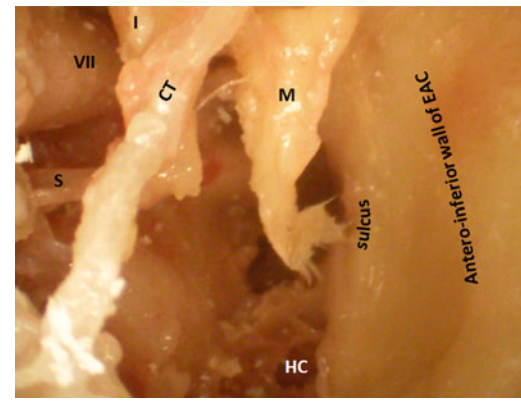

Fig. 4.6 Endoscopic view of a right ear showing hypotympanic cells in the inferior and medial wall of the hypotympanum. *M* malleus, *I* incus, *S* stapes, *CT* chorda tympani, *VII* tympanic segment of the facial nerve

4.3.2.2 Retrofacial Cells

The retrofacial cells extend from the central mastoid tract medial to the facial nerve and drain into the hypotympanic space.

Surgical Application

Retrofacial Hypotympanotomy

Dissecting the retrofacial cells medial to the vertical segment of the facial nerve between the jugular bulb inferiorly and the posterior semicircular canal superiorly provides a good access to the hypotympanum and the related structures without transposing the facial nerve or taking down the posterior external auditory canal wall (retrofacial hypotympanotomy) [10]. A high-riding jugular bulb obstructs this approach (see Fig. 2.12) (see Sect. 2.2.2.2).

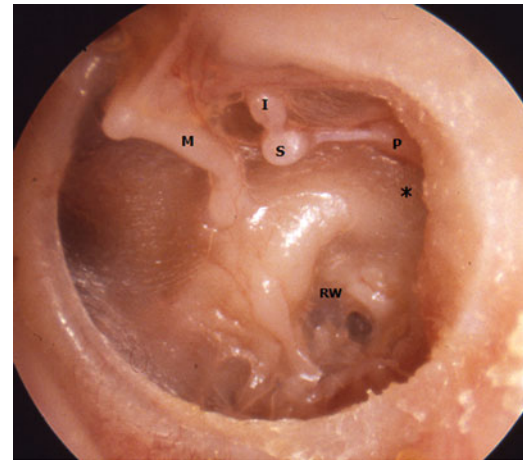

Fig. 4.7 Otoscopic view of a left ear showing adhesive otitis media and a posterior pars tensa retraction pocket into the retrotympanum (*). *I* incus with lysis of its long process, *M* malleus, *S* stapes, *P* pyramidal eminence, *RW* round window

4.4 Anatomy of the Retrotympanum

The retrotympanum is a complex region. It consists of several separate spaces lying in the posterior aspect of the tympanic cavity medial and posterior to the tympanic annulus (Fig. 4.1). The retrotympanum is the site of the highest incidence of middle ear pathologies especially retraction pockets and cholesteatoma (Fig. 4.7).

The retrotympanum includes four spaces: two spaces lie medial to the vertical segment of the facial nerve and the pyramidal eminence and two spaces lie lateral to them. These spaces are separated from each other by the bridges and the eminences of the posterior wall of the middle ear cavity. The pyramidal eminence is the fulcrum of the retrotympanum (Fig. 4.8) (see Sect. 2.3.2).

4.4.1 The Lateral Spaces

The lateral spaces of the retrotympanum form the facial recess. The facial recess is bordered medially by the facial canal and the pyramidal eminence and laterally by the chorda tympani. Superiorly, the facial recess is bounded by the incudal buttress, bony boundary of the incudal fossa, which lodges the short process of the incus. The incudal buttress separates the facial recess from the aditus ad antrum. Inferiorly, the facial recess is limited

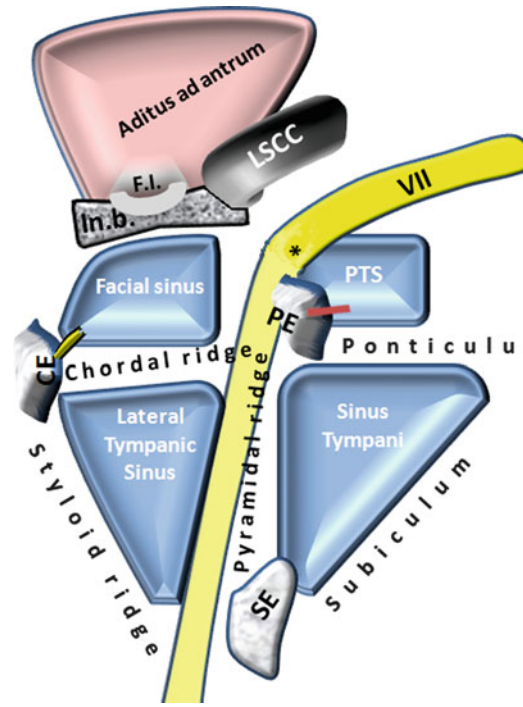

Fig. 4.8 Schematic drawing of the retrotympanum as viewed from the mesotympanum. *PE* pyramidal eminence, *CE* chordal eminence, *SE* styloid eminence, *VII* tympanic segment of facial nerve, * second genu of facial nerve, *FI* fossa incudis. *In.b.* incudal buttress, *PTS* posterior tympanic sinus, *LSCC* lateral semicircular canal

by the chordo-facial angle which ranges from 18° to 30°; the distance between the origin of the chorda tympani and the short process of the incus ranges from 5 to 10 mm [11].

The facial recess size is variable among individuals; however, it does not differ between age groups ranging from newborns to adults, indicating that it is near adult size at birth [12–14]. It measures about 2 mm at the level of the round window and 3 mm at the level of the oval window [15, 16].

The chordal ridge, which runs between the pyramidal eminence and the chordal eminence, divides the facial recess into the facial sinus superiorly and the lateral tympanic sinus inferiorly.

4.4.1.1 The Facial Sinus

The facial sinus is the superior part of the facial recess. It is a small pouch that is situated between the incudal buttress superiorly, the chordal ridge inferiorly, and the second genu of the facial nerve medially. There is no connection of the facial sinus with the air cells of the attic or mastoid process.

4.4.1.2 The Lateral Tympanic Sinus

The lateral tympanic sinus is the inferior part of the facial recess and is the most lateral and narrowest sinus of the retrotympanum. It represents the interval among the three eminences of the styloid complex (pyramidal eminence, styloid eminence, chordal eminence). It lies medial to the chordal eminence, inferior and lateral to the pyramidal eminence, and superior to the styloid eminence. The dimensions of the lateral tympanic sinus vary from 1.5 to 2.5 mm [17, 18]; it has no connection with the attic or the antrum.

Surgical Application

The facial recess serves as a posterior window to reach the middle ear from the mastoid cavity, enabling the visualization of the oval window and ponticulus superiorly and the round window and subiculum inferiorly. This important surgical approach is called transmastoid posterior tympanotomy; it is done by a transmastoid drilling of the posterior wall of the facial recess, between the chorda tympani laterally and the facial nerve medially (Fig. 4.9).

