Review article

Lateral approaches to the skull base

Gli approcci laterali alla base del cranio

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SUMMARY

Progress in the study of skull base anatomy and the different lesions involving it has led to more and more precise knowledge of the site. New diagnostic tools have allowed better definition of various diseases, and the use of an operative microscope and modern surgical instruments have all contributed to the development of microsurgery of the skull base. Refinements in microsurgical techniques have led to the description of multiple approaches to the skull base. Lateral approaches to the skull base have been described by pioneering surgeons who created the basis of this surgery and further contributed with their own experience. Refinements and modifications to the original technique have taken place over years, to the point that nowadays the large number of approaches described by oto- and neurosurgeons have led to some confusion. We have attempted to simplify this by retracing it to the original, basic steps based on the most representative publications and personal experience.

KEY WORDS: Skull base approaches • Lateral skull base • Microsurgery of the skull base

RIASSUNTO

I progressi nello studio dell'anatomia chirurgica della base del cranio e delle diverse lesioni che la coinvolgono hanno portato negli anni ad una conoscenza sempre più precisa di questa sede. Gli ulteriori miglioramenti nella tecnica microchirurgica hanno condotto alla definizione di molteplici approcci alla base del cranio. Tali approcci sono stati inizialmente descritti da chirurghi "pionieri" che crearono le basi di questa chirurgia e contribuirono successivamente con la loro stessa esperienza al suo sviluppo e miglioramento. La grande quantità di approcci descritti negli anni da neurochirurghi e otochirurghi è tale da rendere la materia confusa. In questo lavoro abbiamo cercato di semplificare l'argomento, riconducendo gli approcci ai principi di base sui quali sono stati concepiti, basandoci sui lavori più rappresentativi della letteratura e sulla nostra esperienza personale.

PAROLE CHIAVE: *Approcci alla base cranio • Base cranio laterale • Microchirurgia della base cranio*

Introduction

Dealing with surgical approaches to the lateral skull base and describing them in a simple way is a challenging matter. The complexity of the anatomy, the need for lengthy surgical training and the large number of approaches described over the years have contributed to make this subject more difficult. The present review, which does not have the intent to be exhaustive, attempts to simplify current understanding.

Several approaches are currently available to the cerebellopontine angle (CPA), and often two or more are used for the same lesion. A simplified understanding of the multiple approaches to the CPA can be based on the door of entry, the surgical corridor and the target in the CPA.

From entry to target, obstacles are encountered which are handled by retraction, removal or by-pass. There are structures to be removed (bone), retracted (brain, cerebellum), displaced (facial and other nerves, internal carotid artery), and bypassed (labyrinth).

The choice of the surgical corridor depends on the characteristics of the target (mainly size and histology of the lesion in the CPA), the exposure needed to remove the lesion and the degree of morbidity accepted to achieve the goal. The knowledge of which structures will be encountered on the route to the CPA, and which are to be preserved, removed or displaced, is the key to understand and choosing the appropriate surgical corridor.

Where are we going? How will we get there? Where do we start? The answer to these questions is given by the choice of the approach. The axial bone window CT scans allow a simple way to visualize the target, choose the entry door and draw a link between the two.

Personal experience and the available literature were our source of selection and description of lateral approaches to the skull base.

Our personal experience involves more than 1000 cases of vestibular schwannomas operated on with translabyrinthine approach, and around 350 cases operated on with a retrosigmoid or middle cranial fossa approach for hearing

preservation surgery [1-3]. Two hundred twenty infratemporal A and POTS [4 5] approaches were performed in cases of class C paraganglioma and other jugular foramen lesions [6]. Recurrent tumours of the nasopharynx were treated by a type C infratemporal approach [7]. For primary tumours of the external auditory canal, block resections of the temporal bone were performed [8], and surgical approaches to the petrous apex lesions were described [9].

Several experiences reported in the literature were chosen to select the approaches that were clearly described with basic steps in a simple manner, and performed by authors with proven surgical experience [10-21].

From review of our experience and the available literature, the selection of approaches to the lateral skull base involve translabyrinthine, transcochlear, translab-transapical, retrosigmoid, sub-temporal, lateral/subtotal/total petrosectomy, infratemporal and petro-occipital-transigmoid approaches. Various skin incisions and soft tissues flaps have been described, so that only the basic principles of management are reported.

