Manual of Otologic Surgery

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Preface

The gold standard of otological training remains the use of cadaver temporal bones to generate the highest-fidelity simulation model in terms both of visual and tactile realism. Generations of surgeons have relied on this type of training to gain anatomical knowledge and confidence. Many experienced otologists routinely spend time in temporal bone labs to refresh their skills and practice uncommon approaches.

This manual is written for trainees in Otolaryngology, novice surgeons, and those interested in concise descriptions of modern temporal bone dissections. It is not meant to serve as a surgical textbook but a compendium reference source that provides

- Step-by-step introduction to modern temporal bone procedures
- Real-life pictures as seen in the OR without any post processing
- Tips and pearls for surgical dissection in the OR

We would like to acknowledge Prof. Tschabitscher, Prof. Gstöttner, Dr. Riss, and Dr. Honeder for their collaboration and help in the preparation of this manuscript.

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Contents

1 General Considerations

The thorough knowledge of the complex anatomy of the temporal bone builds the firm basis for ear surgery. Even for experienced surgeons, reinforcement of their skills by training on the cadaver is of tremendous importance.

Temporal bone surgery is based upon a clear understanding of relative landmarks in a three-dimensional construct, while absolute measurements are meaningless. A lateral to medial approach in the gradual identification of key landmarks is the essence of a safe and efficient technique. Follow the order of uncovering landmarks described in this manual; avoid locating a deeper structure (e.g., the facial nerve) prior to the identification of important reference points (e.g., Incus and lateral semicircular canal).

The typical surgical setup is shown in Fig. 1.1. The surgeon should be seated in a comfortable chair at a comfortable working distance from the table.

The typical setup includes the following:

- High-speed otologic drill
- Microscope with eyepiece for observers
- Irrigation either included in the drill system or manually with bulb or syringe
- Bonesaw to trim the bone to fit in the dissection bowl
- Dissection bowl/temporal bone holder

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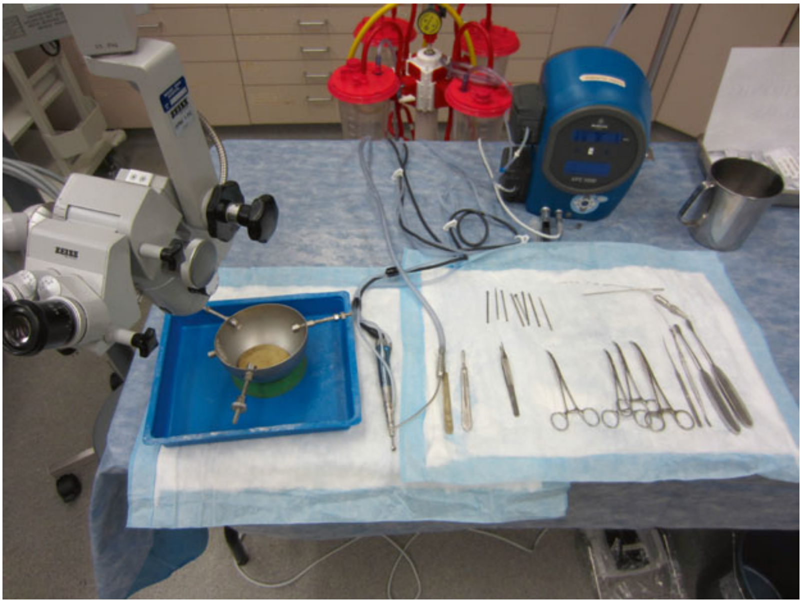

Fig. 1.1 Typical surgical setup in temporal bone lab

- Scalpel
- Periosteum elevator
- Fraser and otologic suctions
- Round knife
- Rosen needle
- Annulus elevator
- Alligator forceps
- Middle ear scissors

Some basic principles of ear surgery apply to all steps of the procedure and should always be memorized:

- Use a firm pencil grip when holding the burr (Fig. 1.2).
- Use the largest burr possible to reduce the risk of injury to important structures. The dissection usually starts with a 5–6-mm cutting burr.
- Run the burr at full speed, usually between 50 and 60 k rpm. This will render the drill more stable and reduce chatter and digging.
- Use ample irrigation to remove bone dust and optimize visualization of structures. This will also avoid heat damage and necrosis to the bone and facial nerve.

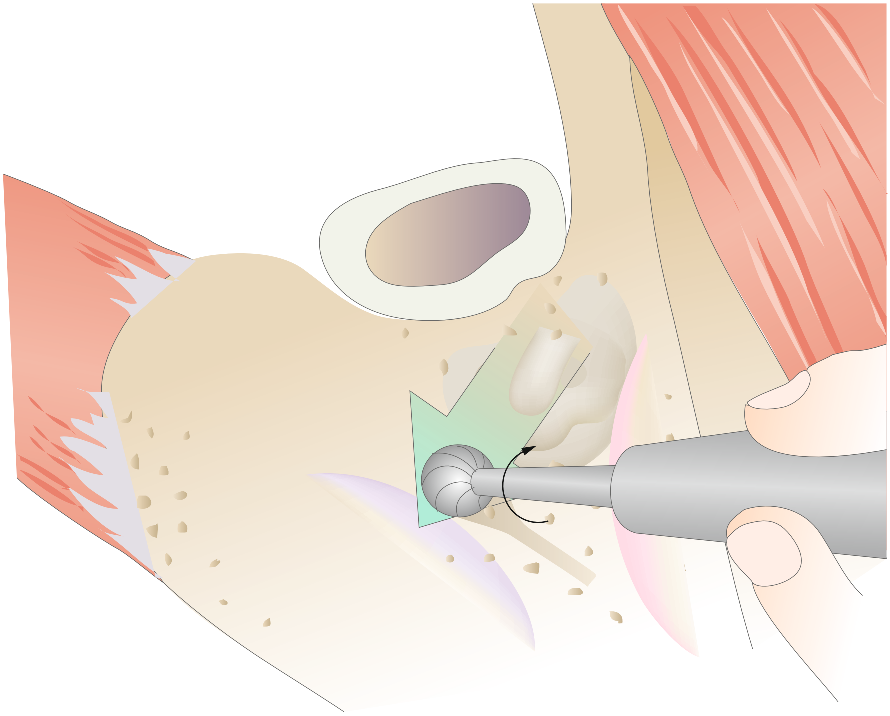

Fig. 1.2 A firm pencil grip, ample irrigation, and a drill run at full speed are the fundaments for successful temporal bone dissection

- Drill with ½″ to 1″ right to left strokes.
- Drill “inside out,” meaning from more medial to lateral, whenever applicable (Fig. 1.3). While drilling, the entire burr should always be visible to avoid inadvertent injury to hidden structures such as the sigmoid sinus and dura.
- Saucerize the edges of your dissection. This will not only provide more light to penetrate deeper into your specimen but also allow your drill and instruments to come into your field from the side and not block your visualization.
- Fast hand motion while drilling does not equate a shorter surgical time! It is important to understand that efficiency of motion in operating a drill becomes more and more important as the dissection deepens into the temporal bone, where there is less room for errors. When using a large cutting burr in the lateral part of the temporal bone, reduced drill speed tends to lead to a skittish and unstable drill. A good rule of thumb for hand motion and drill speed is “…Slower Hands and Faster Drill”!

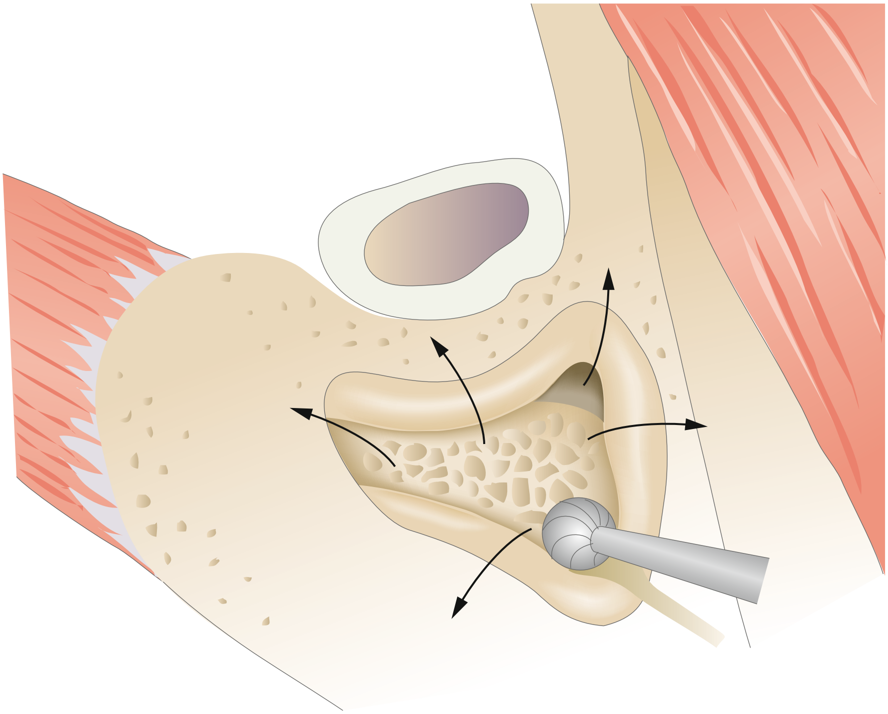

Fig. 1.3 The direction of drilling should be from more medial to lateral (“inside out”) whenever possible

- Develop the discipline of reducing the amplitude of hand movements; use of variable pressure and tactile feedback to advance into the next layer is a technique that bodes well for more advanced skills acquisition. Drilling by feel, or the term “spot drilling,” is often used to describe this technique when very little side-to-side motion is applied (Videos 1 and 9). The drill should be running in the forward direction at full speed for most of the drilling, while reduced speed becomes important in regions that demand less acoustic trauma or directly over a vital structure (e.g., footplate, round window niche, internal auditory canal, etc.). Changing the direction of the drill (i.e., reverse) is important when you wish to “drill-away” from an important structure, in a counterclockwise fashion. An example of this for a right-handed surgeon is when you approach the inferior aspect of the left internal auditory canal (IAC).

Cortical Mastoidectomy

2

Locating the mastoid antrum is one of the earliest steps in the dissection of a temporal bone:

The soft tissue from the *external auditory canal* (EAC) and the *root of the zygoma* should be released from the bone by carefully pushing it forward with the use of an elevator. This helps in identifying the *suprameatal spine* (*spine of Henle*) and the area behind it, named *McEwen's triangle* (delineated by the temporal line, the posterosuperior segment of bony external auditory canal, and the line drawn as a tangent to the EAC).

Landmarks
- Suprameatal spine (spine of Henle)
- Root of zygoma
- Triangle of attack:
  - Linea temporalis
  - EAC
  - Sigmoid sinus

► This maneuver is important to help estimate the thickness of the bone of the EAC, which needs to be thinned out extensively prior to drilling the facial recess (see Fig. 3.2).

First, identify the three structures that create *a triangle of attack* into the mastoid (Fig. 2.1, Video 2). The tracking of one landmark to the other forms the principle of temporal bone surgery.

Identifying these reliable landmarks is important in every case, but especially in cases with poor pneumatization:

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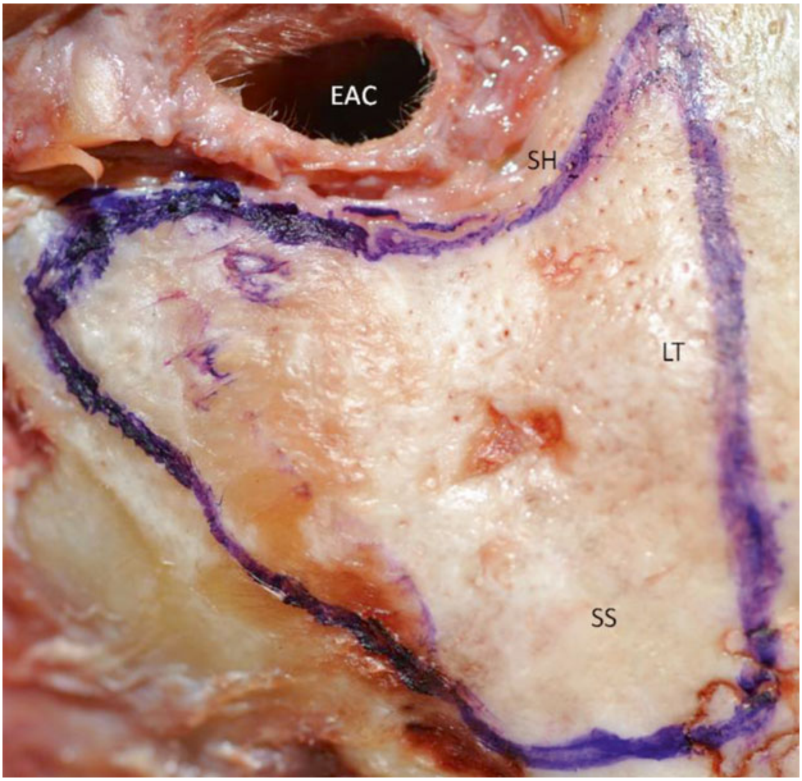

Fig. 2.1 Triangle of attack (*EAC* external auditory canal, *SH* spine of Henle, *LT* linea temporalis, *SS* sigmoid sinus)

- The *temporal line* (inferior limit of temporalis muscle) as the approximate landmark of the *middle fossa plate* is drilled with a large cutting burr in an anterior to posterior direction. Be aware that the brain often hangs much lower than this line, especially in a sclerotic bone.
- A second line is drilled parallel and just posterior to the *external auditory canal*.
- The third line connects the first two lines and presents the probable posterior extent of pneumatization at the level of the *sigmoid sinus*. The sigmoid sinus can extend forward and be located superficially. Avoid injuring the sigmoid sinus and check its location on preoperative CT scans.

Landmarks
- Suprameatal spine (spine of Henle)
- Root of zygoma
- Triangle of attack:
  - Linea temporalis
  - EAC
  - Sigmoid sinus

► The burr should be moved in a parallel fashion to the vital structures to be preserved: anterior-posteriorly versus the middle fossa plate, superior-inferiorly versus the EAC and superior-lateral to inferio-medial versus the sigmoid sinus (Fig. 2.2).

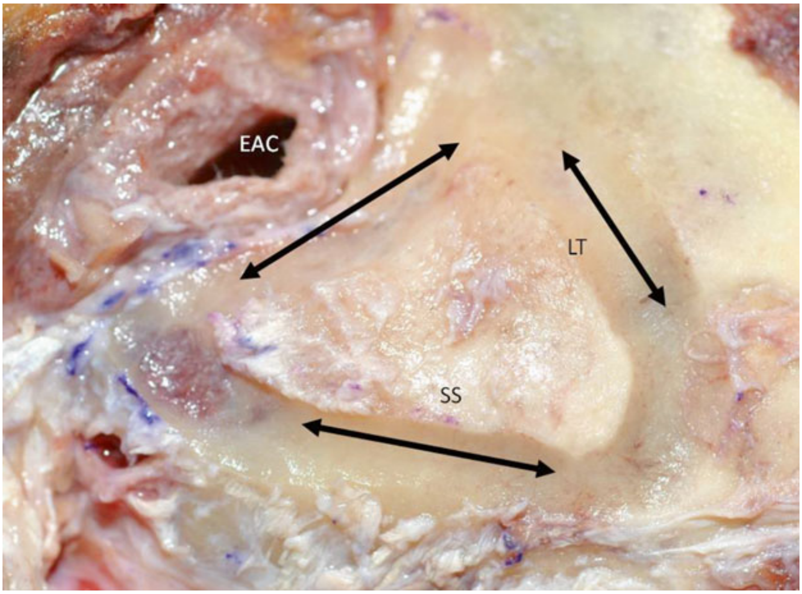

Fig. 2.2 The burr is moved parallel to vital structures (*EAC* external auditory canal, *LT* linea temporalis, *SS* sigmoid sinus)

- ▶ Take care not to drill deep holes, and try to deepen the cavity evenly and gradually, with the deepest point of penetration in the direction of the antrum. The edges should always be rounded for optimal visualization.
- ▶ Always use the largest burr possible as this will help to preserve important structures.
- ▶ Apply frequent and ample irrigation to clear every exposed air cell.

Once the cortex is opened, follow the *honeycomb of air cells* (Fig. 2.3) which will lead you to the *antrum*, found just posterosuperiorly to the external auditory canal.

The segmentation and sequencing of a cortical mastoidectomy is explained in Fig. 2.4. Initially, the middle fossa plate and sigmoid sinus are developed together to establish the lateral locations of these structures. Then, the antrum is entered and the cavity is enlarged posteriorly into the sinodural angle. Lastly, perifacial and retrofacial air cells are developed.