In cases of narrow facial recess or incomplete exposure of the target middle ear structure, extended facial recess approach could be done. In this technique, the chorda tympani nerve is sacrified and drilling is done between the annulus of the

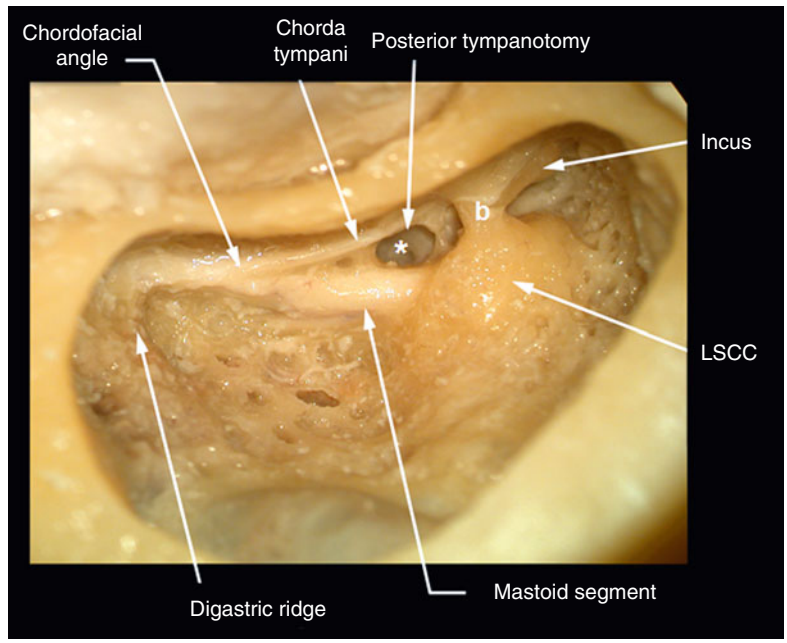

Fig. 4.9 Left ear, transmastoid posterior tympanotomy (*). *b* incudal buttress, *LSSC* lateral semicircular canal

tympanic membrane and the facial nerve. This leads to a wider exposure of the middle ear. The mean width of the extended facial recess is about 5 mm [19, 20].

During posterior tympanotomy, the risk of facial nerve damage and the probability of sacrifying the chorda tympani depend on the dimensions of the facial recess [11, 18, 21, 22], which varies widely in the general population. However, preoperative thin-section CT scans allow surgeons to make a precise assessment of these anatomic structures during preoperative planning (Fig. 4.10).

4.4.2 The Medial Spaces

The medial spaces of the retrotympanum, called the tympanic sinus**,** are the depressions in the posterior wall of the middle ear that lie between the facial nerve and pyramidal eminence laterally and the labyrinth medially (Figs. 4.8 and 4.11).

The ponticulus, which runs from the promontory to the pyramidal eminence, divides the tympanic sinus in two spaces: the posterior tympanic sinus superiorly and the sinus tympani inferiorly.

4.4.2.1 Posterior Tympanic Sinus

The posterior tympanic sinus is present in most middle ears [23]; it lies superior to the ponticulus, medial to the pyramidal eminence and facial nerve. It is about 1 mm deep and about 1.5 mm long [24]. In ears where the ponticulus does not reach the posterior wall of the middle ear, the posterior tympanic sinus merges with the sinus tympani to form one confluent sinus.

Surgical Application

During middle ear surgery, in order to reach the posterior tympanic sinus, section of the stapedial tendon and drilling of the pyramidal process may be required.

4.4.2.2 The Sinus Tympani

The sinus tympani is the largest sinus of the retrotympanum. It lies medial to the mastoid portion of the facial nerve, lateral to the posterior semicircular canal. It is limited superiorly by the

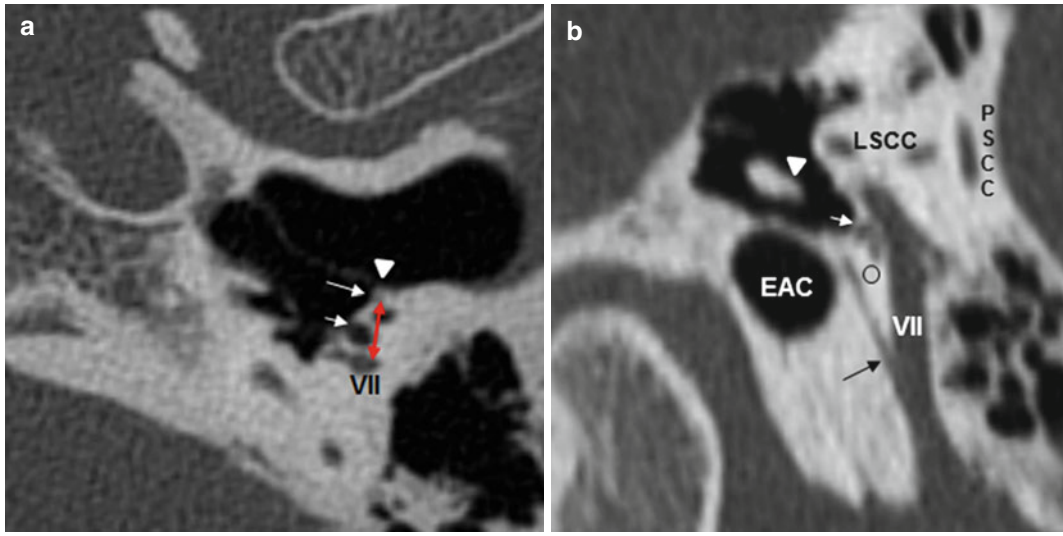

Fig. 4.10 (**a**) A transversal computed tomography showing the distance (*red line*) between the chorda tympani (*long white arrow*) and the mastoid segment of the facial nerve (*VII*); the *arrowhead* shows the annulus. (**b**) Sagittal reconstruction of a computed tomography showing the emergence of the chorda (*black arrow*) from the facial nerve (*VII*) and the bony wall (*circle*) between the chorda and the VII (facial recess approach). *White arrow* facial recess, *white arrowhead* short process of the incus, *LSCC* lateral semicircular canal, *PSCC* posterior semicircular canal

ponticulus and the pyramidal eminence and inferiorly by the subiculum and the styloid eminence.

The sinus tympani has a great variability in size and shape and depth. Its posterior extension varies between 0.2 and 10 mm with an average of 2 mm [25–27].

In about 10 % of the population, the sinus tympani and posterior tympanic sinus form one confluent recess [24].

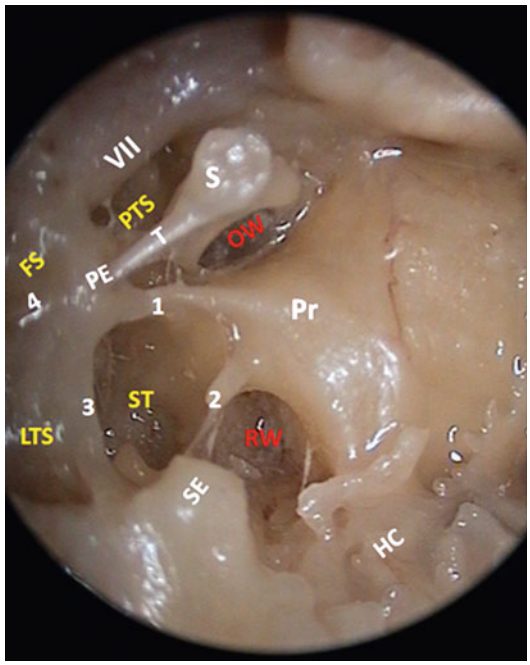

Fig. 4.11 Endoscopic view of a right middle ear showing the different sinuses and recesses of the retrotympanum. *PTS* posterior tympanic sinus, *ST* sinus tympani, *LTS* lateral tympanic sinus, *FS* facial sinus, *PE* pyramidal eminence, *SE* styloid eminence, *1* ponticulus, *2* subiculum, *3* pyramidal ridge, *4* chordal ridge, *OW* oval window, *RW* round window, *S* stapes, *T* stapedial tendon, *Pr* promontory, *HC* hypotympanic cells, *VII* facial nerve

Sinus Tympani Types and Surgical Approaches

Based on its depth, the sinus tympani is classified into three types with an equal frequency in the general population [28, 29] (Fig. 4.12).