Similarly, the basic steps of each approach to the CPA involve sequential and combined removal of bone while preserving or sacrificing some structures. The key bone or soft tissue structures of a lateral approach are listed below, and are to be considered as the individual cornerstones to be assembled in the approach:

1. mastoid;
2. labyrinth;
3. external auditory canal and tympanum;
4. VII cranial nerve, left in site or transposed anteriorly or posteriorly;
5. occipital bone (occipital craniotomy);
6. temporal bone (temporal craniotomy);
7. petrous apex, occipital condyle and clivus;
8. first cervical vertebra (arch and transverse process);
9. dura and brain.

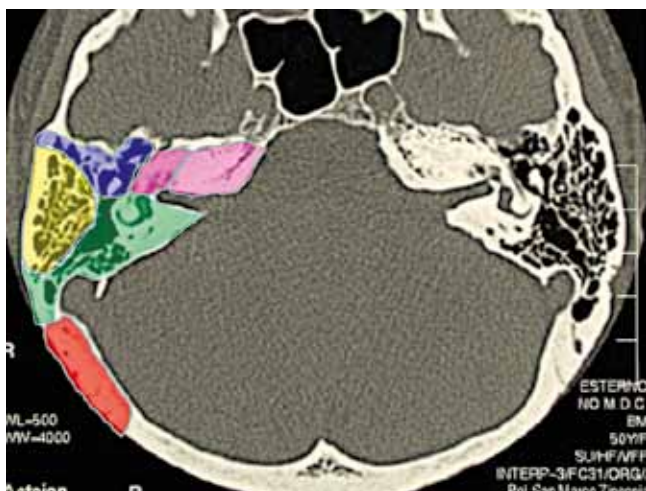Figure 1 shows an axial CT scan of the bone-units involved in the different approaches. The occipital gate (retrosigmoid entry) is depicted in red, in yellow the mastoid with cortical bone and pneumatized cells, in green the mastoid with pneumatized cells and labyrinth, the middle ear with epitympanic area in blue and the cochlea in pink. The petrous apex is visible as well, which is medial and anterior to the internal auditory canal.

Planning of a surgical approach: management of soft tissues

Some basic rules need to be respected when making skin incisions and designing myofascial flaps. The skin incision allows a good skin flap without endangering its vascularization. This is particularly true when revision surgery is necessary (postoperative complications or recurrence of the disease). A skin flap is designed so that it can be turned away from the field and held in place with staying sutures and no retractors. Myofascial flaps can be made using different techniques, but the basic principle is that the base of the flap has to be bigger than its apex so that vascularization is granted. The size and shape of the flap is made in order to expose the underlying bone (mastoid, temporal or occipital squama) without the need for overhanging retractors. At the end of surgery, myofascial flaps have to grant a CSF-tight closure. No tissue harvesting on the myofascial flap is done in order to permit good closure.

Overview on lateral approaches

As a general principle, and sometimes in contrast with the somewhat confusing terminology in the literature, the surgical corridor of a *transpetrous* approach runs through the temporal bone (translab., transcochl., translab-transapical app., lateral/subtotal/total petrosectomy). The surgical corridor of a *transtemporal* approach runs below the temporal lobe and over the petrous bone, reaching areas of the temporal bone without destroying or passing through it. This approach involves temporal bone craniotomy and retraction of the temporal dura and brain (subtemporal extradural transtemporal approach or, as otherwise referred to, a middle cranial fossa approach). The retrosigmoid approach runs posterior to the sigmoid sinus, through the occipital bone by means of an occipital (otherwise defined suboccipital or retrosigmoid) craniotomy. What we refer to as "confusing" literature introduces a more detailed way to describe these approaches. The more detail that is given in describing surgical approaches, the more the simple concept of "from where we start? and where do we want to go? " is missed.

A simple description of the gate-corridor-target should allow better understanding of lateral skull base surgery and fulfill the desired goal.

Trans-petrous approaches

Translabyrinthine approach

The gate of this approach is the mastoid (a retroauricular-transmastoid approach), and the target is the internal

Fig. 1. Bone units of the lateral skull base.

auditory canal and CPA [10-12]. The approach removes the bone lying between the petrous dura-sigmoid sinus posteriorly and the mastoid fallopius anteriorly. The facial nerve, cochlea, tympanic cavity and outer ear canal are left in place. The occipital bone in the retrosigmoid area is partially drilled to expose the retrosigmoid dura and allow retraction of the sigmoid sinus. The dura of the temporal lobe, in the retro- and pre-sigmoid area, is exposed.