In well-pneumatized bones, *Koerner's septum* can be identified as a solid plate of nonpneumatized bone

Landmarks

- Suprameatal spine (spine of Henle)
- Root of zygoma
- Triangle of attack:
  - Linea temporalis
  - EAC
  - Sigmoid sinus
- Mastoid air cells
- Middle fossa dura
- Koerner's septum
- Antrum

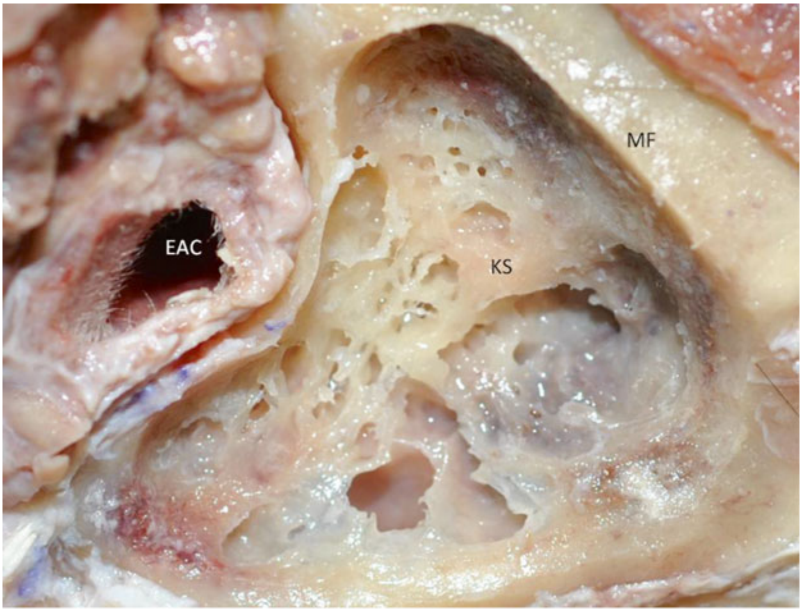

Fig. 2.3 Gradually remove the mastoid air cells between the middle fossa plate, the external auditory canal, and the sigmoid sinus. Koerner's septum can be identified as a solid plate of nonpneumatized bone (*EAC* external auditory canal, *MF* middle fossa, *KS* Koerner's septum)

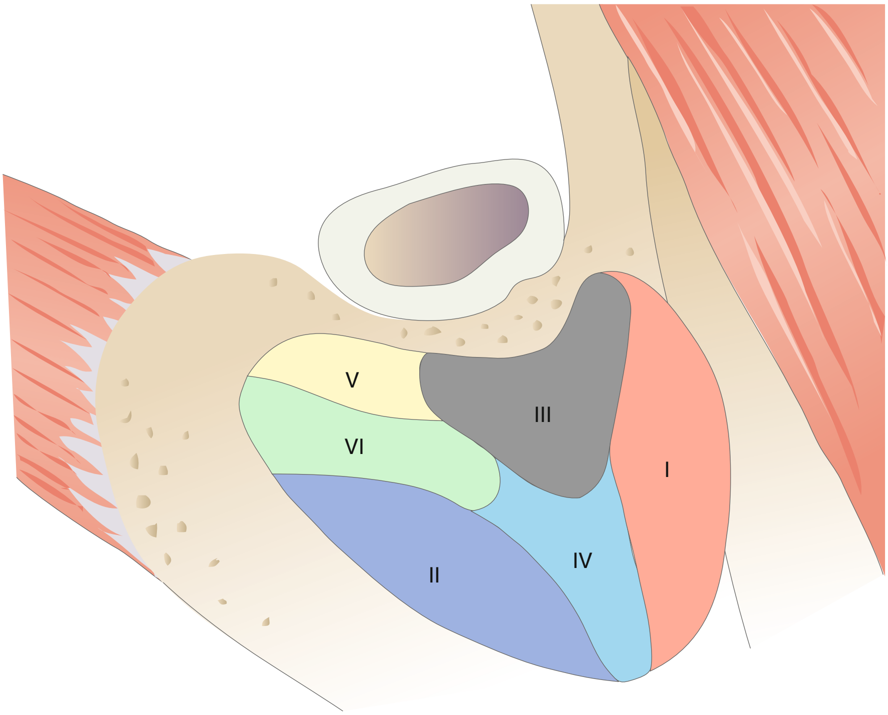

Fig. 2.4 Segmentation and sequencing of transmastoid dissection. (*I* dura middle fossa, *II* sigmoid sinus, *III* antrum, *IV* sinodural angle, *V* perifacial air cells, *VI* retrofacial air cells)

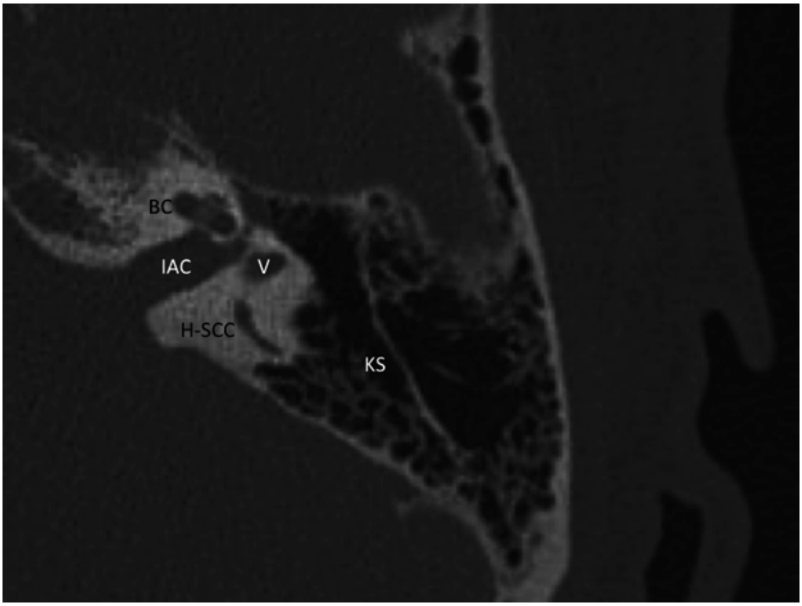

Fig. 2.5 Koerner's septum (petrosquamous suture line) on an axial CT scan of a right temporal bone (*KS* Koerner's septum, *V* vestibule, *H-SCC* horizontal semicircular canal, *IAC* internal auditory canal, *BC* basal turn of cochlea)

extending across the entire mastoid cavity (Figs. 2.3 and 2.5). It is a segment of the petrosquamous suture line, representing the fusion of the squamous and petrous bones.

▶ Koerner's septum can be initially mistaken for the hard bone of the labyrinth and horizontal semicircular canal by the inexperienced surgeon. These structures, of course, lie deep to Koerner's septum.

After penetration of Koerner's septum in the anterior superior quadrant of the septum, the true *antrum* will be seen as a very large air-containing cavity (Fig. 2.6). The antrum is a very consistent and important structure that connects the mastoid air cells with the tympanic cavity. Since there is no important structure lateral to it, the antrum serves as one of the most important landmarks in the initial stage of mastoidectomy.

The middle fossa and sinus plates can be identified by a change in *color* (dura: pink, sinus: blue), change in *burr*

Landmarks
- Middle fossa plate
- EAC
- Sigmoid sinus
- Koerner's septum
- Antrum
- Horizontal semicircular canal

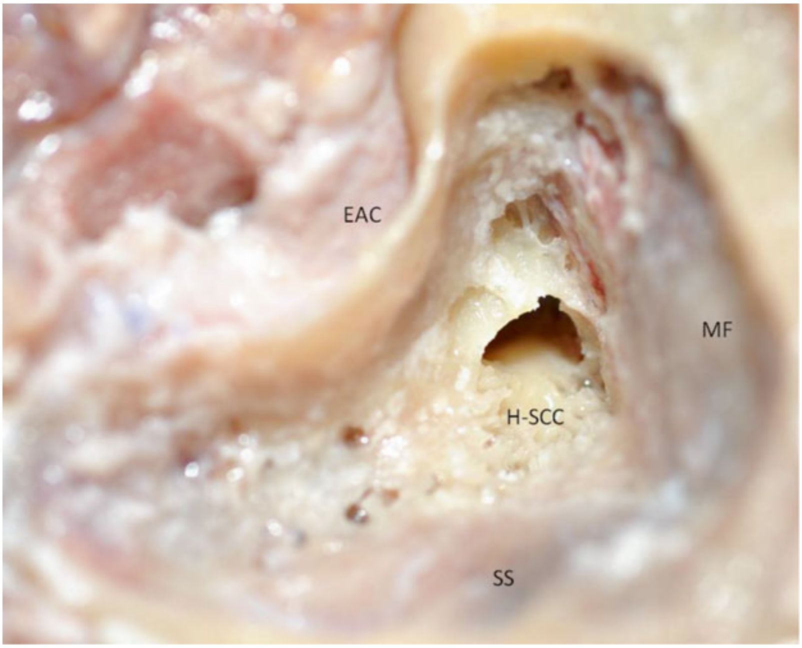

Fig. 2.6 The horizontal semicircular canal can be seen in the bottom of the antrum. Note the different appearance of the bone of the labyrinth as compared to the mastoid bone (*EAC* external auditory canal, *MF* middle fossa, *H-SCC* horizontal semicircular canal, *SS* sigmoid sinus)

Landmarks
- Middle fossa plate
- EAC
- Sigmoid sinus
- Koerner's septum
- Antrum
- Horizontal semicircular canal
- Fossa incudis
- Short process of incus

noise, and (in the OR) *increased bleeding* from the underlying structures.

▶ In the sclerotic mastoid, where almost no air cells can be found, identifying and following the dura and the thinned posterior wall of the EAC is the safest way into the antrum.

In the bottom of the antrum, the *horizontal* (*lateral*) *semicircular canal* can be easily identified by its appearance as smoothly contoured, compact bone (Fig. 2.6).

▶ Bone of the compact labyrinth is different in appearance than the air cells of the mastoid.

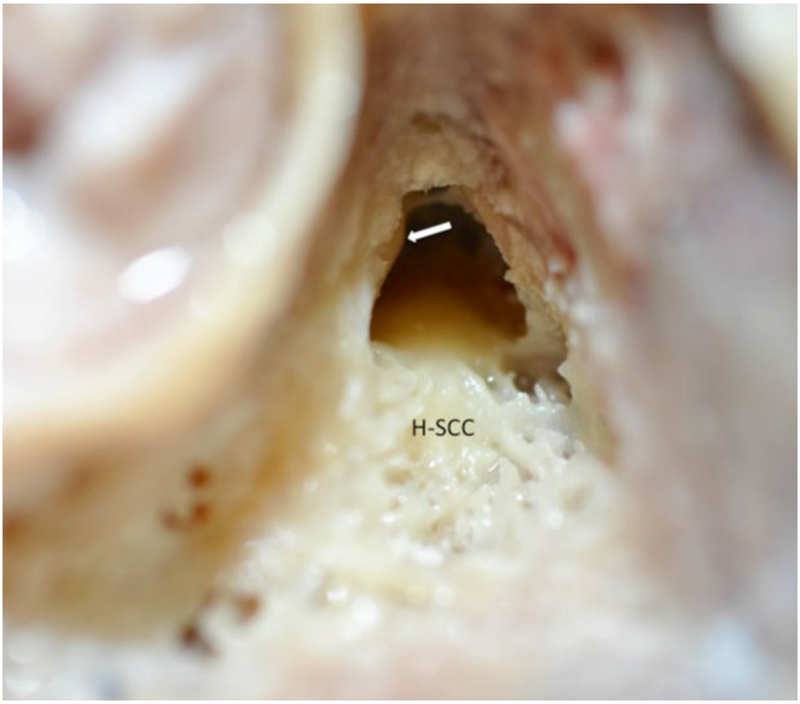

Fig. 2.7 The short process of the incus (*arrow*) can be expected behind a thin bony shell (*H-SCC* horizontal semicircular canal)

The next landmark is the *short process of the incus* in the *fossa incudis*, which will be uncovered by progressive anterior drilling. For this delicate step, the specimen (patient) should be tilted away from the surgeon and a diamond burr should be used. Remember that touching the (intact) ossicular chain with a rotating burr can lead to a subluxation of the chain as well as irreversible inner ear damage.

► Water irrigation into the antrum can help in identifying the short process of the incus (Figs. 2.7 and 2.8).

► After progressively thinning the bone covering the incus, a curette can be used to remove the last layer of bone. This is the safest way to preserve the integrity of the ossicular chain. The curette is moved medially to laterally (inside to outside) in a slightly twisting movement.

Continue carefully drilling and removing the bone with the house curette anteriorly until the articulation of the incus and *head of the malleus* can be identified (Figs. 2.9 and 2.10).

Landmarks
- Antrum
- Horizontal semicircular canal
- Fossa incudis
- Short process of incus
- Head of malleus
- Tympanic segment of the facial nerve

Fig. 2.8 After water irrigation, the short process of the incus can be identified in the fossa incudis (*H-SCC* horizontal semicircular canal, *I* short process of incus)

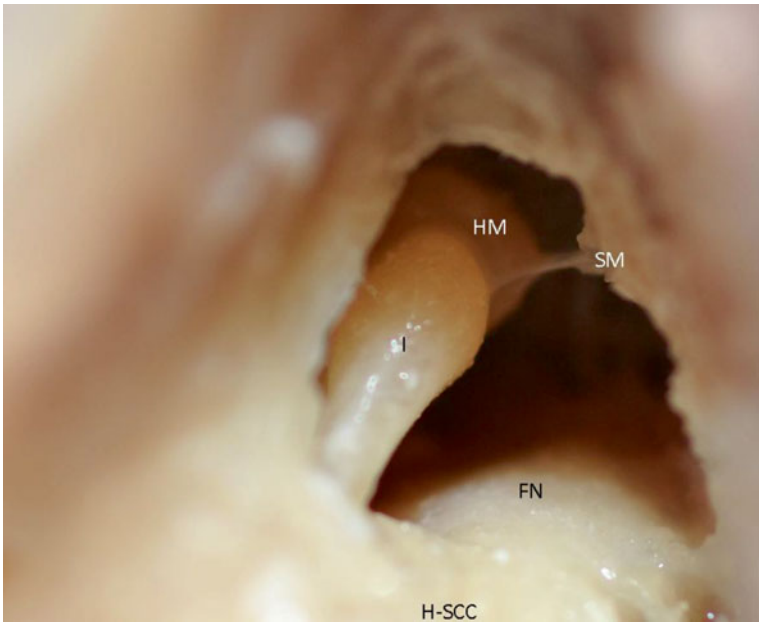

Fig. 2.9 After careful anterior dissection with a diamond burr and a curette, the articulation between the incus and malleus can be identified. On the floor, the tympanic segment of the facial nerve can be seen (*HM* head of malleus, *SM* superior ligament of malleus, *I* short process of incus, *FN* facial nerve, *H-SCC* horizontal semicircular canal)

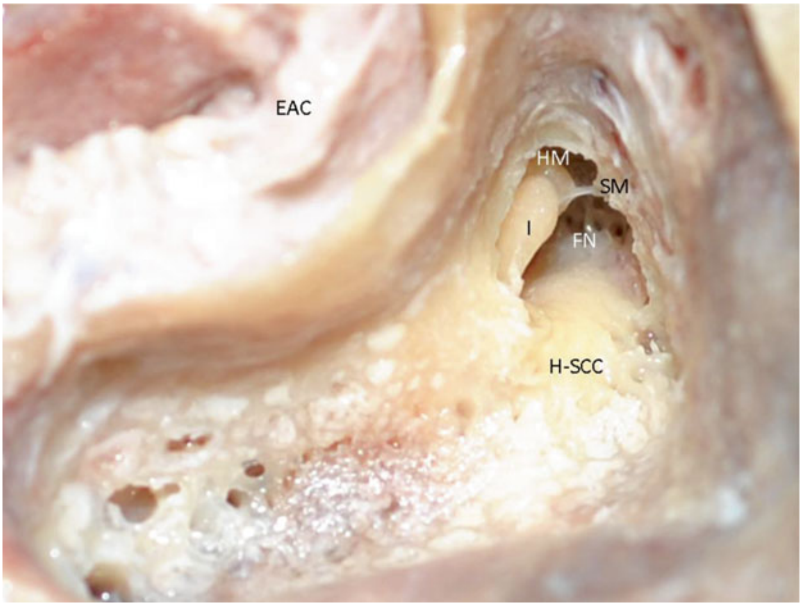

Fig. 2.10 Overview of antrum and mastoid (*EAC* external auditory canal, *HM* head of malleus, *SM* superior ligament of malleus, *I* short process of incus, *FN* facial nerve, *H-SCC* horizontal semicircular canal)

The *tympanic segment* of *the facial nerve* can be identified behind the incus and head of the malleus on the floor of the epitympanum.

▶ Only after all landmarks have been identified, should the mastoid be enlarged by drilling the posterior and inferior aspects of the cavity.

By enlarging the mastoid bowl posteriorly, the *sigmoid sinus* and *sinodural angle* can be identified.

Trautmann's triangle is demarcated by the bony labyrinth (posterior semicircular canal), the sigmoid sinus, and dura of the middle fossa dura plate (or the superior petrosal sinus). *Citelli's angle* is the sinodural angle or the superior part of Trautmann's triangle.

The extension of drilling inferiorly will lead to the *digastric ridge*, a fibromuscular impression of the digastric muscle and groove.

Landmarks
- Antrum
- Horizontal semicircular canal
- Fossa incudis
- Short process of incus
- Head of malleus
- Tympanic segment of the facial nerve
- Sinodural angle
- Digastric ridge

Facial Nerve

3

The next part of the dissection aims at identifying the facial nerve in its *mastoid* (*vertical segment*). The facial nerve is normally located inferior and slightly medial to the horizontal semicircular canal.

► In a "typical" temporal bone the facial nerve runs medial to the horizontal semicircular canal. Always orient your level of dissection in relation to the lateral SCC: if you stay lateral to this important landmark, you are safe.

Try to imagine the *course of the facial nerve* as a line that begins where the short process of the incus points towards – namely just anterior to the inferior portion of the H-SCC – and travels inferiorly and parallel to the bony EAC toward the digastric ridge (Fig. 3.1).