- Type A is a shallow sinus tympani; it is small and does not reach the level of the vertical portion of the facial nerve posteriorly. In such cases surgical transcanal access to the sinus tympani is possible.
- Type B sinus tympani is of intermediate depth; it lies medial to the vertical portion of the facial nerve but does not extend posteriorly deeper than the level of the facial nerve. A total and clear visualization of such sinus tympani could not be achieved without the use of an endoscope. Any blind dissection in the sinus tympani without endoscopic visualization carries a risk of residual disease or a possible injury to a dehiscent facial nerve or a high jugular bulb [30].

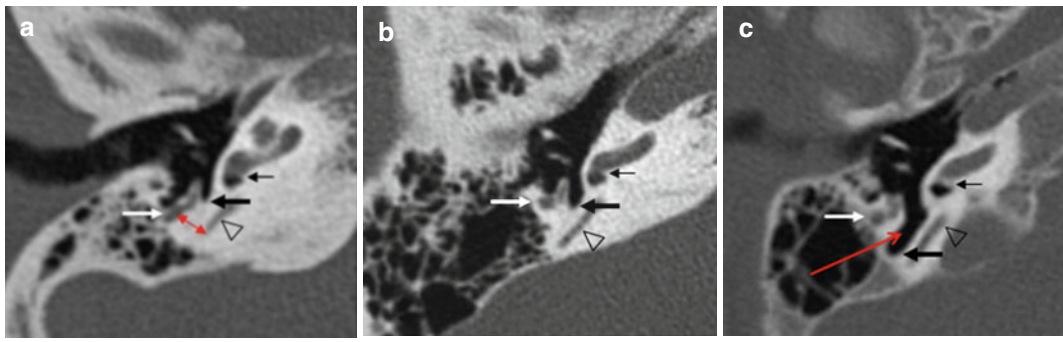

Fig. 4.12 Transversal computed tomographic view of right ears with different depths of the sinus tympani. (**a**) Type A, (**b**) Type B, (**c**) Type C. Deepest point of the sinus tympani (*thick black arrow*), facial nerve (*white arrow*), round window membrane (*thin black arrow*), posterior semicircular canal PSCC (*arrowhead*). The *red arrow* in (**a**) represents the distance between the facial nerve and the PSCC. The *red arrow* in (**c**) represents the retrofacial approach to the sinus tympani

- Type C sinus tympani is very deep; it extends posteriorly more deeply than the vertical portion of the facial nerve. This type is frequently encountered in a well-pneumatized mastoid. Despite the use of an otoendoscope, the pathology of such deep sinus could not be explored entirely from the middle ear; therefore, access should be obtained through a transmastoid retrofacial approach. This approach requires enough distance of more than 2 mm between the facial nerve and the posterior semicircular canal; otherwise, these structures could be easily injured.

4.5 Anatomy of the Attic (The Epitympanum)

The attic is the part of the tympanum situated above an imaginary plane passing through the short process of the malleus. The attic occupies approximately one-third of the vertical dimension of the entire tympanic cavity and lodges the head and neck of the malleus, the body, and the short process of the incus (Fig. 4.13). The attic is bounded by the following walls:

- *The lateral wall* of the attic is formed inferiorly by Shrapnell's membrane and superiorly by a bony wall, called the outer attic wall, "*le mur de la logette des osselets.*"
- *The medial wall* of the attic is a part of the medial wall situated above the tympanic segment of the facial nerve and tensor tympani muscle. It contains the lateral semicircular canal. This wall may be pneumatized by the supralabyrinthine tract (see Sect. 2.6.2 and Fig. 2.33).
- *The posterior wall* is occupied almost entirely by the aditus ad antrum. It is 5–6 mm high and is usually larger above than below. The aditus provides a communication between the antrum and the rest of the tympanic cavity.
- *Inferiorly*, the tympanic diaphragm divides the attic into an upper unit situated above the

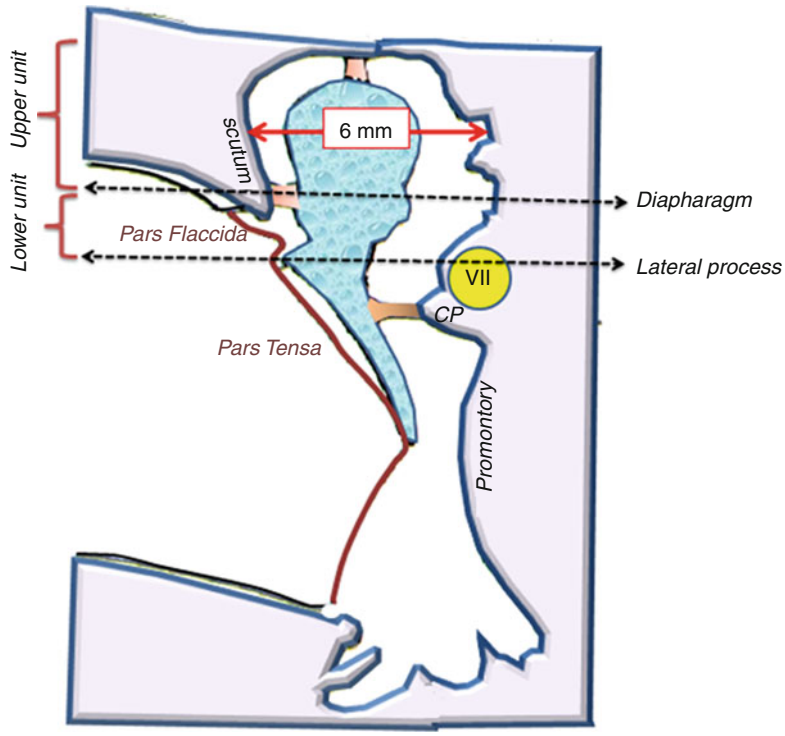

Fig. 4.13 Schema showing the upper unit and the lower unit of the attic. *VII* facial nerve, *CP* cochleariform process