Once the approach is finished, the jugular bulb is the inferior limit. The temporal dura, superior petrosal sinus and tentorium are the superior limits of the approach. The presigmoid dura is transected and the CPA is entered. Disruption of the arachnoid shell opens the cistern. As shown Figure 2, the approach removes all the mastoid bone, the labyrinth and the bone which is lateral, superior and inferior to the internal auditory canal, uncovering it by around 270° of its circumference. The anterior wall of the internal auditory canal is not removed (the incus is removed to allow obliteration with fat or muscle of the epitympanic area in order to separate the tympanum from the rest of the cavity). The entire petrous bone defect of the approach is filled with abdominal fat, and the myofascial and skin flaps are repositioned.

Translabyrinthine-transapical approach

This an extension of the translabyrinthine approach to the petrous apex [10-12]. In the translabyrinthine approach, the anterior wall of the canal may represent an obstacle to the anterior CPA. Removing all of the petrous apex around the canal brings about the concept of surgical unity of the petrous bone and CPA. This allows early and wider exposure of the anterior CPA, and the anterior aspect of a tumour impacting on the petrous bone is exposed at the beginning of the procedure with a larger angle of view. The transapical extension may be an intraoperative choice to obtain a wider corridor. Figures 3 and 4 show how the removal of the anterior wall of the internal auditory canal and the adiacent petrous apex adds room to access the anterior CPA. Obliteration with fat fills the cavity.
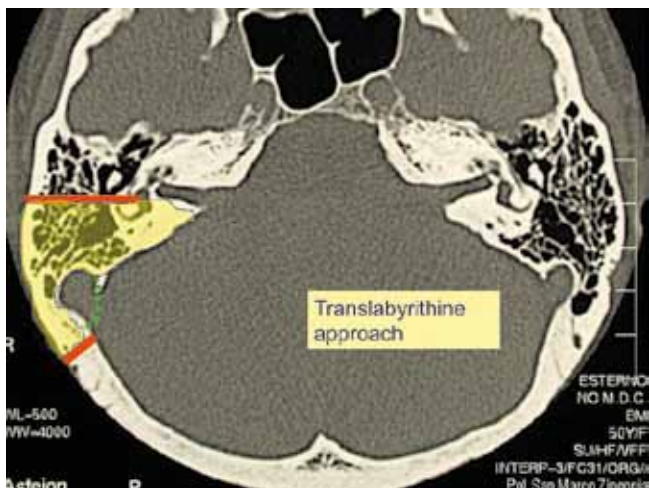

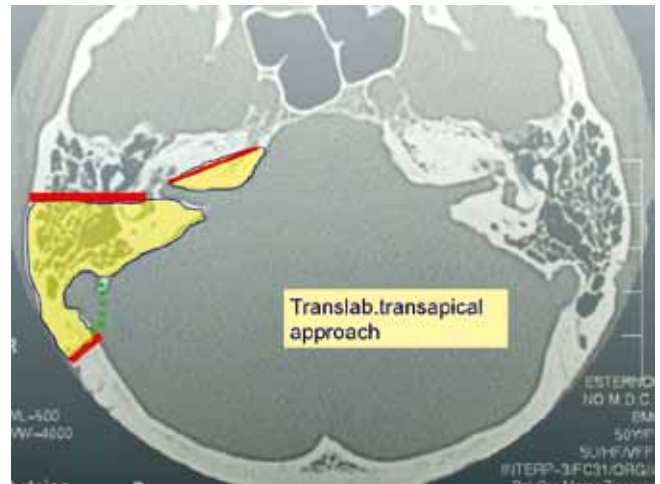**Fig. 2.** Extension of bone removal in a translabyrinthine approach.

Fig. 3. Translabyrinthine-transapical approach.
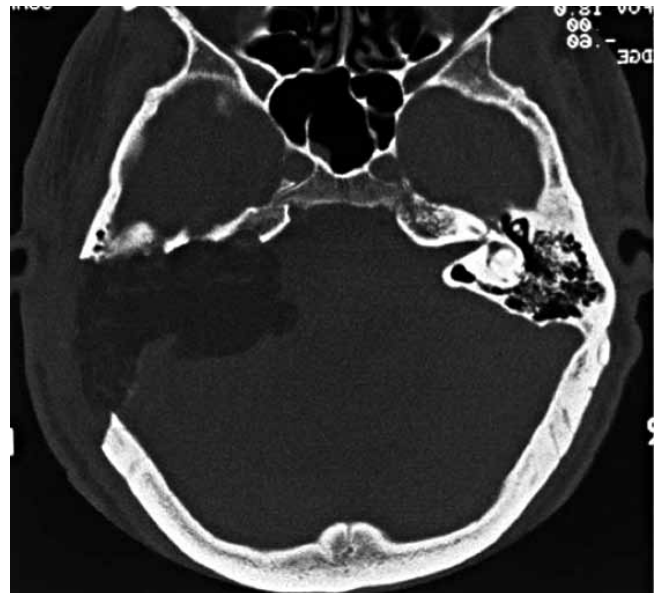

Fig. 4. Postoperative CT of the translabyrinthine-transapical approach.