Landmarks

- Horizontal semicircular canal
- Short process of incus
- Tympanic segment of the facial nerve
- Sinodural angle
- Digastric ridge
- Mastoid segment of the facial nerve
- Chorda tympani

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Fig. 3.1 Imaginary course of the facial nerve and chorda tympani (*CT* chorda tympani, *FN* facial nerve, *I* short process of the incus, *asterisk* digastric ridge)

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Tympanic segment of the facial nerve
- Sinodural angle
- Digastric ridge
- Mastoid segment of the facial nerve
- Chorda tympani

It is of paramount importance to progressively thin the bone of the *external auditory canal* enough to almost see the shadow of an instrument through the bone. This has to be done not only in the lateral but also in the medial aspect of the bony external auditory canal (Fig. 3.2). Doing so avoids winding up too far posteriorly towards the facial nerve when trying to identify the nerve or drilling a posterior tympanotomy.

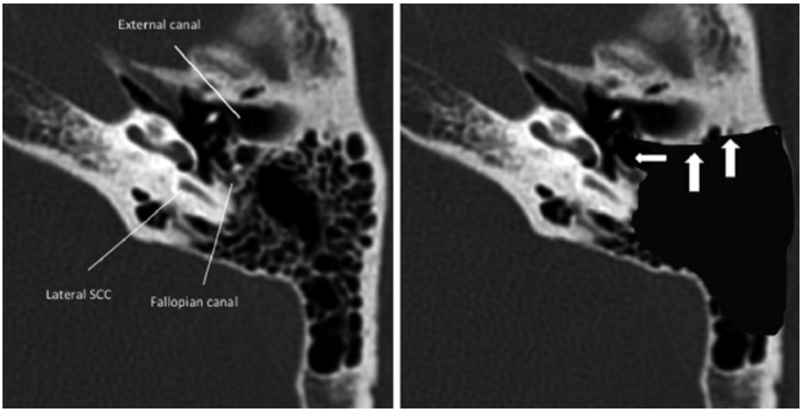

Fig. 3.2 Thinning of the external canal (*vertical arrows*) and the fallopian canal provide the access needed to maximize exposure of the facial recess (*horizontal arrow*). The external auditory canal needs to be thinned out along its whole extent and not only in its most lateral aspect

► Always drill parallel to the course of the nerve using a diamond drill with copious irrigation and continuous suction. Thin out the EAC evenly and broadly (in order to avoid drilling holes into the EAC) until you notice the pink (living specimen) or stark white (cadaver) colour of the nerve.

The facial nerve in most otologic procedures is usually only *skeletonized* but never exposed, with the exception in the rare cases of facial nerve decompression. Before actually uncovering the nerve, prominent vessels are often encountered, such as those on the posterior surface of the external genu (transition between tympanic and mastoid segment).

4 Facial Recess (Posterior Tympanotomy or "Wullstein Window")

The facial recess (posterior tympanotomy) is a *triangular region* delineated by the fossa incudis superiorly, the facial nerve posteriorly, and the chorda tympani anteriorly (Figs. 4.1 and 4.2). Anterior to the chorda tympani lies the annulus fibrosus of the tympanic membrane.

The safest and the most effective identification of the facial recess was best described by Ugo Fisch. He used an imaginary line drawn through the profile of the incus in the *"slot" position* to delineate the FR. This is when the temporal bone is rotated away from the surgeon in such a way to create the maximal space medial to the ossicles (Figs. 4.3 and 4.4). In this view, the fallopian canal in the tympanic segment can be visualized.

Once the slot position is obtained by rotating the temporal bone, imagine a *line* drawn through the *body of the incus* in its profile (Figs. 4.1 and 4.2); extend this line along the posterior canal wall in a curvilinear fashion following the contour of the bone toward the *digastric ridge*. This line will define the very center of the facial recess (Video 3).

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Tympanic segment of the facial nerve
- Mastoid segment of the facial nerve
- Chorda tympani
- Incus buttress
- Posterior tympanotomy air cell tract
- Chordal crest

Electronic supplementary material Supplementary material is available in the online version of this chapter at 10.1007/978-3-7091-1490-2_4. Videos can also be accessed at http://www.springerimages.com/videos/978-3-7091-1489-6.

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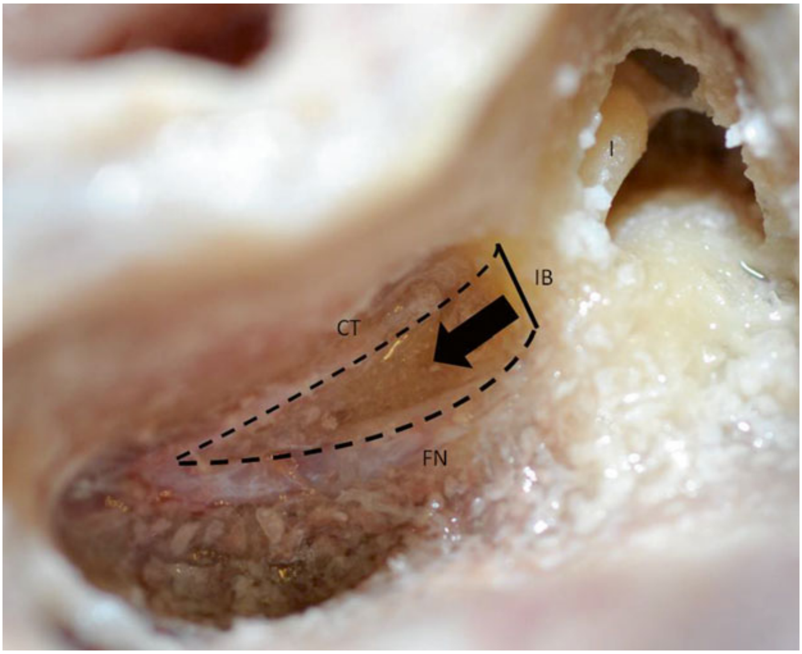

Fig. 4.1 After the external auditory canal is thinned out, drilling is evenly advanced medially (*arrow*). The posterior tympanotomy is opened between the facial nerve and chorda tympani. The superior border is formed by a bony strut (incus buttress) which protects the incus (*FN* facial nerve, *CT* chorda tympani, *IB* incus buttress, *I* incus in fossa incudis)

The key to drilling the facial recess safely is to (Video 3):

1. Start the drilling as close to the buttress as possible to create a small area of depression, with the intent of opening into a small *air cell tract* that usually exists here (Fig. 4.5). This air cell tract can commonly be mistaken for the more lateral air cells adjacent to the EAC, so the importance of completely thinning the canal is further highlighted here. The best choice of the burr for this type of work is a 2-mm cutting (round) burr. In well pneumatized bones, a bony bridge called the *chordal crest* can often be identified within the facial recess.

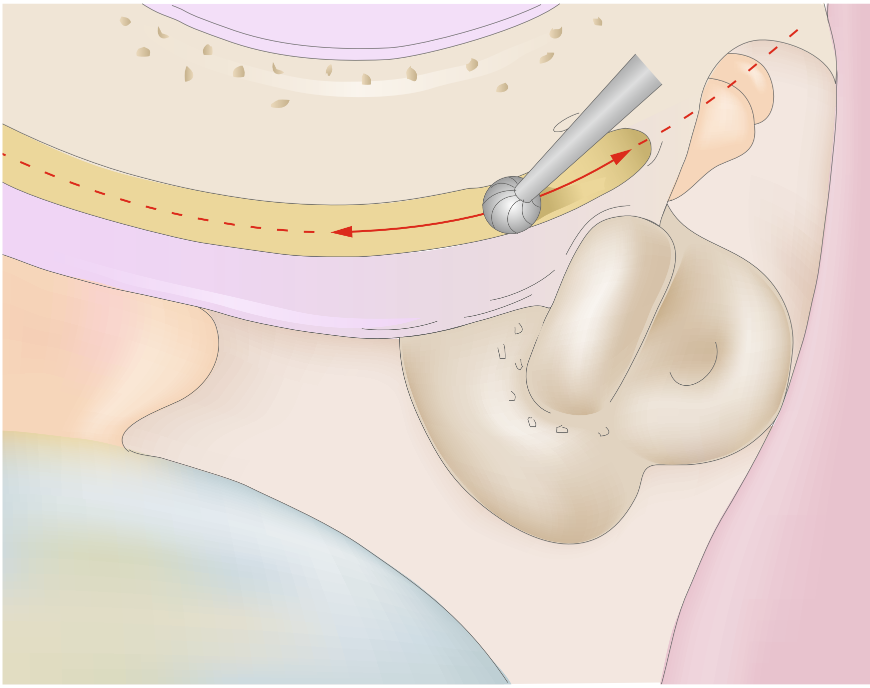

Fig. 4.2 The facial recess is defined by the line drawn through the body of the incus, across the posterior bony canal wall. Be faithful to this line during the initial dissection. Use a 2 mm cutting burr to start. Look for small air cells to guide you

2. Drill *away from the buttress* toward the mastoid tip and follow the imaginary line "faithfully" to stay in the center of the facial recess (Fig. 4.2). Gradually deepen the exposure, constantly refer to the incus as a reference landmark. Remember that the drill should be pointing towards the middle ear space and not towards the facial nerve (Figs. 4.3 and 4.4).
3. Once the facial recess exposure is deepened, use a *"roll-over"* technique in an *inside-out* fashion to gradually thin out the bone overlying the fallopian canal (Video 1). If the space is confined, switch to a 1.5-mm diamond burr for this step.

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Tympanic segment of the facial nerve
- Mastoid segment of the facial nerve
- Chorda tympani
- Incus buttress
- Posterior tympanotomy air cell tract
- Chordal crest

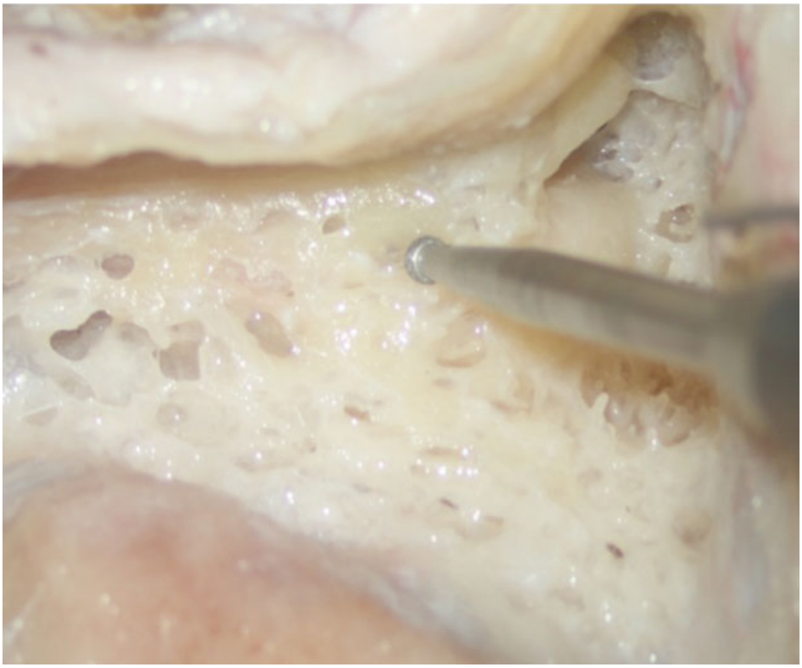

Fig. 4.3 Incorrect position of the patient (no slot position) and direction of drill towards the facial nerve during drilling of the facial recess

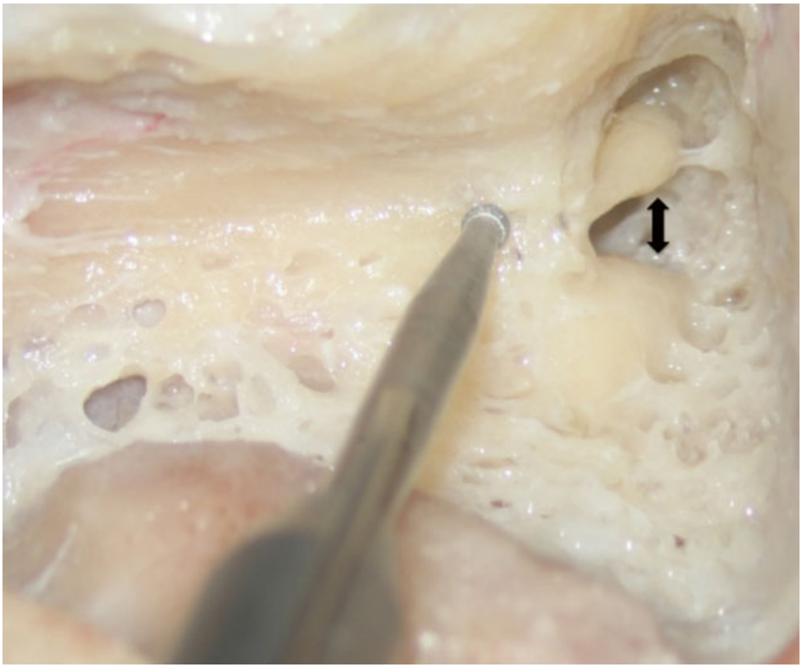

Fig. 4.4 Correct position of the patient and drill during drilling of the facial recess: patient is tilted away to delineate the slot position between ossicles and fallopian canal (*arrow*). This slot also delineates the facial recess

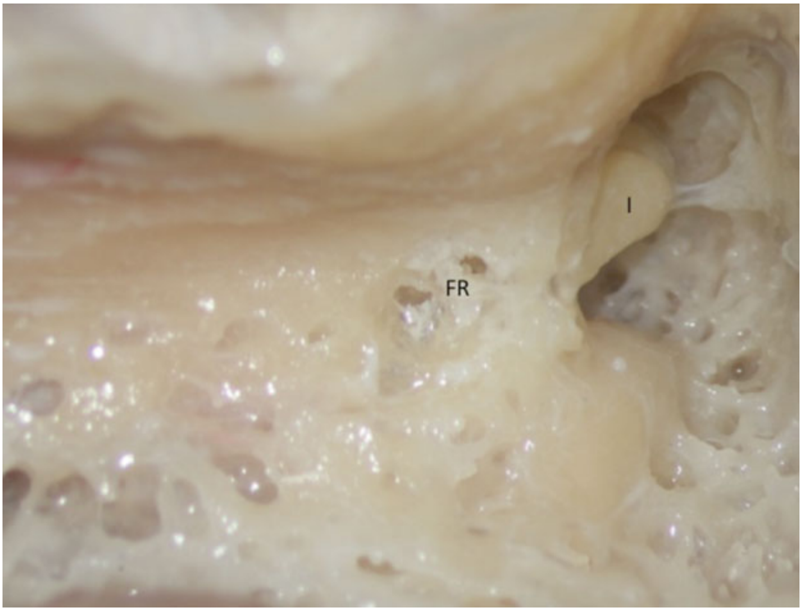

Fig. 4.5 In most cases, an air cell tract within the posterior tympanotomy can be found and carefully followed medially (*FR* facial recess, *I* incus)

4. Continue drilling by deepening followed by rolling over to expand the facial recess both *transversely* and *antero-posteriorly* (Fig. 4.6). The task is to create a wedge shape connection into the middle ear space. As the dissection gets deeper, there should be less and less hand movement, and the drilling should feel more and more deliberate. The *"press-release"* and *"spot drilling"* technique becomes more important here (Video 1).
5. It is critical to realize that the fallopian canal will begin to turn more anteriorly and laterally in the inferior aspect of the facial recess. This is a common region of epineurial exposure. To improve exposure during drilling, place the *suction at the additus* to effectively evacuate the irrigation solution from the middle ear. A small frazier sucker works best at the beginning. When the facial recess becomes more exposed and irrigation is reduced, a 18 G house-urban microsuction tip becomes more user-friendly.
6. To better identify the facial nerve as the fallopian canal is thinned, look for a subtle *color change* when the nerve can be seen through the semi-translucent bone. Frequently, a small *vessel* would point you to the right

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Tympanic segment of the facial nerve
- Mastoid segment of the facial nerve
- Chorda tympani
- Incus buttress
- Posterior tympanotomy air cell tract
- Chordal crest

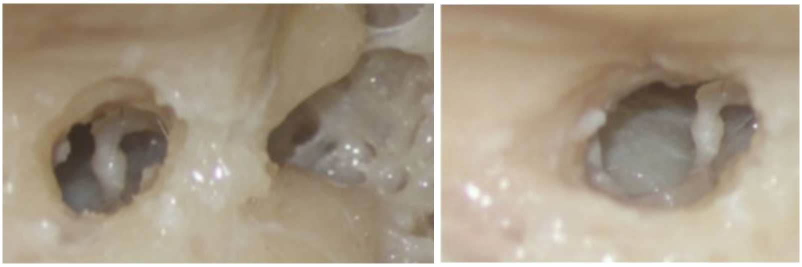

Fig. 4.6 The facial recess is opened both transversely and anteroposteriorly

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Tympanic segment of the facial nerve
- Mastoid segment of the facial nerve
- Chorda tympani
- Incus buttress
- Posterior tympanotomy air cell tract
- Chordal crest

direction, but do not be paralyzed by the fear of injuring the nerve as it is usually necessary to drill over the vessels in order to stop the bleeding and obtain the right exposure.

7. To improve exposure, thinning of the posterior canal wall is important. Keep in mind that the annulus and canal skin can be injured easily when the exposure is limited. Be mindful of the anterior aspect of your burr.

Superiorly, a buttress of bone is preserved between the short process of the incus and the facial recess (Figs. 4.1 and 4.7). This buttress is referred to as the *"incus buttress"* as it protects the incus and its posterior ligament attachment which lies just behind it. When an active middle ear implant, such as a Med-El Vibrant Soundbridge is positioned onto the long process of the incus, the facial recess has to be enlarged both anteroposteriorly and superiorly (Fig. 4.7). This step often requires the sacrifice of the chorda tympani and significantly thinning the incus buttress.