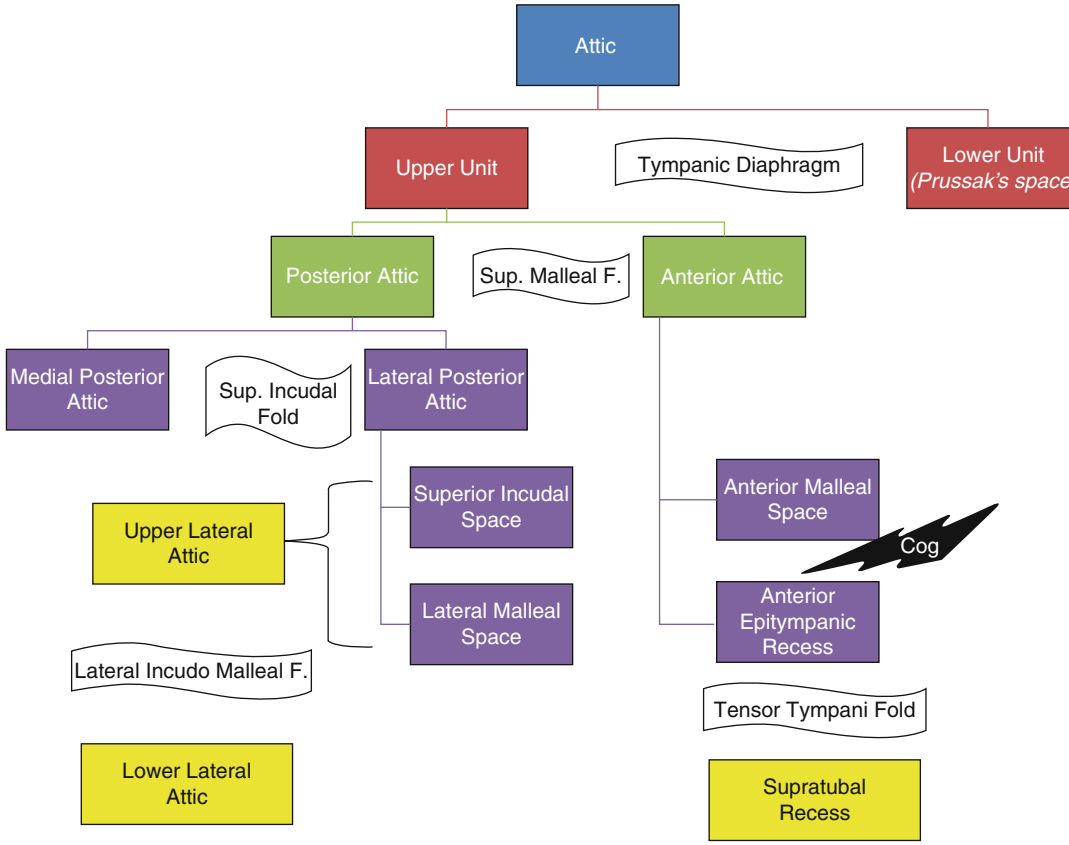

Fig. 4.14 Table showing the organization of the different compartments of the attic

tympanic diaphragm and a lower unit of the attic (the Prussak's space), which is below the diaphragm. Medially, the tympanic diaphragm separates the upper unit of the attic from the underlying upper mesotympanum. The upper unit of the attic and the mesotympanum communicate together for ventilation purposes through an opening through the diaphragm called the tympanic isthmus [33, 34] (Figs. 4.13 and 4.14) (see Sect. 3.6.3).

4.5.1 The Upper Unit of the Attic

The upper unit of the attic lies above the tympanic diaphragm (see Chap. 3, Mucosal Folds). Medially, the tympanic diaphragm separates the upper unit of the attic completely from the underlying upper mesotympanum. A communication between both spaces for ventilation purposes is only possible through an opening of the tympanic diaphragm, called the *tympanic isthmus* (see Fig. 3.41). The tympanic isthmus is situated between the tensor tympani muscle anteriorly and the posterior incudal ligament posteriorly (see Sect. 3.6.4) Laterally, the tympanic diaphragm separates the upper unit of the attic from the lower unit of the attic, the Prussak's space. Posteriorly, the upper unit of the attic communicates with the mastoid cavity through the aditus ad antrum.

In addition to this separation by the tympanic diaphragm in the horizontal plane, several folds and ligaments in the perpendicular planes lead to further divisions and spaces of the upper unit of the attic:

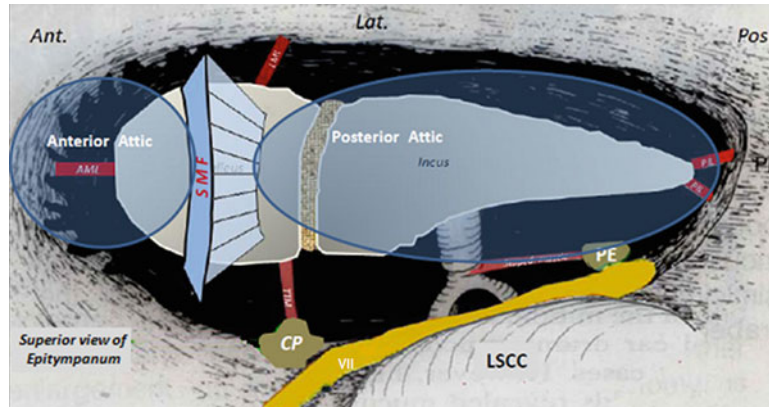

Fig. 4.15 Superior view of a right middle ear, showing the attic divided by the superior malleal fold (*SMF*) into a smaller anterior attic and a larger posterior attic. *AML* anterior malleal ligament, *LML* lateral malleal ligament, *TTM* tensor tympani muscle tendon, *PB* petrous bone, *PIL* posterior incudal ligament, *PE* pyramidal eminence, *CP* cochleariform process, *VII* facial nerve, *LSCC* lateral semicircular canal

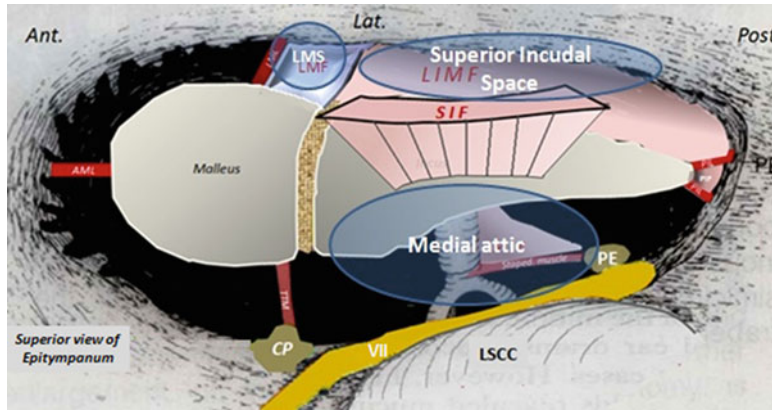

Fig. 4.16 Superior view of the right middle ear, showing the different compartments of the posterior attic. The medial attic lies medial to the superior incudal fold (*SIF*), the superior incudal space lies above the lateral incudomalleal fold (LIMF) and superior to SIF, the lateral malleal space (*LMS*) lies above the lateral malleal fold (*LMF*). *MIF* medial incudal fold, *AML* anterior malleal ligament, *LML* lateral malleal ligament, *TTM* tensor tympani muscle, *PB* petrous bone, *PIL* posterior incudal ligament, *PE* pyramidal eminence, *CP* cochleariform process, *VII* facial nerve, *LSCC* lateral semicircular canal

The *superior malleal fold* with a coronal orientation divides the upper unit of the attic into two different spaces: a posterior and larger one, *the posterior attic*, and an anterior and smaller one, *the anterior attic* (Figs. 4.14 and 4.15).

4.5.1.1 Posterior Attic or Posterior Epitympanum

The posterior attic is largely occupied by the posterior part of the head of the malleus, the body, and short process of the incus. In adult, the distance from the tip of the incus to the attic roof is about 6 mm [31].