In the postoperative translabyrinthine-transpical approach, the entire petrous bone has been removed, and only the carotid canal is left. Figure 4 shows a postoperative CT above the level of the outer ear canal.

Transcochlear approach

The transcochlear approach is an extension of the translabyrinthine approach, with three main additional steps: removal of outer ear canal and tympanum and entire petrous bone up to the clivus, posterior transposition of the facial nerve, drilling of the cochlea and cul-de-sac closure of the external auditory canal, as in subtotal petrosectomy [23-26]. The approach gives wide access to the CPA and is suitable for large lesions with anterior extension into the prepontine cistern. The cavity is filled with fat. The approach is the widest surgical corridor in the lateral skull base, but is related to unavoidable morbidity of the facial nerve. After its transposition, a III° HB is the best result that can be obtained.

The transotic approach is the precursor of the transcochlear approach, and is a subtotal petrosectomy with drilling of the cochlea. The facial nerve is left in place, and it runs like a bridge in the surgical field limiting the surgical corridor to the anterior CPA. This approach is rarely used as it allows no real improvement of the surgical view compared to a translabyrinthine-transapical approach. As shown by CT (Fig. 5), in the transcochlear approach all the apex is removed. The approach allows wide exposure of the anterior and posterior CPA and prepontine cistern, and the surgical corridor is traced from the external ear to the clivus.

The complete petrous bone is removed including the external ear and middle ear. As seen in postoperative CT (Fig. 6), the approach allows good exposure of the complete CPA, with the surgical corridor extending from the anterior wall of the external ear canal to the clivus, making a surgical cavity of the entire petrous bone.

Pre-sigmoid-retrolabyrinthine approach (conservative petrosectomy), transtentorial and subtemporal

This surgical corridor extends between the sigmoid sinus, which lies posteriorly and can be depressed after being uncovered, and the labyrinth, which is the anterior boundary. The facial nerve is skeletonized but left in place. This is a classical retro-auricular-trans-mastoid approach, otherwise termed "conservative petrosectomy".

As shown Figure 7, it is a narrow corridor. It allows access to the area of dura from sigmoid to labyrinth, and to the adjacent portion of the posterior CPA. It becomes an important approach if combined with a subtemporal-tanstentorial approach, involving temporal craniotomy, sectioning of the tentorium and retraction of the temporal lobe. There is a large gate from temporal squama to the mastoid, and a large corridor of both sides of the tentorium to the CPA, pontine cistern and mesencephalic cistern.

Petrosectomies: lateral, subtotal, total

When the posterior wall of the external auditory canal (as in a canal-wall down tympanoplasty) and the middle ear are removed, the overlying skin is closed in "cul-de-sac", the facial nerve is left in place and the labyrinth is the medial boundary of bone removal, the procedure is a "lateral" petrosectomy or, according to Fisch, "subtotal" petrosectomy [25]. We believe that the term "lateral" is a better transposition of the concept that bone removal stops at the labyrinth, remaining lateral to it. If the extension of bone removal includes the labyrinth and internal auditory canal (independently if the procedure becomes extra- or transdural), a "sub-total" petrosectomy" is then performed, or as Fisch described, "total" petrosectomy.