▶ Remember that the chorda tympani is immediately beneath the annulus fibrosus of the tympanic membrane. Care must be taken not to perforate the tympanic membrane during this step.

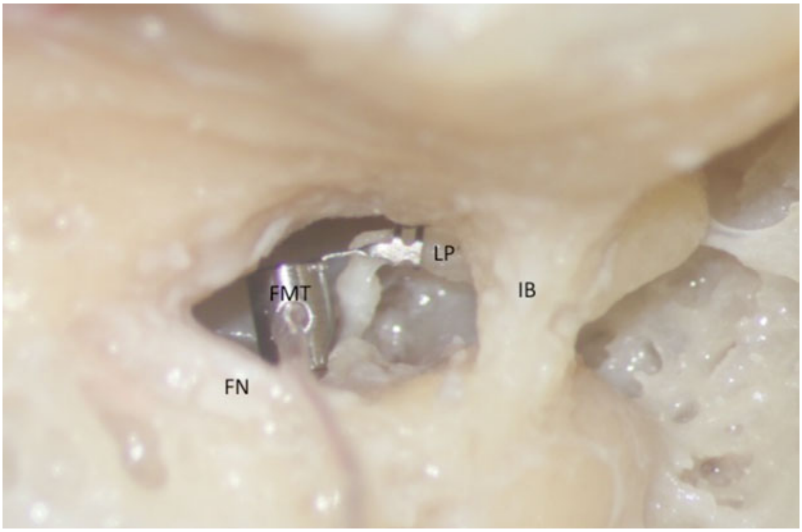

Fig. 4.7 To position an active middle ear implant onto the incus, the size of the facial recess has to be maximized (*FN* facial nerve, *FMT* floating mass transducer, *LP* long process of incus, *IB* incus buttress)

► Another common error is to penetrate the posterior canal wall and expose the EAC lumen. Such perforations must be filled with bone paté (bone dust and fibrin glue) to avoid a permanent mastoid-cutaneous fistula.

The so called *chorda-facial angle*, where the chorda tympani leaves the facial nerve, can be detected inferiorly. This region is variable in location as is the distance between the chorda and facial nerve, rendering the facial recess more or less narrow in different temporal bones.

After stepwise enlargement of the facial recess, the following landmarks can be visualized: the *horizontal (tympanic) portion* of the facial nerve, the *lenticular process* of the incus, the *incudostapedial joint*, the *crura of the*

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Tympanic segment of the facial nerve
- Sinodural angle
- Digastric ridge
- Mastoid segment of the facial nerve
- Incus buttress
- Round window
- Stapedial tendon
- Stapes
- Long process of the incus
- Incudostapedial joint

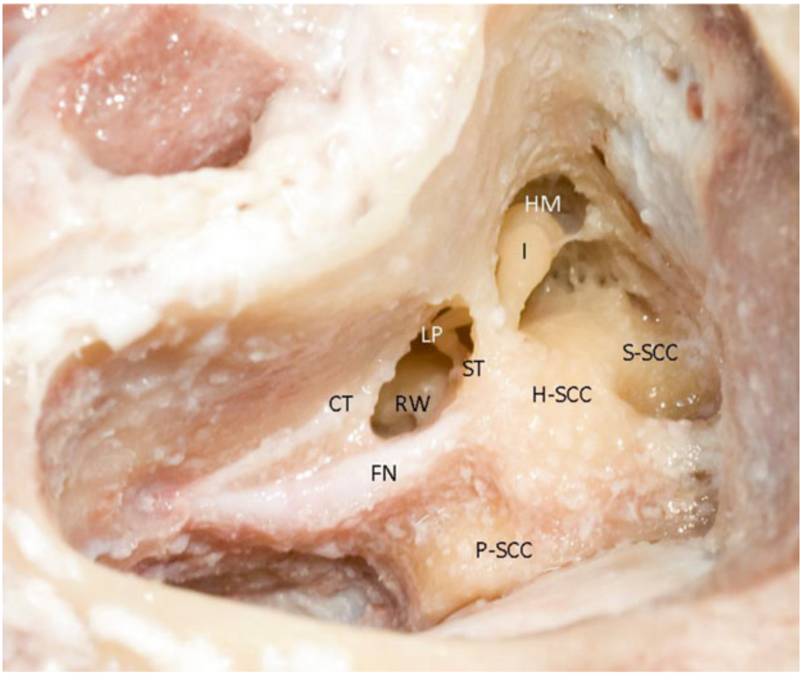

Fig. 4.8 After the facial recess is opened, landmarks in the middle ear are visualized (*CT* chorda tympani, *FN* facial nerve, *RW* round window, *ST* stapedial tendon, *LP* long process of incus, *I* short process of incus, *HM* head of malleus, *H-SCC* horizontal semicircular canal, *S-SCC* superior semicircular canal, *P-SCC* posterior semicircular canal)

stapes, the *stapedial tendon* exiting the *pyramidal process*, and the *round window niche* (Fig. 4.8).

As the patient is tilted away, the *cochleariform process* which anchors the *tensor tympani tendon* medially can be seen. More anteriorly, the *eustachian tube* opening into the middle ear is identified (Fig. 8.1).

Landmarks

- Horizontal semicircular canal
- Short process of incus
- Tympanic segment of the facial nerve
- Mastoid segment of the facial nerve
- Chorda tympani
- Incus buttress
- Round window
- Stapedial tendon
- Stapes
- Long process of the incus
- Incudostapedial joint
- Head of malleus
- Tensor tympani muscle

Round Window Exposure

5

In the context of cochlear implantation, visualization of the round window is very important: first, if the electrode is inserted directly through the round window membrane, and second when a cochleostomy is performed, the round window serves as an important landmark.

► For the inexperienced surgeon, a hypotympanic air cell can be mistaken for the round window and a faulty electrode insertion may occur (Fig. 5.2, left).

To see the full extent of the membrane, the subject is tilted back from the slot position towards the surgeon. Sometimes, bone removal medial to the facial nerve is necessary to expose the round window (Fig. 5.1). The *pseudomembrane* which may be partially or fully covering the round window niche is removed using a Rosen needle, and the bony overhang (*subiculum*) is drilled away to visualize the membrane (Fig. 5.2).

Landmarks
- Lateral semicircular canal
- Tympanic segment of the facial nerve
- Mastoid segment of the facial nerve
- Incus buttress
- Stapedial tendon
- Long process of the incus
- Incudostapedial joint
- Round window

Electronic supplementary material Supplementary material is available in the online version of this chapter at 10.1007/978-3-7091-1490-2_5. Videos can also be accessed at http://www.springerimages.com/videos/978-3-7091-1489-6.

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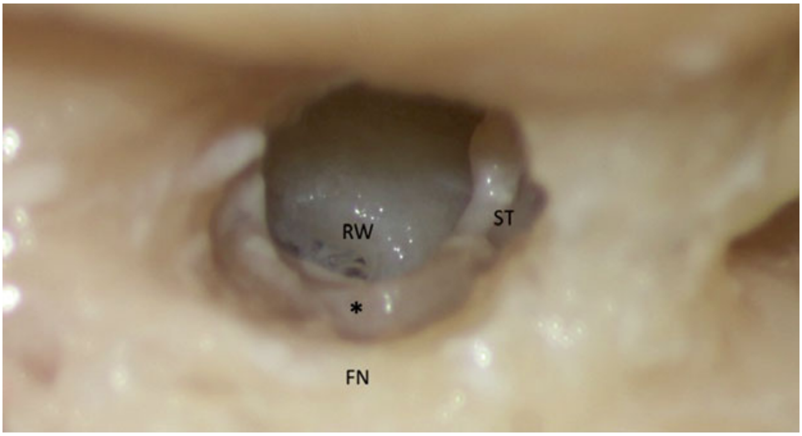

Fig. 5.1 To expose the round window the patient is now tilted towards the surgeon again. Depending on the anatomical situation, sometimes bone medial to the facial nerve (*asterisk*) needs to be removed to visualize the round window (*RW* round window, *FN* facial nerve, *ST* stapedial tendon)

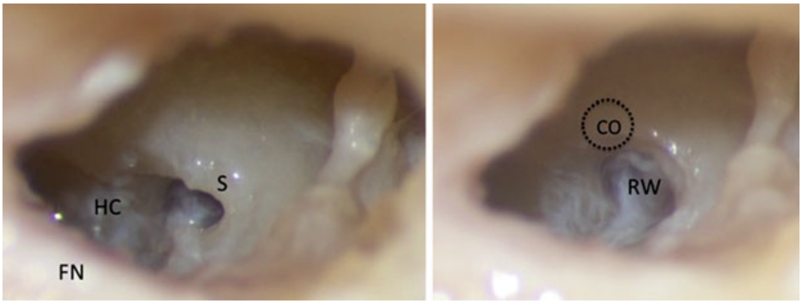

Fig. 5.2 The true round window membrane is usually covered by a pseudomembran and the bony overhang (subiculum) impedes visualization of the whole membrane (*left*). After removing the pseudomembrane and subiculum, the whole round window can be visualized (*right*). A cochleostomy should be performed anterior and inferior to the RW (*FN* facial nerve, *HC* hypotympanic cell, *S* subiculum, *RW*=round window, *CO* cochleostomy)

Landmarks
- Lateral semicircular canal
- Tympanic segment of the facial nerve
- Mastoid segment of the facial nerve
- Incus buttress
- Stapedial tendon
- Long process of the incus
- Incudostapedial joint
- Round window

After opening the round window membrane, the electrode can be inserted directly through the round window (Fig. 5.3, Video 3). At the inferior margin of the round window the crista fenestra (*cochlea hook region*) sometimes creates some resistance during insertion.

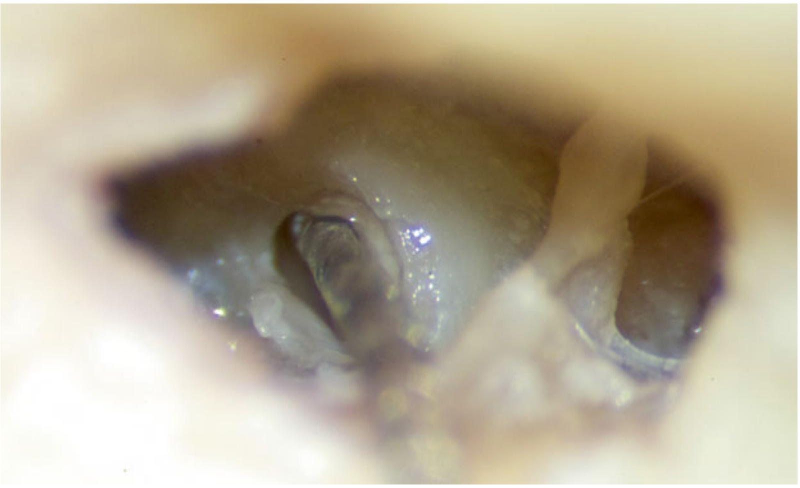

Fig. 5.3 An electrode (Med-El Flex24) is inserted through the round window

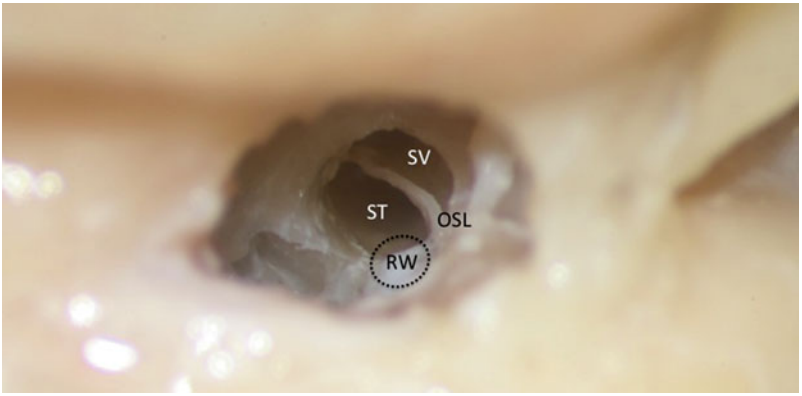

Fig. 5.4 To understand the relation of the round window and the two scalae is of paramount importance. The importance of drilling a cochleostomy anterior and inferior to the round window in order to avoid hitting the osseus spiral ligament is further highlighted here (*RW* round window, *ST* scala tympani, *SV* scala vestibuli, *OSL* osseus spiral ligament)

If a cochleostomy is performed, it should be located anterior and inferior to the round window (Fig. 5.2). In this manner, the *osseous spiral ligament* is avoided and trauma to the inner ear and neural structures are minimized (Figs. 5.4 and 5.5).

Landmarks
- Scala tympani
- Scala vestibuli
- Mastoid segment of the facial nerve
- Incus buttress
- Round window
- Stapedial tendon
- Long process of the incus
- Incudostapedial joint

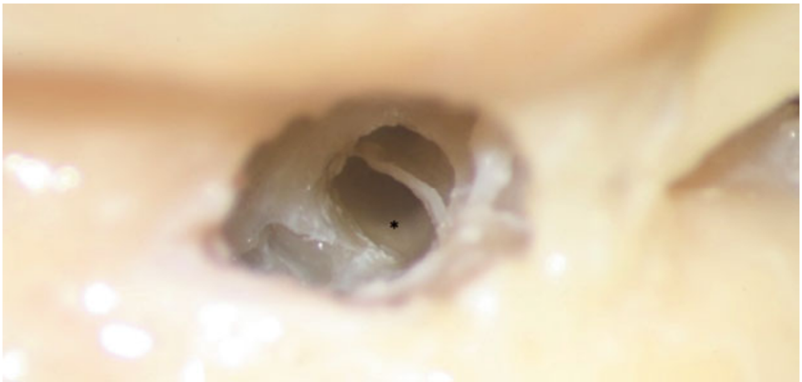

Fig. 5.5 When the round window membrane is opened, the crista fenestra (hook region) can be visualized (*asterisk*)

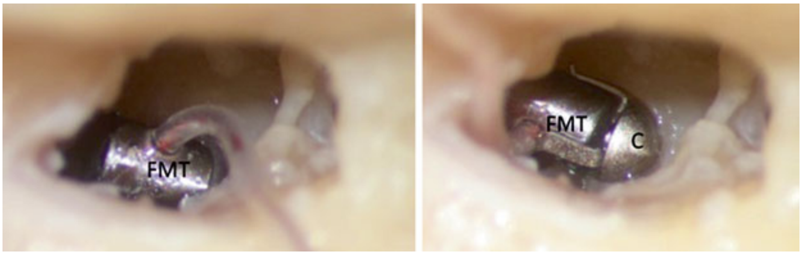

Fig. 5.6 The floating mass transducer of an active middle ear implant is positioned directly onto the round window membrane (*left*) or with the use of a coupler (*right*; *FMT* floating mass transducer, *C* coupler)

Landmarks
- Scala tympani
- Scala vestibuli
- Mastoid segment of the facial nerve
- Incus buttress
- Round window
- Stapedial tendon
- Long process of the incus
- Incudostapedial joint

For positioning an active middle ear implant directly onto the round window (so-called vibroplasty), the membrane needs to be exposed maximally. The transducer can either be positioned directly onto the membrane or with the use of a coupler (Fig. 5.6, Video 4).

Alternative Approaches to the Cochlea

6

Finding a patent cochlea may be very challenging in postmeningitic patients with labyrinthis ossificans. A myriad of cochlear drill out procedures including access to the scala vestibuli and mid/apical cochleostomies have been described.

Landmarks
- Facial recess
- Facial nerve tympanic segment
- Round window
- Oval window niche
- Stapedial tendon
- Long process of the incus
- Incudostapedial joint
- Tensor tympani muscle

Scala Vestibuli Approach

Due to pathophysiological mechanisms that are not fully understood, the process of postmeningitic ossification of the inner ear often starts in the lateral semicircular canal, then reaches the scala tympani and finally affects both scalae in a basal to apical progress pattern. Whereas the status of the lateral SCC serves as an important marker for early detection of ossification by MRI, the fact that the scala vestibuli is often spared from ossification initially renders it an important alternative route for electrode insertion.

After the *scala tympani* is drilled open for a few millimeters and no lumen can be found, a *scala vestibuli* approach is performed: The *incus* and *stapes suprastructure* are removed. The footplate of the stapes is left in place.