The posterior attic is divided into the medial posterior attic and the lateral posterior attic by the superior incudal fold oriented in a sagittal plane (Figs. 4.14 and 4.16).

The Medial Posterior Attic

The medial posterior attic or the medial incudal space is the larger compartment of the posterior attic; it is bounded by the lateral semicircular canal and the Fallopian canal medially and the ossicles and the superior incudal fold laterally. The distance between the lateral semicircular canal and the incus body is 1.7 mm [33]. The medial posterior attic contains essentially the tympanic isthmus that is divided by the medial incudal fold into an anterior and a posterior tympanic isthmus. These openings represent the main

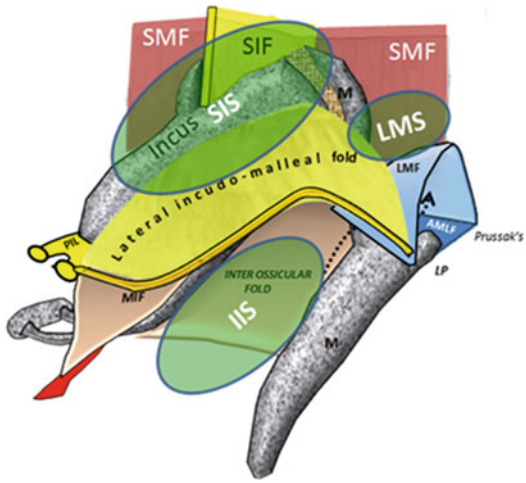

Fig. 4.17 Lateral view of a right middle ear after removal of the tympanic membrane and the outer attic wall, showing the different compartments of the lateral attic: the superior incudal space (*SIS*) above the lateral incudomalleal fold (*LIMF*), the inferior incudal space below the LIMF, and the lateral malleal space (*LMS*) above the lateral malleal fold (*LMF*) on a more inferior level than the SIS, but usually in open communication with each other. The posterior boundary of the LMS is represented by the descending portion of the LIMF. *SMF* superior malleal fold, *SIF* superior incudal fold, *PIL* posterior incudal ligament, *MIF* medial incudal fold, *M* malleus, *LP* lateral process of malleus, *AMLF* anterior malleal ligamental fold

route of aeration of the whole epitympanum (Figs. 4.14 and 4.16).

The Lateral Posterior Attic

The lateral posterior attic is narrower, located between the outer attic wall laterally and the malleus head, incus body, and superior incudal fold medially. The lateral posterior attic is further divided into three spaces: the superior incudal space and the lateral malleal space forming the upper lateral attic and the inferior incudal space, called the lower lateral attic (Figs. 4.14 and 4.16).

Upper Lateral Attic

The upper lateral attic is composed of two spaces that are largely opened to each other, but at different levels: posteriorly the space lying above the lateral incudomalleal fold is called the superior incudal space, and more anteriorly the space lying above the lateral malleal fold is called the lateral malleal space (Figs. 4.14, 4.16, and 4.17).

- *Superior incudal space (SIS)*

The superior incudal space lies in a more superior position in relation to the lateral malleal space. It is limited inferiorly by the incudomalleolar fold which separates it from the inferior incudal space (Figs. 4.14, 4.16, and 4.17).

- *The lateral malleal space (LMS)*

The lateral malleal space is a distinct anatomic area, part of the lateral attic, and lies above the lateral malleal fold. It is limited medially by the malleus head and neck, laterally by the outer attic wall, anteriorly by the anterior malleal fold, and posteriorly by the downwards turning end of the incudomalleal fold [32]. The lateral malleal space is regularly opened superiorly and thus in free communication with the superior incudal space (Figs. 4.14, 4.16, and 4.17).

Infrequently, the lateral malleal fold is incomplete and a direct communication exists between the Prussak's space and the lateral malleal space [33–37].

In rare cases the incudomalleal fold may extend over the entire lateral malleal space; that means that the lateral incudomalleal fold slopes down and joins the posterior malleal fold. In such cases, the lateral malleal space is isolated, separated from the superior incudal space, but it gets in direct communication with the inferior incudal space [32].

Lower Lateral Attic: Inferior Incudal Space (IIS)

The inferior incudal space lies below the lateral incudomalleal fold, therefore inferior to the tympanic diaphragm. It is located between the more dependent portion of the short process and the body of the incus medially and the scutum laterally (Figs. 4.14 and 4.17). A particular region of the mesotympanum guarantees the ventilation of this space. This region of ventilation for the inferior incudal space is limited medially by the medial incudal fold and anteriorly by the interossicular fold which lies between the long process of the incus and the upper 2/3 of the malleus handle [31].

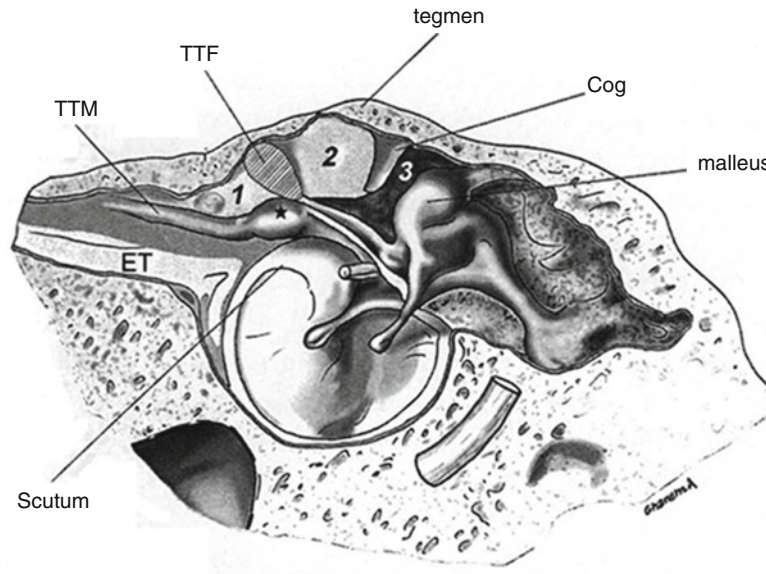

Fig. 4.18 Schema of a medial view of a right middle ear showing the different spaces of the anterior attic: *1* supratubal recess, *TTF* tensor tympani fold, *2* anterior epitympanic recess, *3* anterior malleal space, TTM tensor tympani muscle (Reproduced with permission from the Journal of Otolaryngology-Head And Neck Surgery, Decker Publishing Publisher [43])

4.5.1.2 Anterior Attic or Anterior Epitympanum

The anterior attic is a separate cavity of varying shape. It is situated anterior to the head of malleus and the superior malleal fold.

The anterior epitympanum is divided into two spaces by the cog [36]. The cog is a bony crest that extends inferiorly from the tegmen; it is superior to the cochleariform process and anterosuperior to the malleus head. It divides the anterior attic into a small posterior space, the anterior malleal space, and large anterior space: the anterior epitympanic recess (Figs. 4.14, 4.15, and 4.18).

The Anterior Malleal Space (AMS)

The anterior malleal space is of variable size and situated between the head of the malleus posteriorly and the cog anteriorly (Figs. 4.14 and 4.18).

The Anterior Epitympanic Recess (AER) (Figs. 4.14 and 4.18)

The anterior epitympanic recess has been given different names such as anterior epitympanic sinus, anterior epitympanic space, sinus epitympani, and even supratubal recess. However, additional anatomic studies identified the supratubal recess (STR) and the anterior epitympanic recess (AER) as two distinct spaces separated by the tensor tympani fold (TTF) [6, 31, 37]. Therefore, the term anterior epitympanum should be reserved for the whole anatomic entity composed of the anterior malleal space and the AER. The supratubal recess is considered as a part of the protympanum (see Sect. 4.2.2).

The AER presents the following boundaries [37–39]:

- *Superiorly*: the anterior part of the tegmen tympani
- *Anteriorly*: the zygomatic root
- *Posteriorly*: the cog
- *Laterally*: the scutum
- *Medially*: the anterior portion of the tympanic portion of the facial nerve and the geniculate ganglion
- *The floor*: represented by the cochleariform process and the TTF (Fig. 4.18).

The TTF is an integral part of the tympanic diaphragm (see Sect. 3.6.3). When the TTF is complete, the anterior tympanic recess and the supratubal recess form two separate spaces. When there is a defect in the TTF (in 15 % of

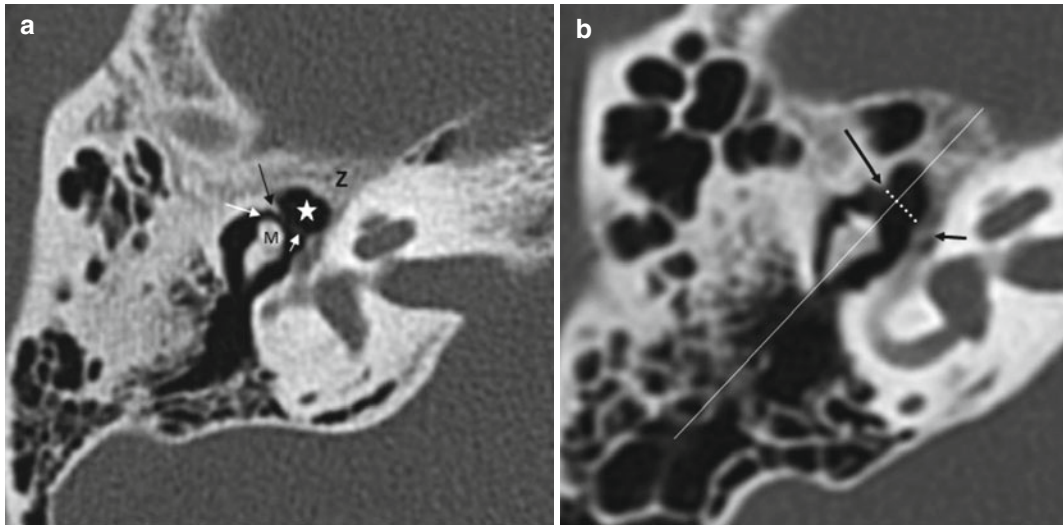

Fig. 4.19 Axial computed tomographic views of the anterior epitympanum. (**a**) The cog with its largest lateral part (*black arrow*) and its continuity towards the medial attic wall (*small white arrow*); anterior malleal space (*white long arrow*); anterior epitympanic recess AER (*); *M* malleus head, *Z* zygoma. (**b**) Mensuration of the relevant transversal diameter of the AER (*punctated line*), perpendicular to the incudo-malleal axis (*long white line*) between the lateral limit of the cog (*long black arrow*) and the cochleariform process (*short black arrow*)

cases), the AER is in direct communication with the supratubal recess serving as an accessory route of aeration of the attic called the anterior route of ventilation, the posterior route being represented by the anterior and posterior tympanic isthmus [35, 36, 38].

The size of the AER is variable between individuals. CT scan permits the measurement of the size of the recess; its mean size is about 4×4 mm. Transmastoid approach to the AER with conservation of the ossicular chain requires minimum dimensions of 3×3 mm [37] (Fig. 4.19).

Clinical Applications

The AER in Chronic Otitis Media (Fig. 4.20)

The AER is highly important to consider in cases of recurrent otorrhea with central or anterior perforation not responding to conventional medical therapy or in front of mucoid middle ear effusion that persists or recurs despite repetitive myringotomies with tube insertion. In addition the AER must be investigated in the presence of retraction pocket especially when it is anterosuperiorly oriented. In these cases the TTF is complete and blocks the aeration of the anterior epitympanum from the anterosuperior mesotympanum creating a dysventilation syndrome. This situation will not respond to posterior atticotomy alone.

When performing middle ear surgery for dysventilation pathology with isthmus blockage, an imaging study of the AER with CT scan is mandatory not only to assess its involvement but also to obtain its dimensions in order to select the surgical approach. Resection of the cog and the TTF is fundamental to create an anterior route of ventilation between the protympanum, the supratubal recess, the AER, and the posterior attic [35, 37].

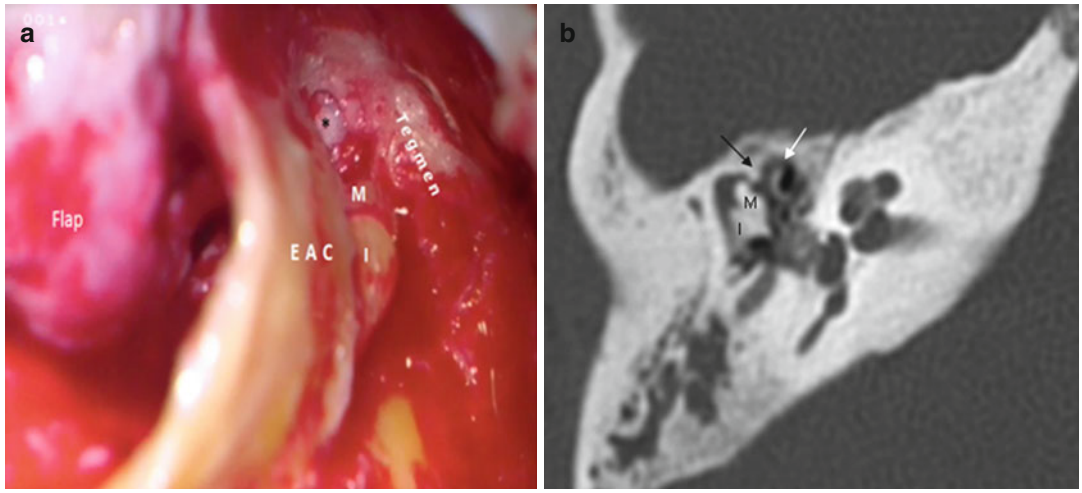

Fig. 4.20 (**a**) Left ear after transmastoid anterior atticotomy showing a complete tensor tympani fold (*) after removal of the cog. *I* incus, *M* malleus head, *EAC* external auditory canal. Notice that the tensor tympani fold is thick and inflammatory secondary to chronic otitis media. (**b**) Axial computed tomographic view of a right ear, showing an unusual image of a sclerotic TTF (tensor tympani fold, *white arrow*) secondary to an invasive tympanosclerosis. *Cog black arrow, M* malleus, *I*, incus

4.5.2 The Lower Unit of the Attic (Prussak's Space) (Figs. 4.13, 4.14, and 4.21)

In 1867, Prussak described a superior pouch of the tympanic membrane located between Shrapnell's membrane and the neck of malleus and distinct from the anterior and posterior pouches of von Tröltsch. Later this superior pouch was renamed Prussak's space [40].