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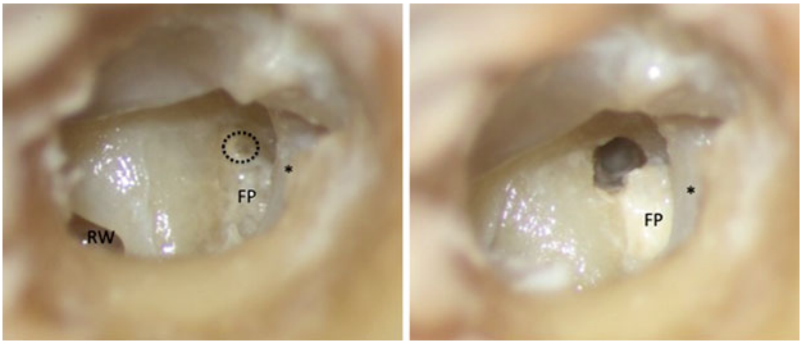

Fig. 6.1 A tympanomeatal flap is raised and an atticotomy is performed to visualize the middle ear structures. After removal of the incus and stapes suprastructure, a scala vestibuli cochleostomy is drilled in the anterior niche of the oval window (*RW* round window, *FP* footplate, *asterisk* facial nerve, *dashed line indicates* area of scala vestibuli cochleostomy)

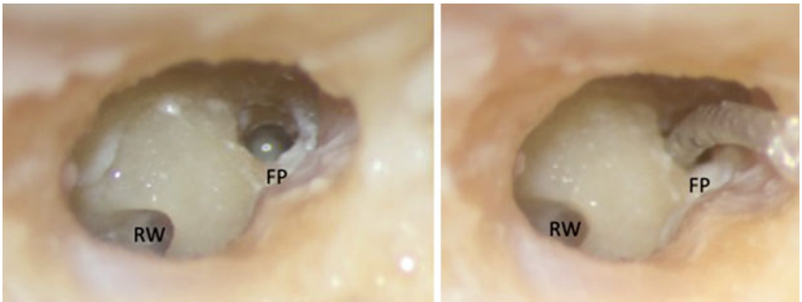

Fig. 6.2 Scala vestibuli cochleostomy and electrode insertion seen through facial recess (*RW* round window, *FP* footplate)

Landmarks
- Facial recess
- Facial nerve tympanic segment
- Round window
- Oval window niche
- Stapedial tendon
- Long process of the incus
- Incudostapedial joint
- Tensor tympani muscle

The cochleostomy of the scala vestibuli is performed in the *anterior niche* of the *oval window*, lateral to the spiral ligament (Figs. 6.1 and 6.2).[1]

Middle/Apical Turn Cochleostomy

If a lumen cannot be found in the basal turn of the cochlea in either scalae, a superior (middle or apical turn) cochleostomy can be performed. For this approach,

[1] Kiefer J et al., Scala vestibuli insertion in cochlear implantation: a valuable alternative for cases with obstructed scala tympani. ORL J Otorhinolaryngol Relat Spec. 2000.

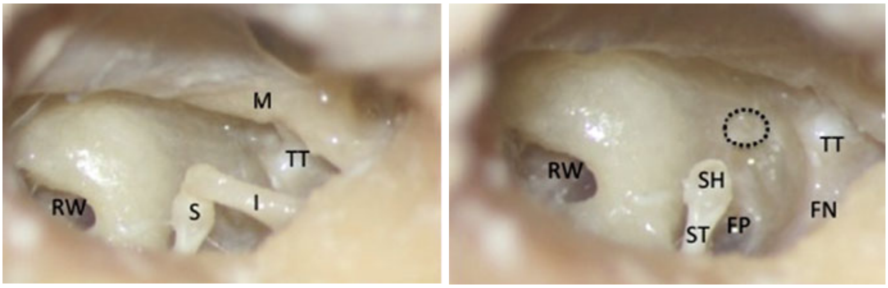

Fig. 6.3 After atticotomy and removal of the incus, a superior cochleostomy is drilled anterior to the oval window niche and just inferior to the tensor tympani muscle and cochleariform process (*RW* round window, *S* stapes, *I* incus, *TT* tensor tympani, *M* malleus, *SH* stapes head, *ST* stapedial tendon, *FP* footplate, *FN* facial nerve, *dashed line indicates* area of superior cochleostomy)

a *tympanomeatal flap* is raised, and an *atticotomy* is performed with a 1.5-mm diamond drill to improve visualization of the middle ear structures. If not already done during a scala vestibuli approach, after separation of the incodostapedial joint with a 45° hook or a joint knife, the *incus* is removed.

A cochleostomy is drilled approximately 2 mm anterior to the *oval window* margin and just inferior to the *cochleariform process* (tensor tympani; Figs. 6.3 and 6.4). The electrode can then either be inserted in an antero- or retrograde manner.[2] The localization is very similar to the scala vestibuli approach, and due to variations in anatomy (size, rotation of cochlea) it is often rather unclear for the surgeon which part of the cochlea is opened until radiological studies are performed.

Landmarks
- Facial recess
- Facial nerve tympanic segment
- Round window
- Oval window niche
- Stapedial tendon
- Long process of the incus
- Incudostapedial joint
- Tensor tympani muscle

[2] Senn P et al. Retrograde cochlear implantation in postmeningitic basal turn ossification. Laryngoscope. 2012.

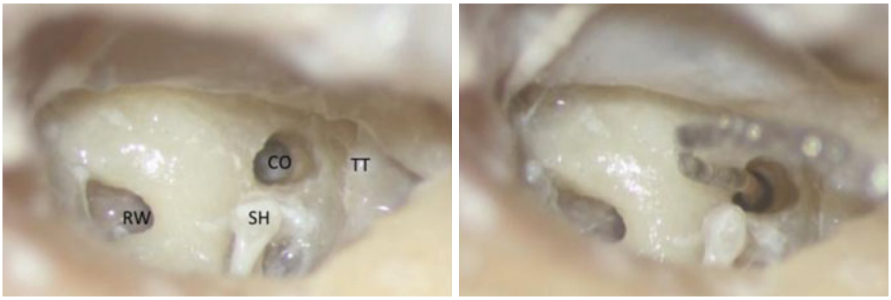

Fig. 6.4 The superior cochleostomy is drilled and an electrode is inserted into the cochlea (*RW* round window, *SH* stapes head, *CO* cochleostomy, *TT* tensor tympani)

Landmarks
- Arcuate eminence
- Greater superfical petrosal nerve
- Internal auditory canal
- Facial nerve
- Cochlea

Middle Fossa Approach to the Cochlea

An approach via the middle cranial fossa was described mainly for ears with chronic inflammation. Due to the invasiveness of this procedure this approach is rarely used and mentioned herein only for the sake of completeness. As in a middle fossa approach to the IAC, a temporal craniotomy is performed, the temporal lobe is retracted and the cochlea is localized (Fig. 13.7):[3,4] The lack of constant landmarks and the variation in anatomic features make this procedure extremly challenging even for experienced surgeons. After identification of the superior semicircular canal and the greater superfical petrosal nerve, the IAC is identified and blue lined in a medial to lateral fashion. Once the lateral wall of the IAC is located drilling proceeds anterolaterally until the cochlear basal turn is identified and opened.

[3] Colletti V, Fiorino FG. New window for cochlear implant insertion. Acta Otolaryngol 1999.

[4] Bento RF et al. Cochlear implantation via the middle fossa approach: surgical and programming considerations. Otol Neurotol. 2012.

Unroofing the Epitympanum

7

In chronic otitis media, cholesteatoma formation classically starts in the space just medially to the pars flaccida portion of the tympanic membrane and the *scutum* (a sharp bony spur formed by the lateral wall of the tympanic cavity and the superior wall of the external auditory canal, usually the first bony structure to erode as a result of a cholesteatoma). This space is referred to as *Prussak's space*. It continues posteriorly to become the *epitympanum*. So, to access this space posteriorly, it is necessary to unroof the epitympanum. This is done by removing air cells in the root of the zygoma between the middle fossa dura and the thinned posterior canal wall until the *head of the malleus* and the *incudomalleolar joint* are identified (Figs. 2.9 and 2.10). The floor of the dissection is the tympanic portion of the facial nerve and the superior semicircular canal. If necessary, the dissection can be carried anteriorly through the zygomatic root to the glenoid fossa. In the anterior epitympanum, after removal of the head of the malleus and the body of the incus, a bony spicule *(the cog)* descending from the tegmen can sometimes be identified (Fig. 8.1). This spicule separates the epitympanum in anterior and posterior compartments. If present, this landmark can be identified on pre-operative CT scans and needs to be removed in order to fully remove disease in the anterior epitympanum.

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Tympanic segment of the facial nerve
- Head of the malleus
- Incudomalleolar joint
- Cog

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Canal Wall Down (Radical Cavity)

8

The *posterior canal wall* is taken down mainly in cholesteatoma cases when a wide overview of the middle ear structures is necessary. Initially the canal wall is usually preserved to have a landmark for the mastoidectomy. When the canal wall is then taken down, drilling is performed parallel to the facial nerve. Once you are medial to the tympanic annulus, it is important to take down the bone overlying the facial nerve ("*facial ridge*") as much as possible to allow cleaning and inspection of the middle ear space (Video 5). This is known as lowering the facial ridge and an important step to reduce the incidence of leaving cholesteatoma matrix behind. In this context, also the importance of a wide *meatoplasty* should be highlighted (Video 6). Once the canal wall is removed, the entrance into the eustachian tube and the canal of the tensor tympani can be seen. The carotid artery lies medial to the eustachian tube (Fig. 8.1).

Landmarks
- Horizontal semicircular canal
- Tympanic segment of the facial nerve
- Head of the malleus
- Incudomalleolar joint
- Cog
- Tensor tympani
- Eustachian tube
- Supratubal recess
- Carotid artery

Electronic supplementary material Supplementary material is available in the online version of this chapter at 10.1007/978-3-7091-1490-2_8. Videos can also be accessed at http://www.springerimages.com/videos/978-3-7091-1489-6.

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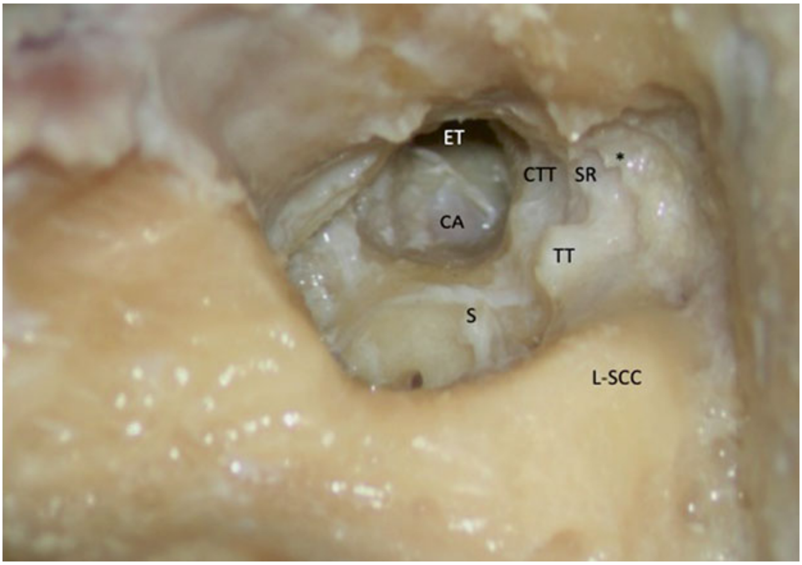

Fig. 8.1 The posterior canal wall is taken down to gain a wide overview of the middle ear structures (*L-SCC* lateral semicircular canal, *TT* tensor tympani, *S* stapes, *asterisk* cog, *SR* supratubal recess, *CTT* canal of tensor tympani, *CA* carotid artery, *ET* eustachian tube)

9 Skeletonizing the Facial Nerve

A diamond burr is used to skeletonize the facial nerve in its descending (mastoid) portion. As mentioned, the direction of preparation should always be parallel to the course of the nerve. The nerve should be skeletonized broadly using slow deliberate strokes of the drill. Excessive hand movement should be avoided to minimize inadvertent injury to the facial nerve.

► It is important to understand that the most proximal part of the labyrinthine portion of the facial nerve, as well as the geniculate ganglion, cannot be exposed via the mastoid without performing a labyrinthectomy or a middle fossa approach. The meatal foramen in particular, which is the narrowest point of the fallopian canal and should always be included if the whole intratemporal facial nerve is meant to be decompressed, can only be reached via the middle fossa or translabyrinthine routes (Fig. 9.1).

Landmarks
- Horizontal semicircular canal
- Mastoid segment of the facial nerve
- Tympanic segment of the facial nerve
- Labyrinthine segment of the facial nerve
- Meatal segment of the facial nerve
- Geniculate ganglion
- Retrofacial air cell tract

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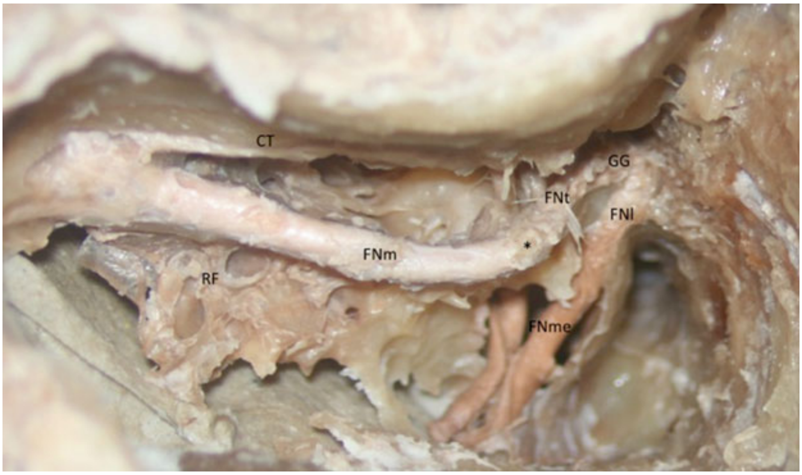

Fig. 9.1 The facial nerve has been decompressed in its whole intratemporal course (*FNm* mastoid segment of facial nerve, *asterisk* second genu, *FNt* tympanic segment of facial nerve, *GG* geniculate ganglion, *FNl* labyrinthine segment of facial nerve, *FNme* meatal segment of facial nerve, *RF* retrofacial air cell tract, *CT* chorda tympani)

Endolymphatic Sac Dissection (Retro-/Infralabyrinthine)

10

The *endolymphatic sac* (*ELS*) can be found in a thickened portion of the *posterior fossa dura* medial to the *sigmoid sinus* and inferior to the *posterior canal*. A classic landmark that consistently defines the upper boundary of the ELS is known as "*Donaldson's line*". This line is drawn through the lateral semicircular canal (SCC), which bisects the posterior SCC; the ELS is usually at and below this line.

After completing a cortical mastoidectomy with identification of the lateral SCC, the posterior SCC should be delineated by removing the surrounding *perilabyrinthine air cells*. The approximate location of the vertical segment of the fallopian canal can be identified by the relative anatomy of the SCCs and the posterior canal wall, which is gradually thinned out. The *fallopian canal* is further delineated from behind while skeletonizing the sigmoid sinus and removing the *retrofacial air cells*. In this manner, the bone deeper (medial) to the sigmoid sinus is gradually removed to reveal the posterior fossa plate that covers the dura and the ELS (Figs. 10.1, 10.2 and 10.3). If the sigmoid sinus is very prominent or very anterior, the overlying bone may have to be uncovered partially or completely to permit compression and exposure of the ELS. When the bony plate over the dura is removed anterior to the sigmoid sinus, the ELS becomes recognizable as a thickened area at and below the Donaldson's line.

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Superior semicircular canal
- Posterior semicircular canal
- Common crus
- Fallopian canal
- Posterior fossa dural plate
- Endolymphatic sac
- Endolymphatic duct

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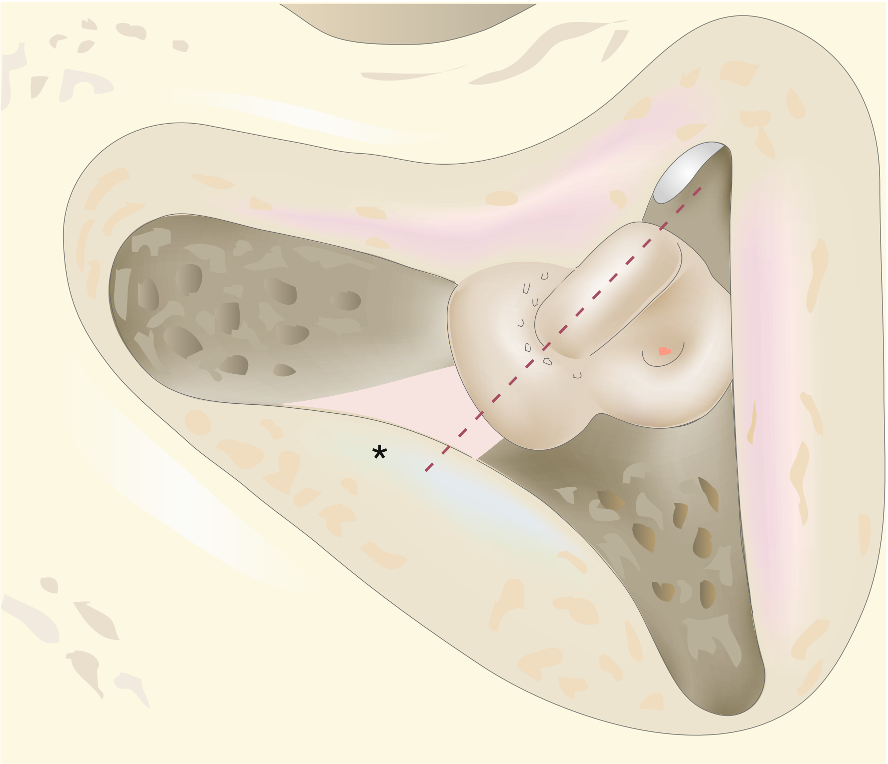

Fig. 10.1 Localization of the endolymphatic sac; the Donaldson's line is an imaginary line through the horizontal semicircular canal and defines the upper limit of the endolymphatic sac (*asterisk*)

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Superior semicircular canal
- Posterior semicircular canal
- Common crus
- Fallopian canal
- Posterior fossa dural plate
- Endolymphatic sac
- Endolymphatic duct

At this point, perilabyrinthine dissection should be completed to fully delineate the three SCCs. By hugging the *middle fossa dural plate* (tegmen) and carefully removing the *subarcuate air cells*, the superior SCC and the posterior SCC can be found to merge together to form the *common crus*. It is important to note that this region represents the deepest part of the bony labyrinth. Further, it is also important to know that the ampullated end of the posterior SCC is hidden medial to the *second genu of the fallopian canal* that is not easily accessible except in a very well penumatized bone.