The Prussak's space is formed from the posterior pouch of von Tröltsch as a prolongation of either a low portion or a high portion of the superior saccus, replacing the mesenchymal tissue between the neck of the malleus and Shrapnell's membrane [2]. The aeration pathway remains the same as the route of origin which is the posterior pouch of von Tröltsch.

The Prussak's space is situated inferior to the tympanic diaphragm and represents the lower unit of the attic. Laterally, the Prussak's space extends superior to the roof of the external auditory canal by 0.4 mm and attains its largest cross section of 2.6 mm at the level of the roof of the external ear canal [4]. It presents the following limits:

- *The roof* is the lateral malleal fold which is a low portion of the tympanic diaphragm.

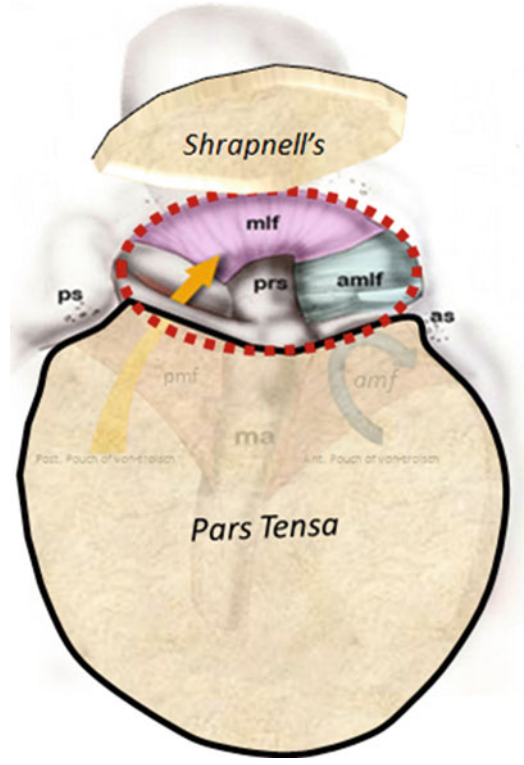

Fig. 4.21 Lateral view of the Prussak's space (prs) after reflection of the Shrapnell's membrane. *mlf* lateral malleal fold, *amlf* anterior malleal ligamental fold, *ps* posterior tympanic spine, *as* anterior tympanic spine. *Yellow arrow*, aeration of Prussak's space through the posterior pouch of von Tröltsch. Reproduced with modification from Marchioni [44, Fig. 1] (With kind permission from Springer Science and Business Media, Springer and the original publisher)

- *The floor* is formed by the neck of the malleus.
- *The anterior limit* is the anterior malleal fold.
- *The lateral wall* is formed by the pars flaccida and the lower edge of the outer attic wall, the scutum.
- *The posterior wall* is opened to the posterior pouch of von Tröltsch and then to the mesotympanum.

The Prussak's space ventilation route is independent of the upper unit of the attic. The Prussak's space is ventilated through the posterior pouch of von Tröltsch which is particularly rough and narrow, as compared to the tympanic isthmus that is wider and provides large ventilation of the upper unit of the attic [32] (Fig. 4.21).

Clinical Applications

Prussak's Space Dysventilation and Attical Cholesteatoma

The possibility of closure of the posterior pouch of von Tröltsch following thick mucus secretion formation during chronic inflammatory otitis is high. This event may cause a selective dysventilation of Prussak's space and development of pars flaccida retraction pocket with adhesion to the malleus neck (Fig. 4.22). This event may take place without any involvement of the other compartments of the upper unit that are situated superior to the tympanic diaphragm [41].

Initially the sac of the retraction pocket remains small and superficial to the ossicles. However, continued retraction and keratin accumulation lead to enlargement of the sac and its expansion via pathways of least resistance.

The growth pathways of attical cholesteatoma could be one of the following (Fig. 4.23):

Pathway 1: The cholesteatoma progresses through the posterior pouch of von Tröltsch. The posterior tympano-malleolar fold directs this expansion towards the inferior incudal space. From there, cholesteatoma may extend medial to the long process of the incus and then, through the tympanic isthmus, into the medial attic (Fig. 4.24).

Pathway 2: The cholesteatoma progresses through a thin part of the lateral malleal fold directly to the upper unit of the attic and from there to the posterior attic, aditus, and then to the antrum (Fig. 4.25).

Pathway 3: The cholesteatoma progresses from the lateral malleal space to the anterior attic, anterior epitympanic recess, and then it extends downwards to invade the supratubal recess and the protympanum (Fig. 4.26).

It should be emphasized that the folds of the attic direct the spread of cholesteatoma, but they do not constitute effective barriers to retain its expansion [4].

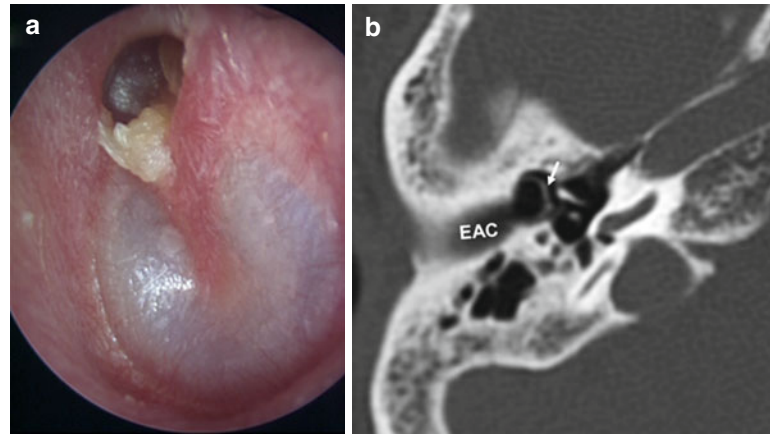

Fig. 4.22 (**a**) Attical cholesteatoma. (**b**) Transversal computed tomographic view of a right ear, showing a retraction pocket with its thickened capsule (*white arrow*) in the Prussak's space, extending anteriorly into the lateral attic. *EAC* external auditory canal

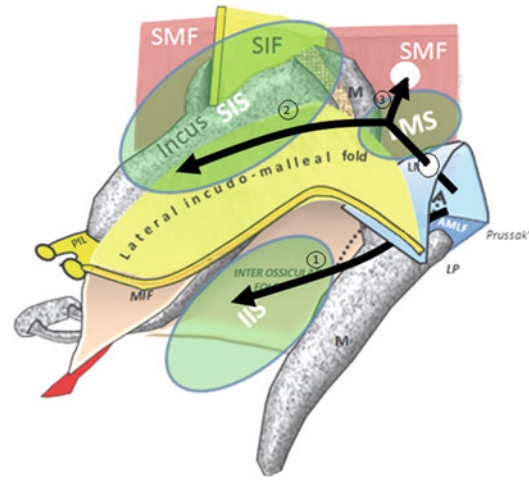

Fig. 4.23 Attical cholesteatoma growth pattern. From the Prussak's space cholesteatoma can extend through one of the following three tracts: (*1*) through the posterior pouch of von Tröltsch to the lower lateral attic (inferior incudal space, *IIS*), (*2*) through a defect in the lateral malleal fold (*LMF*) to the lateral malleal space (*LMS*) and then to the superior incudal space (*SIS*), or (*3*) from the lateral malleal space through the superior malleal fold defect (*SMF*) to the anterior attic. *SIF* superior incudal fold, *PIL* posterior incudal ligament, *MIF* medial incudal fold, *M* malleus, *LP* lateral process of malleus, *AMLF* anterior malleal ligamental fold