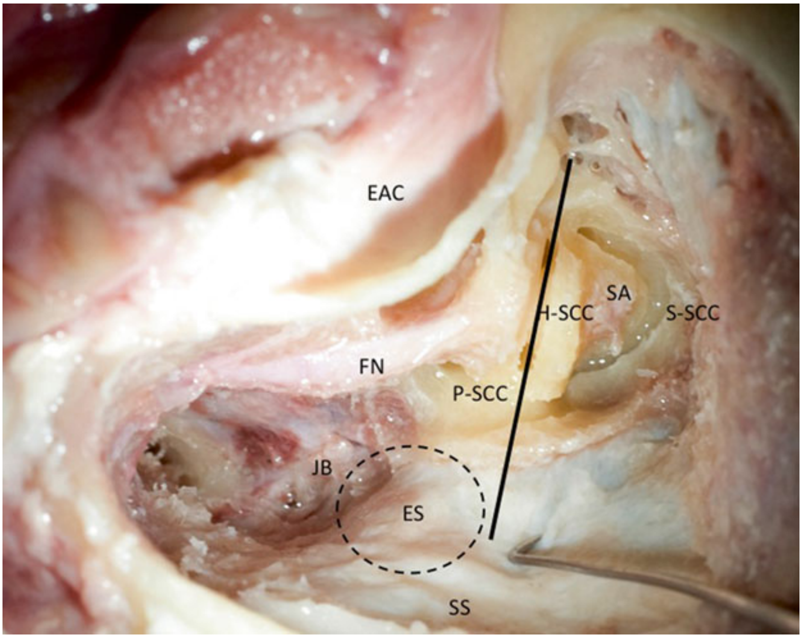

Fig. 10.2 Localization of the endolymphatic sac; the Donaldson's line is an imaginary line through the horizontal semicircular canal (*EAC* external auditory canal, *FN* facial nerve, *H/S/P-SCC* horizontal/superior/posterior semicircular canal, *SA* subarcuate artery, *ES* endolymphatic sac, *SS* sigmoid sinus, *JB* jugular bulb)

The ELS is sometimes only identifiable as a *thickened white area* next to the normally darker, single-layered dura, or by the presence of increased vascularity on its surface. Also, when the posterior fossa dura is gently retracted with an instrument, the membranous *endolymphatic duct* can be visualized as it connects the sac with the osseous *vestibular aqueduct* (Fig. 10.3). This structure travels medial to the posterior SCC, entering the medial aspect of the vestibule. Finally, the ELS can be incised with a #15 blade to fully appreciate its thickness, in contradistinction to the dura. Stenting the ELS with a small tapered piece of silastic while avoiding a breach in the dura should be attempted.

Landmarks
- Horizontal semicircular canal
- Short process of incus
- Superior semicircular canal
- Posterior semicircular canal
- Common crus
- Fallopian canal
- Posterior fossa dural plate
- Endolymphatic sac
- Endolymphatic duct

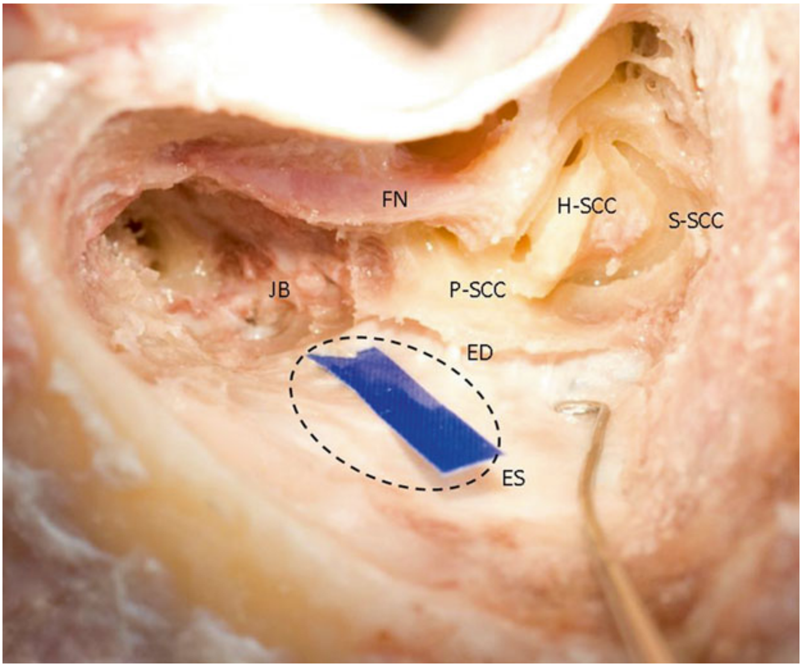

Fig. 10.3 Localization of the endolymphatic sac: After retraction of the posterior fossa dura, the endolymphatic duct can be visualized (*FN* facial nerve, *H/S/P-SCC* horizontal/superior/posterior semicircular canal, *ES* endolymphatic sac with piece of silicone, *ED* endolymphatic duct, *JB* jugular bulb)

Labyrinthectomy

11

Completely drilling out the semicircular canals and removing all the soft tissue of the canals and the vestibule is referred to as labyrinthectomy. The indication for this procedure is the eradication of labyrinthine vertigo which is a hallmark symptom of conditions such as Meniere's disease. In addition, it is a common (non hearing preserving) surgical route to the *internal auditory canal* (*IAC*) and *cerebellopontine angle* (*CPA*).

Prior to the labyrinthectomy, a cortical mastoidectomy is first carried out which is then followed by the identification of the *facial nerve* and all *three semicircular canals* (*SCC*). To reach this goal, a *wide exposure* of the middle and posterior dural plate as well as a complete drill-out of the *sinodural angle* is necessary. Only in this way, both the neurotologist and neurosurgeon will have enough space (instruments and light) to work deep in the CPA and IAC. Therefore, the term "*medial temporal bone resection*" for this approach describes very well the extensive amount of bone removal that is necessary for an appropriate exposure.

For a labyrinthectomy, the semicircular canals should be drilled out in a *systematic fashion* to identify the vestibule of the inner ear (Videos 7 and 8).

Landmarks
- Horizontal semicircular canal
- Superior semicircular canal
- Posterior semicircular canal
- Common crus
- Superior fossa dural plate
- Posterior fossa dural plate
- Subarcuate artery
- Sinodural angle
- Facial nerve

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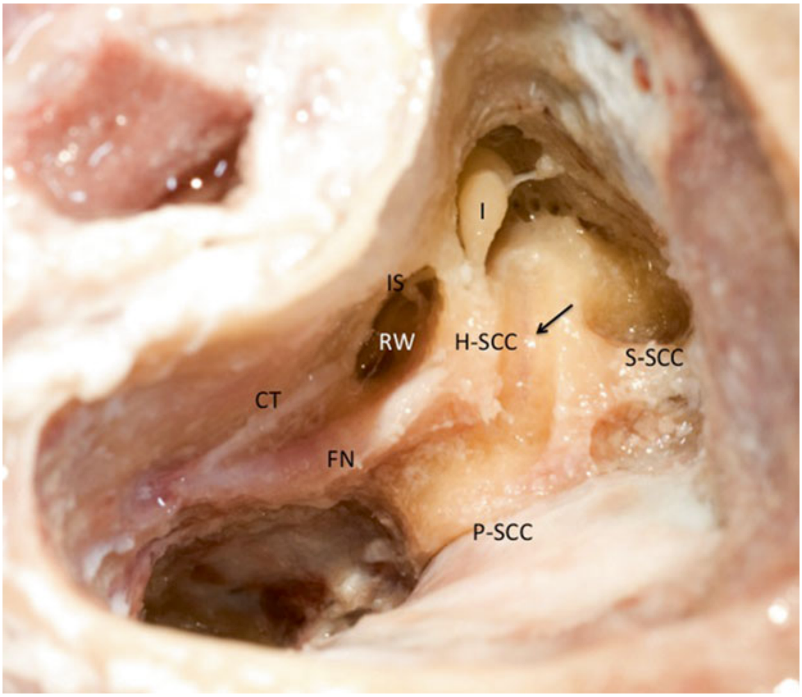

Fig. 11.1 Blue lining of the horizontal semicircular canal (*H-SCC* horizontal semicircular canal, *arrow* blue-lined H-SCC, *S-SCC* superior semicircular canal, *P-SCC* posterior semicircular canal, *FN* facial nerve, *CT* chorda tympani, *RW* round window, *IS* incudostapedial joint, *I* incus)

Landmarks

- Horizontal semicircular canal
- Superior semicircular canal
- Posterior semicircular canal
- Common crus
- Superior fossa dural plate
- Posterior fossa dural plate
- Subarcuate artery
- Sinodural angle
- Facial nerve

The initial step is usually opening the superior side of the *lateral* (*horizontal*) *semicircular canal* using a sharp cutting burr. A burr of 3-mm is a perfect size for this step. The canal should be slowly opened until the membranous labyrinth can be seen ("*blue lining*"; Fig. 11.1). Work in a front-to-back fashion. Proceed to open the lateral semicircular canal.

► The fenestrated canals ("*snake eyes*") are followed in their extent to provide *continuing landmarks*. Try to develop a three-dimensional concept of the canal planes!

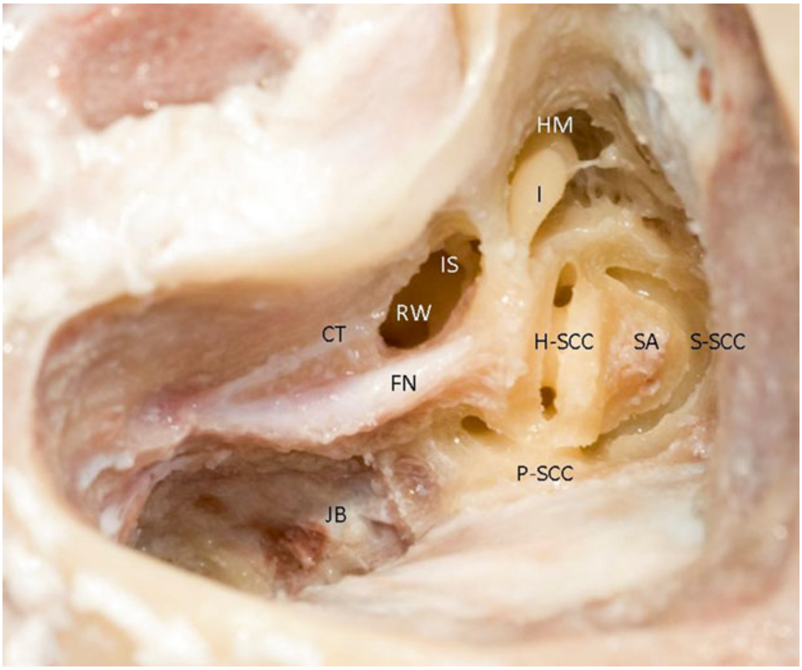

Fig. 11.2 The semicircular canals are opened in a systematic fashion starting with the horizontal canal (*H/S/P-SCC* horizontal/superior/posterior semicircular canal, *SA* subarcuate artery, *JB* jugular bulb, *FN* facial nerve, *CT* chorda tympani, *RW* round window, *IS* incudostapedial joint, *I* incus, *HM* head of malleus)

After opening the lateral SCC, open the posterior SCC by drilling directly posterior and perpendicular to the lateral canal. You should transect the posterior canal. Next you would follow the posterior SCC superiorly toward the *common crus*. You can then follow the superior canal anteriorly toward the ampulla. Alternatively after the posterior canal is transected, you can instead move anteriorly and begin to blue-line the superior semicircular canal. Start superior to the ampulla of the lateral SCC. Take care not to go too anteriorly and harm the facial nerve in its tympanic segment. Again, work in a front-to-back fashion, away from the facial nerve. Follow the curvature of the superior SCC, toward the posterior SCC, until it becomes the *common crus* in its junction with the posterior SCC. In the center of the circle inscribed by the superior semicircular canal, the *subarcuate artery* can be found. Progressively open all three canals. The posterior SCC is followed inferiorly and anteriorly under the descending portion of the facial nerve (Fig. 11.2).

Landmarks
- Horizontal semicircular canal
- Superior semicircular canal
- Posterior semicircular canal
- Common crus
- Superior fossa dural plate
- Posterior fossa dural plate
- Subarcuate artery
- Sinodural angle
- Facial nerve

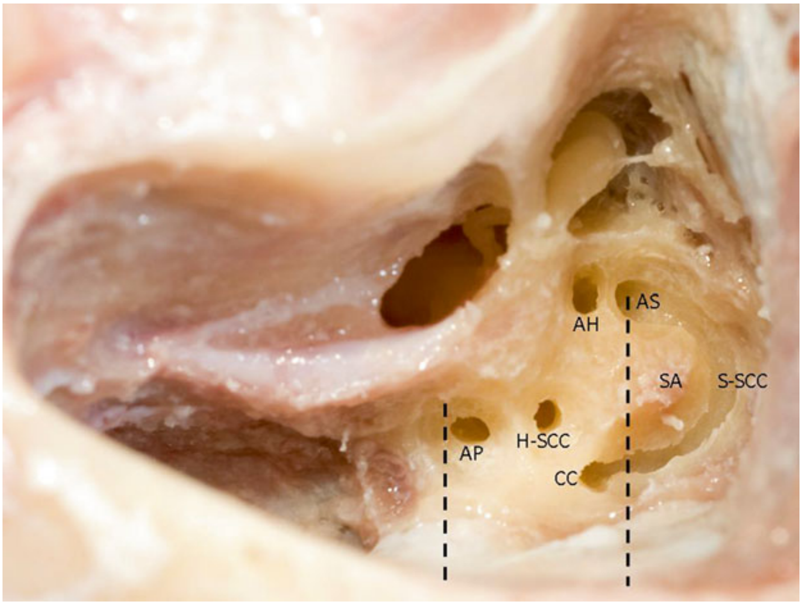

Fig. 11.3 The ampullae of the semicircular canals are important landmarks for the internal auditory canal (*dotted line*; *AP* ampulla of posterior semicircular canal, *H-SCC* horizontal semicircular canal posterior part, *AH* ampulla of horizontal semicircular canal, *AS* ampulla of superior semicircular canal, *S-SCC* superior semicircular canal, *SA* subarcuate artery, *CC* common crus)

Landmarks

- Ampulla of horizontal semicircular canal
- Ampulla of superior semicircular canal
- Ampulla of posterior semicircular canal
- Common crus
- Vestibule
- Vestibular aqueduct
- Internal auditory canal

The *ampullae of the semicircular canals* are important landmarks for the dissection of the *internal auditory canal*. The ampulla of the superior semicircular canal represents the approximate superior border, and the ampulla of the posterior canal the inferior border of the internal auditory canal. The "*cat*'*s eyes*" refer to the opened ampullae of the lateral and superior semicircular canal (Fig. 11.3).

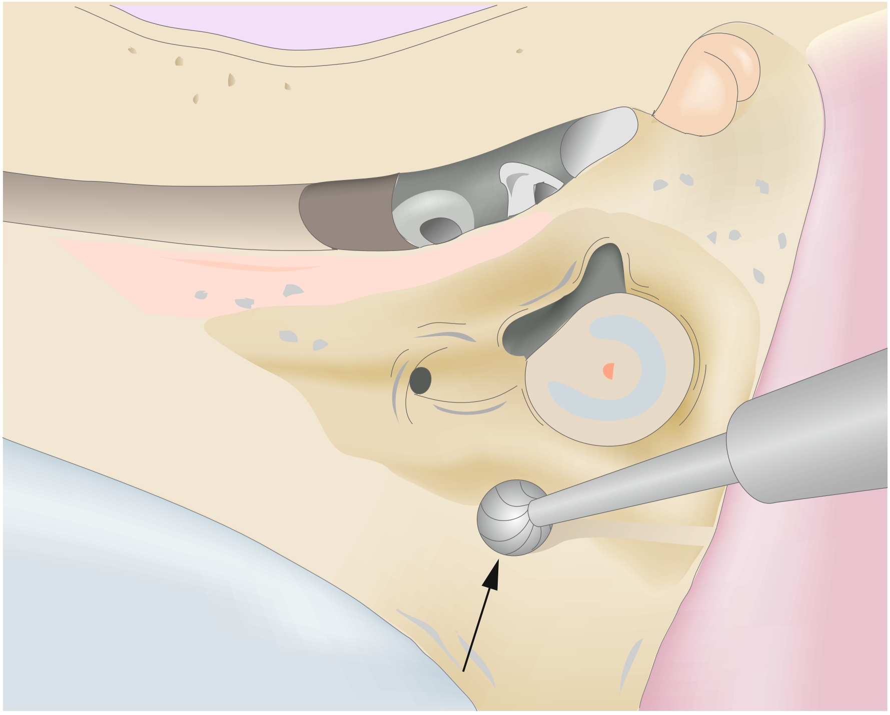

Fig. 11.4 The vestibular openings of the lateral and superior SCC can be easily identified and connected to create a large open vestibule. To connect the ampulla of posterior SCC to the vestibule, the bone needs to be tilted away. Be aware that you are drilling medial to the facial nerve

The openings of the three canals are traced out and followed to their respective entry points into the *vestibule* (five in total). The soft tissue (neuroepithelia) inside the canals is removed. The vestibular openings of the lateral and superior SCC can be easily identified and connected to create a large open vestibule (Fig. 11.4). This defines the lateral most region of the internal auditory canal (IAC).

Landmarks
- Ampulla of horizontal semicircular canal
- Ampulla of superior semicircular canal
- Ampulla of posterior semicircular canal
- Common crus
- Vestibule
- Vestibular aqueduct
- Internal auditory canal

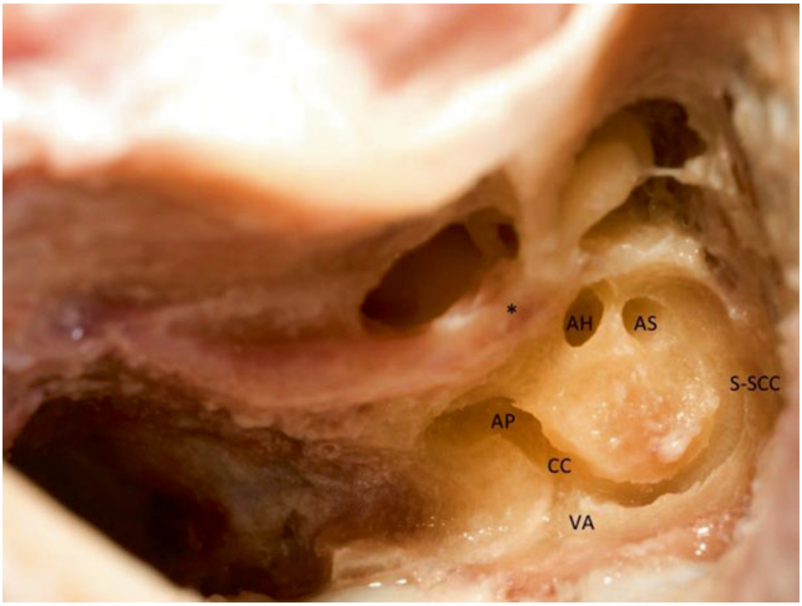

Fig. 11.5 The dissection is advanced toward the vestibule (*asterisk* second genu of facial nerve, *S-SCC* superior semicircular canal, *AP* ampulla of posterior SCC, *AH* ampulla of horizontal SCC, *AS* ampulla of superior SCC, *CC* common crus, *VA* vestibular aqueduct)

Landmarks
- Ampulla of horizontal semicircular canal
- Ampulla of superior semicircular canal
- Ampulla of posterior semicircular canal
- Common crus
- Vestibule
- Vestibular aqueduct
- Internal auditory canal

To connect the ampulla of posterior SCC to the vestibule, the bone needs to be tilted away. Be aware that you are drilling medial to the *second genu* (transition of tympanic to mastoid segment) of the *facial nerve* to complete the three-canal-labyrinthectomy.

Inside the vestibule, the more anterior *spherical recess* for the saccule and the more posterior *elliptical recess* for the utricle can be inspected. The *vestibular aqueduct* can be visualized as it enters into the medial wall of the vestibule just medial to the common crus remnant at the utriculo-endolymphatic valve (Fig. 11.5).

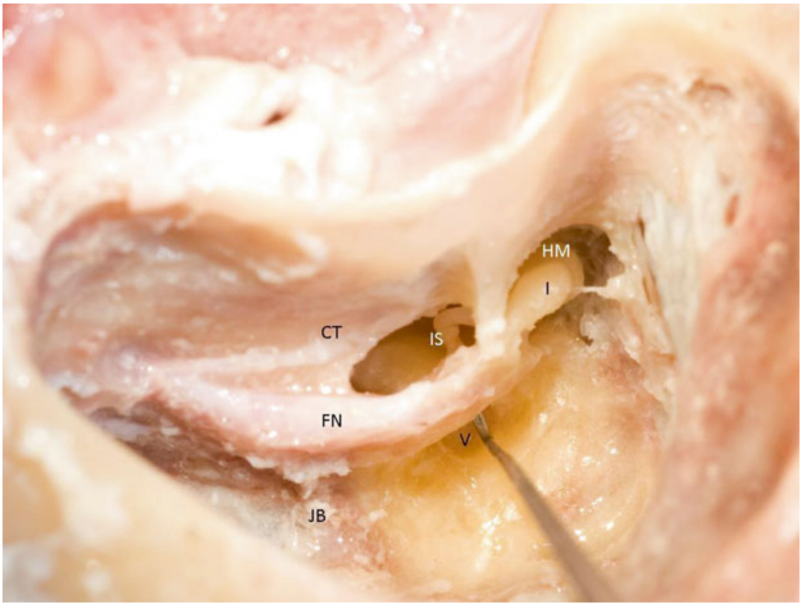

Fig. 11.6 The stapes footplate can be moved from its medial side (*CT* chorda tympani, *FN* facial nerve, *IS* incudostapedial joint, *I* incus, *HM* head of malleus, *V* vestibule, *JB* jugular bulb)

The stapes footplate can be moved through the vestibule from its medial side and its proximity to the saccule and utricle should be noticed (Fig. 11.6).

Landmarks
- Ampulla of horizontal semicircular canal
- Ampulla of superior semicircular canal
- Ampulla of posterior semicircular canal
- Common crus
- Vestibule
- Vestibular aqueduct
- Internal auditory canal

Internal Auditory Canal (IAC)

12

It must be understood that the medial wall of the vestibule forms the lateral wall of the internal auditory canal. Therefore, a small amount of bone removal is sufficient to unroof the internal auditory canal at its anterior (lateral) end, the *fundus*. Posteriorly, the route to the *porus acusticus* (the medial end of the canal) is much deeper because the canal is slanting away from the fundus to the porus. The IAC is in the same axis as the external auditory canal. It has a much more acute angle (more vertical) than most trainees expect.

Landmarks
- Ampulla of horizontal semicircular canal
- Ampulla of superior semicircular canal
- Ampulla of posterior semicircular canal
- Common crus
- Vestibule
- Vestibular aqueduct
- Internal auditory canal
- Cochlear aqueduct

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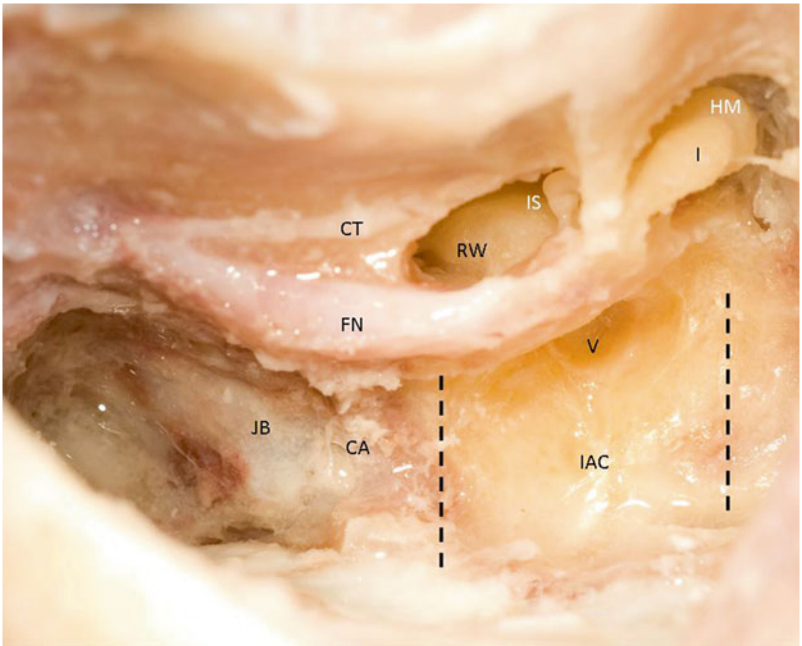

Fig. 12.1 The medial wall of the vestibule forms the lateral wall of the internal auditory canal. The superior (ampulla of superior-SCC and subarcuate artery) and inferior (cochlear aqueduct and ampulla of posterior-SCC) limits are plotted (*CT* chorda tympani, *FN* facial nerve, *RW* round window, *IS* incudostapedial joint, *I* incus, *HM* head of malleus, *V* vestibule, *IAC* internal auditory canal, *CA* cochlear aqueduct, *JB* jugular bulb)

Landmarks

- Ampulla of horizontal semicircular canal
- Ampulla of superior semicircular canal
- Ampulla of posterior semicircular canal
- Common crus
- Vestibule
- Vestibular aqueduct
- Internal auditory canal
- Cochlear aqueduct

The superior limit of the IAC is defined by both the subarcuate artery and the ampullated end of the superior SCC. The inferior limit of the IAC is defined by the cochlear aqueduct medially and the P-SCC ampulla laterally. Of course, the real position of the IAC is subject to anatomic variations as well as underlying pathologies (e.g., meatal tumors). The *cochlear aqueduct* will appear during dissection between the jugular bulb and the internal auditory canal as a small white discoloration in the bone (Fig. 12.1). Cerebrospinal fluid will be released upon entry into the cochlear aqueduct. This can be done to intentionally release CSF.

► It is important to understand that extending the dissection anterior and inferior to the cochlear aqueduct will endanger the lower cranial nerves IX, X, XI, and the jugular bulb.

Fig. 12.2 Before opening the IAC, the adjacent bone needs to be removed to skeletonize the jugular bulb, posterior fossa dura, sigmoid sinus, and middle fossa dura

When approaching the IAC during a *translabyrinthine approach*, it is key to generate a maximum of exposure to facilitate dissections in the IAC and cerebellopontine angle. Therefore, first the bone adjacent to the (expected) location of the IAC should be removed: the *jugular bulb* is skeletonized as well as the *posterior fossa dura* adjacent to the jugular bulb and the sigmoid sinus. The *cochlear aqueduct* is identified just superior and anterior to the jugular bulb. Next, the posterior and superior boundaries of the IAC are skeletonized. The bony exenteration along the middle fossa dura, posterior fossa dura, and the bony covering of the IAC is completed. Superior to the IAC (*suprameatal dissection*), the proximity to the facial nerve has to be considered. The pattern of bone removal inferior and superior to the IAC before opening the meatus can be compared to eating an apple and sparing the apple core (Fig. 12.2, Videos 8 and 9).

Landmarks
- Ampulla of horizontal semicircular canal
- Ampulla of superior semicircular canal
- Ampulla of posterior semicircular canal
- Common crus
- Vestibule
- Vestibular aqueduct
- Internal auditory canal
- Cochlear aqueduct

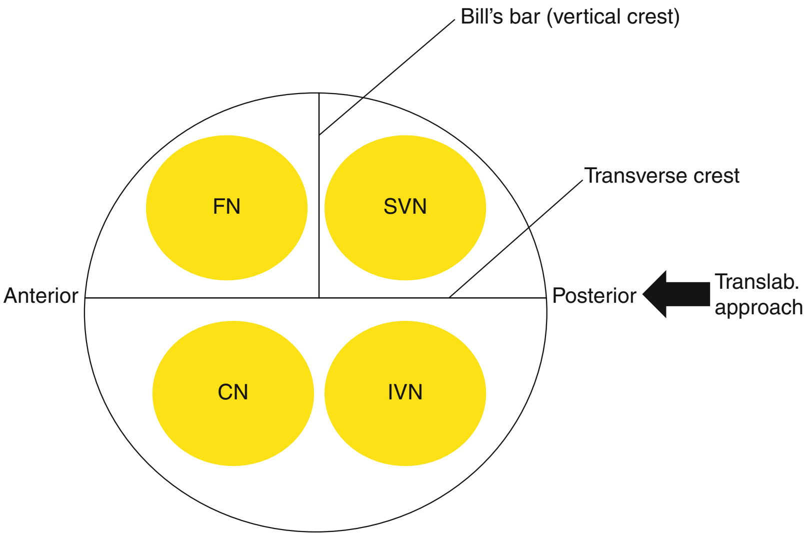

Fig. 12.3 Anatomy of the fundus of the IAC. The transverse crest and vertical crest (Bill's bar) separate the fundus into four quadrants (*FN* facial nerve, *CN* cochlear nerve, *SVN* superior vestibular nerve, *IVN* inferior vestibular nerve)

Landmarks
- Internal auditory canal
- Cochlear aqueduct
- Superior vestibular nerve
- Inferior vestibular nerve
- Vertical crest (Bill's bar)
- Transverse crest
- Facial nerve
- Cochlear nerve

In the tight confines of the IAC and porus acousticus, a 2-mm diamond burr should be used in a *spot drilling* manner: hand movement and amplitude of drilling are kept to a minimum (Videos 1 and 9). It is always attempted to drill away from the IAC (e.g., set the burr in reverse for the right ear). The bone covering the IAC is thinned to an "*egg shell*" quality and cracked through by spot drilling in different spots to allow bone fragment removal by piecemeal.

▶ Using a diamond drill, the internal auditory canal is skeletonized approximately 270°, until the anterior wall of the canal is exposed. This exposure is necessary to prevent bony overhangs and facilitate working within the canal.

Some surgeons prefer to preserve the *ampulla of the superior semicircular canal* as a landmark to localize the *superior vestibular nerve*. The nerve can be retracted with a small hook, and just underneath it the *vertical crest* (*Bill's bar*) can be palpated. This bony crest separates the superior vestibular nerve (posteriorly) from the anteriorly running *facial nerve* (Figs. 12.3 and 12.4). It should be visualized that as the FN leaves the lateral end of the IAC

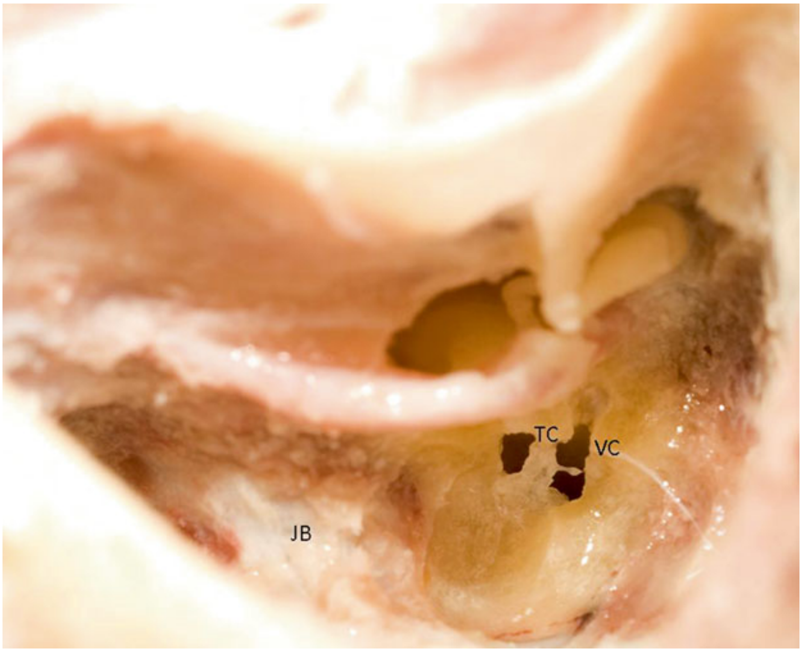

Fig. 12.4 The transverse crest and vertical crest (Bill's bar) separate the fundus into four quadrants (*TC* transverse crest, *VC* vertical crest, *JB* jugular bulb)

at the *meatal foramen* (the narrowest point of the Fallopian canal), it courses superiorly and anteriorly along the labyrinthine segment to reach the *geniculate ganglion*. The *transverse crest*, which separates the superior from the inferior vestibular nerve and the facial from the *cochlear nerve*, is identified on the posterior aspect of the internal auditory canal (Fig. 12.4).

Middle Fossa Approach (Anterior Transpetrosal/Subtemporal Approach)

13

The most common indications for this approach are repair of superior semicircular canal dehiscence and approach to the IAC for acoustic neuroma resections. Usually small, intracanalicular tumors with good hearing are approached via this route. Vestibular nerve section and total facial nerve decompression, CSF leak, and meningocele repair are other less common indications for this approach. There is significant temporal lobe retraction during this approach, so this makes it less suitable for older patients.

For the middle fossa approach, the surgeon sits at the head of the table, the patient is in supine position, and the head is rotated to the contralateral side. A skin incision starting anterior to the tragus (*preauricular crease*) and extending superiorly to the *parietal suture* in a straight line or lazy-S configuration is performed (Fig. 13.1).

The temporalis muscle can be incised to create a rotational flap permitting its use for subcranial reconstruction as shown in Fig. 13.1. Alternatively, a vertical linear incision can be made and retracted to expose the skull directly below. An approximately 4×6-cm (or larger) craniotomy is performed.

► The craniotomy should be positioned as low as possible to maximize exposure of the middle fossa floor. Sometimes it is necessary to drill the inferior bony margin of the craniotomy to reach the floor (Fig. 13.2).