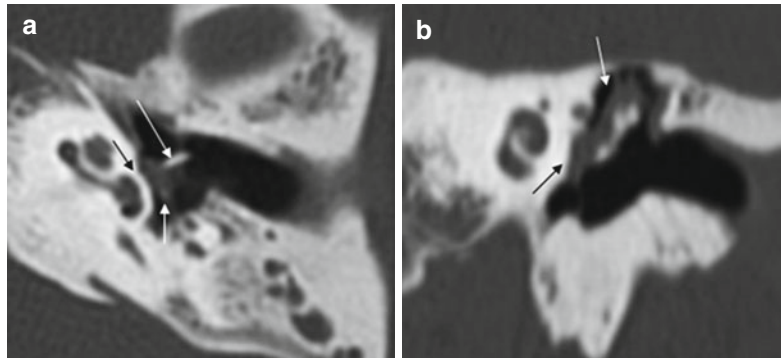

Fig. 4.24 Transversal (**a**) and coronal (**b**) computed tomographic view of a left ear with cholesteatoma growing according to the first pathway (Fig. 4.23). (**a**) Obliteration of the interossicular space between the malleus handle (*long white arrow*) and the long process of the incus (*short white arrow*) reaching the promontory (*black arrow*). (**b**) Further growth of the cholesteatoma from the medial mesotympanum (*black arrow*) to the medial attic (*white arrow*) along the ossicular chain

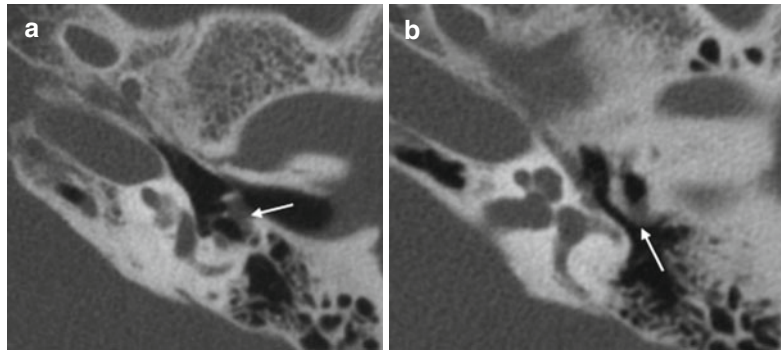

Fig. 4.25 Transversal computed tomographic view of a left ear showing a cholesteatoma growing from the Prussak's space according to the second pathway (Fig. 4.23). (**a**) Obliteration of the superior incudal space (*white arrow*). (**b**) On a more superior cut than (**a**), the obliteration shows a convex posterior contour (*white arrow*) due to the anatomical configuration of the lateral incudomalleal fold and the posterior incudal ligament

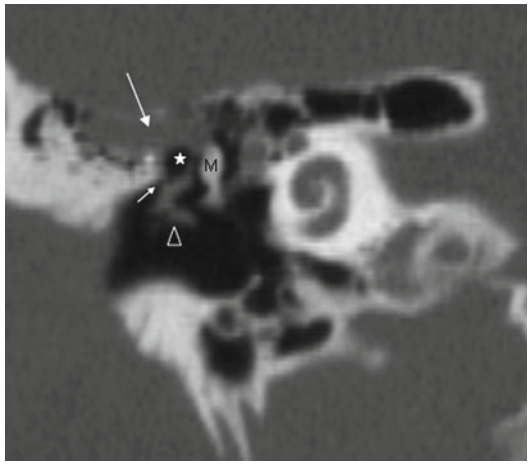

Fig. 4.26 Coronal computed tomographic view of a cholesteatoma in a right ear growing to the anterior epitympanum (*long arrow*) according to the third pathway (Fig. 4.23): retraction pocket from the Prussak's space (*), with amputation of the scutum (*short arrow*), detached keratine debris (*empty arrowhead*). *M* malleus

4.6 The Mesotympanum

The mesotympanum is the central and the biggest compartment of the middle ear cavity. However, it is the narrowest one; its depth is about 2 mm only. It is limited medially by the promontory and laterally by the pars tensa of the tympanic membrane. It is widely open anteriorly, inferiorly, and posteriorly to the protympanum, hypotympanum, and retrotympanum, retrospectively. Superiorly it is separated from the attic by the tympanic diaphragm.

The mesotympanum acts like a channel, allowing air coming from the Eustachian tube, to pass through the tympanic isthmus upward to provide aeration of the whole attic.

The lateral wall of the mesotympanum houses two important compartments:

4.6.1 Tympanic Membrane Compartments (Fig. 4.27)

4.6.1.1 Tympanic Membrane Pouches

- Anterior pouch of von Tröltsch: This pouch is situated between the anterior malleal fold and the pars tensa of the eardrum; it communicates with the supratubal recess and the protympanum [42].
- Posterior pouch of von Tröltsch: This pouch is situated between the posterior malleal fold and the pars tensa of the eardrum. The posterior pouch of von Tröltsch develops posteroinferiorly, and it opens in the most cranial portion of the mesotympanum [42]. It is the main route of ventilation of the Prussak's space.

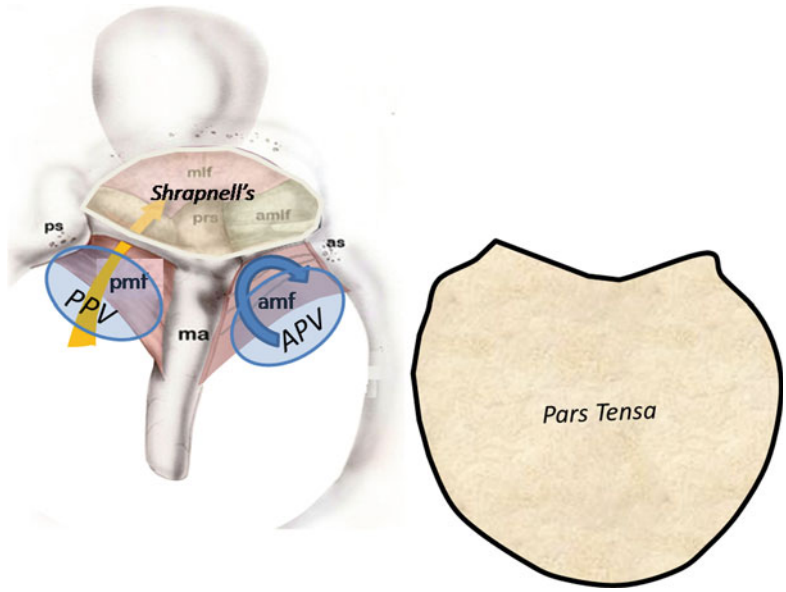

Fig. 4.27 Schema of a right middle ear lateral wall compartments after removal of the pars tensa, showing the anterior pouch of von Tröltsch (*APV*) that is isolated from the Prussak's space (*blue arrow*) and the posterior pouch of von Tröltsch (*PPV*) that is in communication with the Prussak's space (*yellow arrow*). *as* anterior tympanic spine, *ps* posterior tympanic spine, *amf* anterior malleal fold, *pmf* posterior malleal fold, *ma* malleus handle

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