Landmarks
- Preauricular crease
- Parietal suture
- Middle fossa floor
- External auditory canal
- Petrous ridge
- Superior petrosal sinus
- Arcuate eminence
- Greater superfical petrosal nerve
- Geniculate ganglion
- Foramen spinosum

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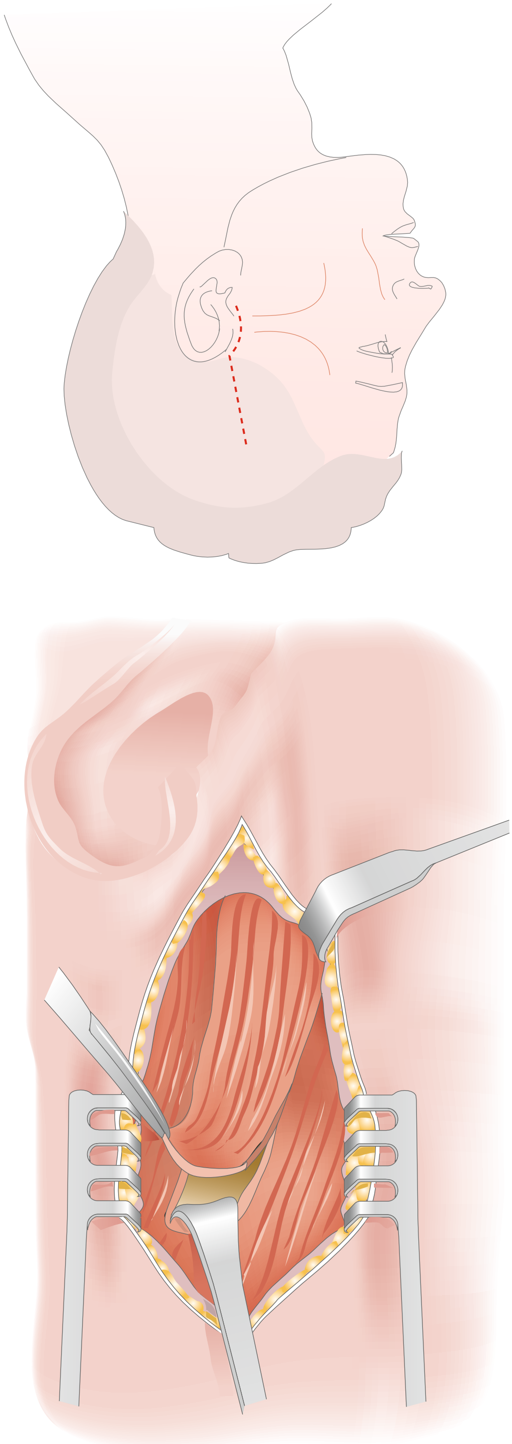

Fig. 13.1 A skin incision from the preauricular crease to the parietal suture is performed. The temporalis muscle is incised and retracted

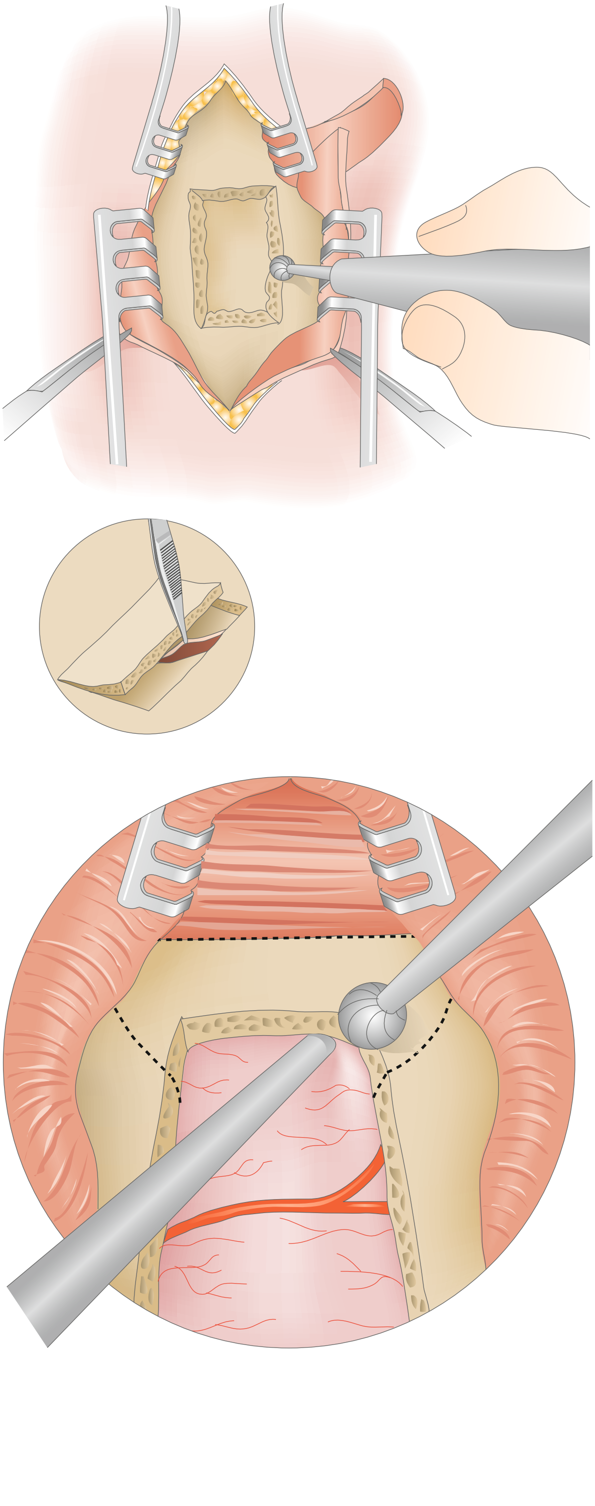

Fig. 13.2 A craniotomy of 4×6 cm is performed with the use of an otologic drill or a craniotome. Care is taken not to perforate the dura. The inferior margin of the craniotomy is drilled down to be flush with the floor of the middle fossa (*right side*, *dashed line*)

Landmarks
- Preauricular crease
- Parietal suture
- Middle fossa floor
- External auditory canal
- Petrous ridge
- Superior petrosal sinus
- Arcuate eminence
- Greater superfical petrosal nerve
- Geniculate ganglion
- Foramen spinosum
- Internal auditory canal
- Cochlea
- Facial nerve
- Tegmen tympani

If the temproal bone is well pneumatized and air cells are exposed during this apporach they must be obliterated with bone wax at the end of the case to minimize the risk of a post-operative cerebrospinal fluid leak.

▶ Usually the craniotomy is positioned in a way that about two thirds of the craniotomy is anterior and one third is posterior to the EAC to facilitate exposure of the IAC.

The dura can be deliberately incised to release CSF and facilitate the temporal lobe retraction. The amount of retraction depends on the type of surgery. If a superior canal dehiscence is to be repaired, less retraction is necessary compared to IAC exposure for more medial exposure. In the latter case, the temporal lobe is retracted medially to the level of the *petrous ridge* and *superior petrosal sinus*. During this step, a dehiscent geniculate ganglion may potentially lead to the damage of the facial nerve. This is why dural elevation should be performed posteriorly, to anteriorly.

Despite the complex anatomy and presence of many structures located near the middle fossa floor, the landmarks are few once the dura is elevated: the *arcuate eminence*, the *greater superficial petrosal nerve* (GSPN), and the *middle meningeal artery* (foramen spinosum; Fig. 13.3). Note that in up to 20 % of the cases involving this approach, the arcuate eminence can only be visualized after removal of air cells directly overlying the superior aspect of the superior semicircular canal. In the case of a superior canal dehiscence repair, a congenital blue lining or frank dehiscence of the superior semicircular canal is usually found. In order to improve orientation, the *tegmen tympani* can be deliberately opened to visualize the *head of the malleus, incus,* and *cochleariform process* for the purpose of orientation.

Landmarks
- Arcuate eminence
- Greater superfical petrosal nerve
- Geniculate ganglion
- Foramen spinosum
- Internal auditory canal
- Cochlea
- Facial nerve
- Tegmen tympani

For identification of the IAC, different techniques have been described: In the *House* method, the GSPN is retrogradely traced to the geniculate ganglion and from here the facial nerve is followed to its labyrinthine segment and to the IAC. From here, the remainder of the IAC is skeletonized using a diamond drill and copious amounts of irrigation fluid. The *Fisch* method uses the angle between superior semicircular canal and IAC: after blue-lining the SCC, a 60° angle anterior to the ampullated end of the SCC defines the position of the IAC

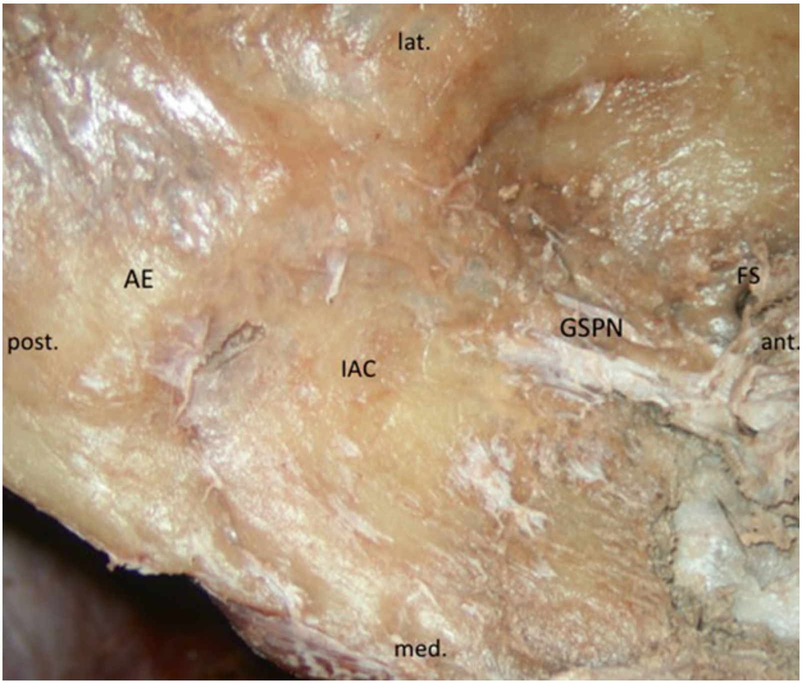

Fig. 13.3 Superior topography of a left temporal bone after removal of dura (*AE* arcuate eminence, *IAC* internal auditory canal, *GSPN* greater superficial petrosal nerve, *FS* foramen spinosum)

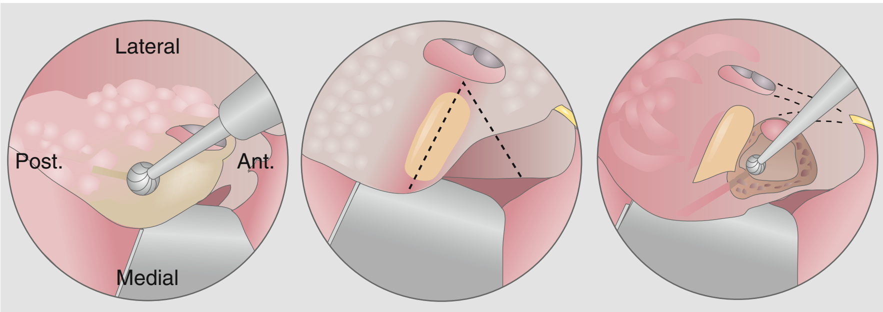

Fig. 13.4 Surgeon's view on superior surface of a left temporal bone. The superior semicircular canal is identified and blue-lined after air cells underneath the middle fossa floor have been opened (*left*). Then, a 60° angle is used to identify the IAC (*middle*). The IAC is skeletonized in a stepwise fashion (*right*)

(Fig. 13.4). Finally, if the GSPN and SCC can both be visualized, the IAC can be identified by the line that bisects the angle (approximately 120°) between the arcuate eminence and the GSPN. We favor the latter method, where drilling is started medially near the *porus*. At this

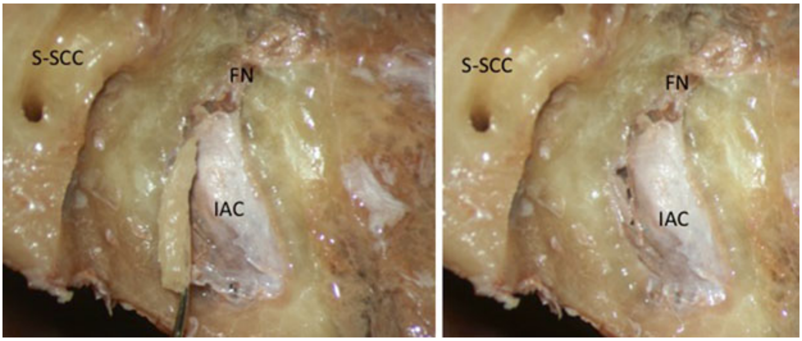

Fig. 13.5 Uncapping the internal auditory canal (*S-SCC* superior semicircular canal, *FN* facial nerve, *IAC* internal auditory canal)

Landmarks
- Arcuate eminence
- Greater superfical petrosal nerve
- Geniculate ganglion
- Foramen spinosum
- Internal auditory canal
- Cochlea
- Facial nerve
- Tegmen tympani
- Vertical crest
- Horizontal crest
- Carotid artery
- Eustachian tube
- Tensor tympani muscle

medial end, the IAC can be skeletonized and unroofed with less risk. As the dissection is carried laterally toward the fundus, a clear understanding of the hidden structures within the temporal bone is needed to avoid injuring the following: *the cochlea*, the labyrinthine segment of the facial nerve, and the ampulla of the superior semicircular canal. If the cochlea or superior semicircular canal is inadvertently fenestrated in a living patient, suctioning should be avoided, and the defect should be immediately closed with bone wax to preserve hearing.

After unroofing the IAC (Fig. 13.5), the *vertical crest (Bill's bar)* can be identified at the fundus separating the facial nerve from the superior vestibular nerve as it enters the superior ampulla next to the facial nerve (Fig. 13.6). Deeper in the IAC lies the *horizontal crest*, separating the superior (facial nerve and superior vestibular nerve) from the inferior (cochlear nerve and inferior vestibular nerve) compartment.

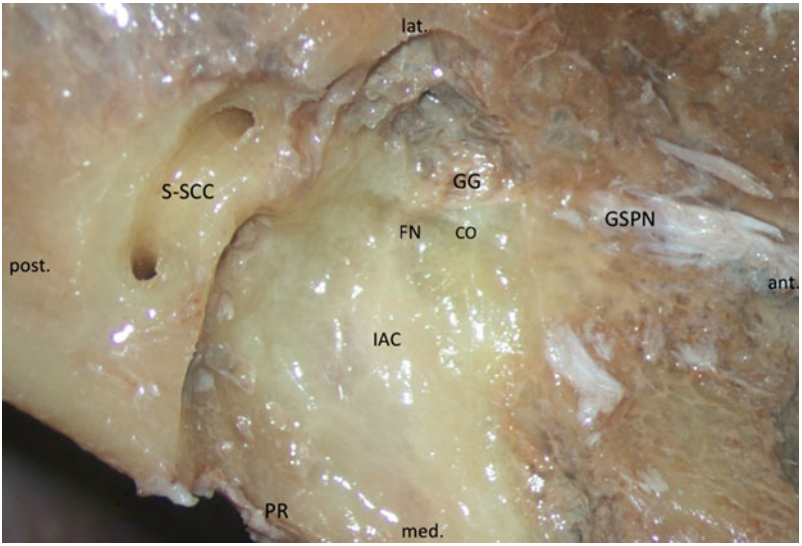

Fig. 13.6 The IAC, facial nerve, and geniculate ganglion have been skeletonized (*S-SCC* superior semicircular canal, *FN* facial nerve, *GG* geniculate ganglion, *CO* cochlea, *GSPN* greater superficial petrosal nerve, *IAC* internal auditory canal, *PR* petrous ridge)

Medial to the IAC is the *petrous apex* which often contains large air cells. Anterior to these air cells lies the carotid artery with its horizontal (petrous) segment. Medial to the internal carotid artery lies *Kawase's triangle* (Fig. 13.7). It is bounded by the petrous ridge and posterior fossa dura medially, the *trigeminal ganglion* (Meckel's cave) anteriorly, and the cochlea and IAC posteriorly.

Landmarks
- Arcuate eminence
- Greater superfical petrosal nerve
- Geniculate ganglion
- Foramen spinosum
- Internal auditory canal
- Cochlea
- Facial nerve
- Tegmen tympani
- Vertical crest
- Horizontal crest
- Carotid artery
- Eustachian tube
- Tensor tympani

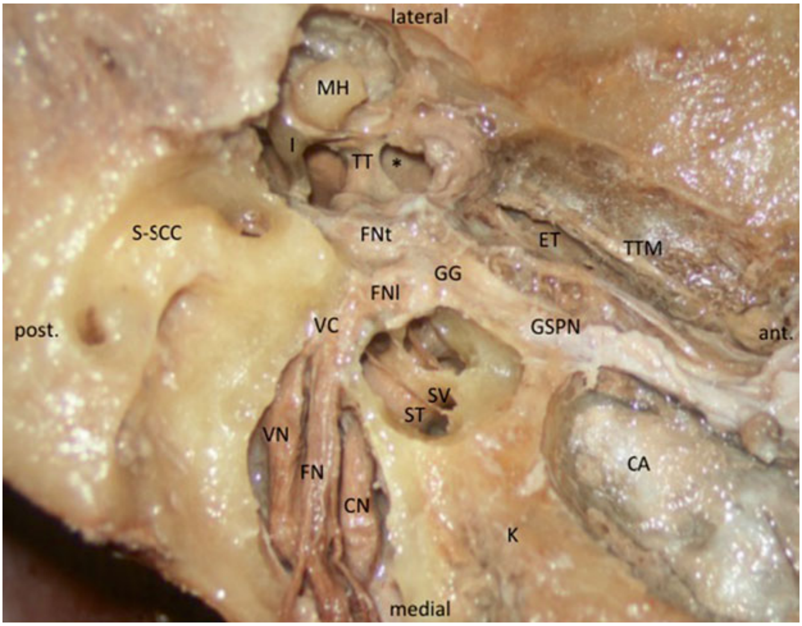

Fig. 13.7 The tegmen tympani is opened to allow identification of middle ear structures from the middle fossa. Note the close relationship of the cochlea to the fundus of the IAC and the carotid artery (*S-SCC* superior semicircular canal, *VN* vestibular nerve, *FN* facial nerve, *CA* carotid artery, *CN* cochlear nerve, *VC* vertical crest, *FNl* labyrinthine segment of facial nerve, *GG* geniculate ganglion, *GSPN* greater superficial petrosal nerve, *ST* scala tympani, *SV* scala verstibuli, *K* Kawase's triangle, *FNt* tympanic segment of facial nerve, *TT* tensor tympani tendon, *MH* malleus head, *I* incus, *ET* eustachian tube, *TTM* tensor tympani muscle, *asterisk* medial surface of tympanic membrane)

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