En-block resections of the petrous bone are indicated for cancer of the temporal bone [13][14].
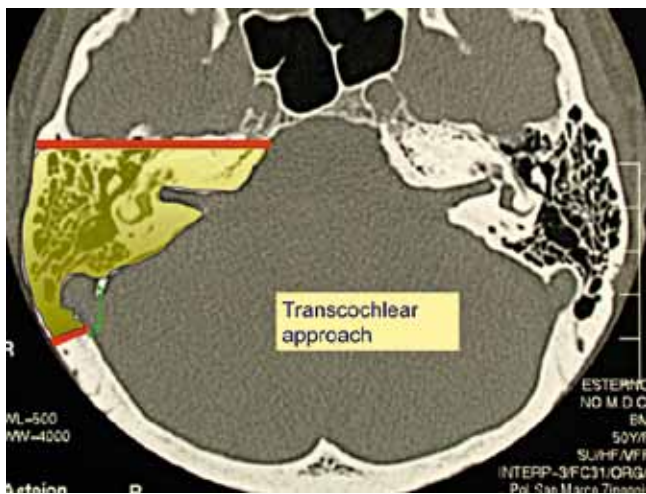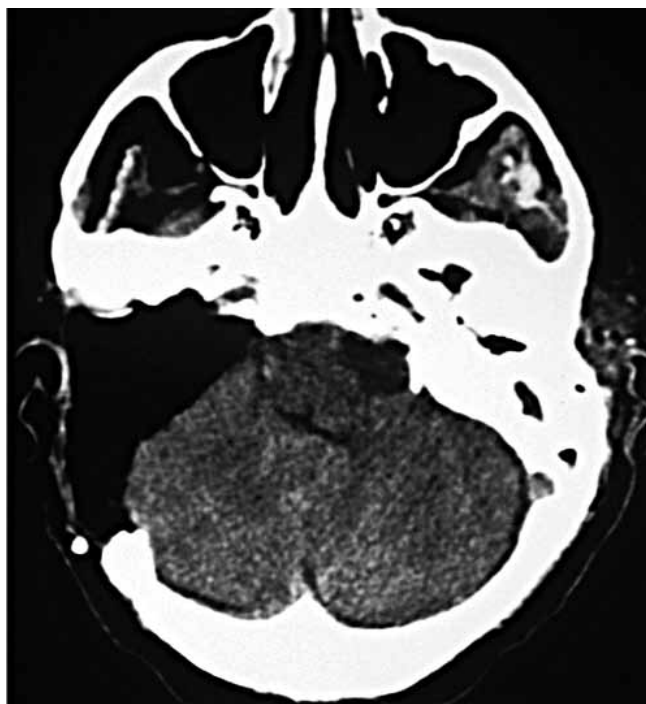

Fig. 5. Transcochlear approach.

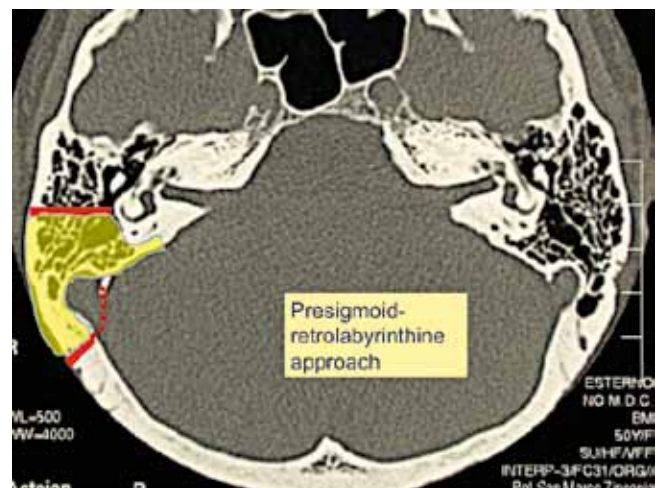**Fig. 6.** Postoperative CT scan of the transcochlear approach.

Fig. 7. Presigmoid-retrolabyrinthine approach.

Lateral petrosectomy [14] involves a block resection of the complete outer canal including the eardrum and a portion of mastoid.

In the subtotal petrosectomy, the inner boundary of the block resection extends from the carotid canal to the jugular fossa, and includes transection of the petrous bone medial to the labyrinth and through the internal auditory canal. Hearing and the facial nerve are sacrificed.

Total petrosectomy extends further to include the petrous apex. In both subtotal and total petrosectomy, the dura is preserved or, if resected, repaired.

Infratemporal approaches

A type A infratemporal approach is not an approach to the infratemporal fossa, as is often misunderstood, but rather an approach that exposes the inferior aspect of the temporal bone, with the jugular foramen and the adjacent area of the parapharyngeal space including the jugulo-carotid vessels [4 18-20]. Figure 8 shows how the surgical corridor runs through the temporal bone, posterior to the mandibular condyle, along the lowest aspect of the temporal bone to expose the area of the jugular foramen and the lower clivus and upper neck.

Transposition of the facial nerve opens a straight surgical corridor to and around the area of the jugular foramen. The pars vascularis and pars nervosa can be exposed, together with the vertical tract and part of the horizontal tract of the internal carotid artery.

A large retroauricular and upper neck incision opens the entry area. The dissection of the upper neck exposes the jugular vein and carotid artery. Removal of the outer ear canal and anterior transposition of the VII cranial nerve allow drill out removal of the infralabyrinthine petrous bone up to the entire jugular foramen, to the occipital condyle and low clivus. This typical skull base approach allows removal of lesions from the CPA to the jugular foramen and parapharyngeal space. Staging in two procedures is done for large intra-extra cranial lesions to prevent CFS leak.
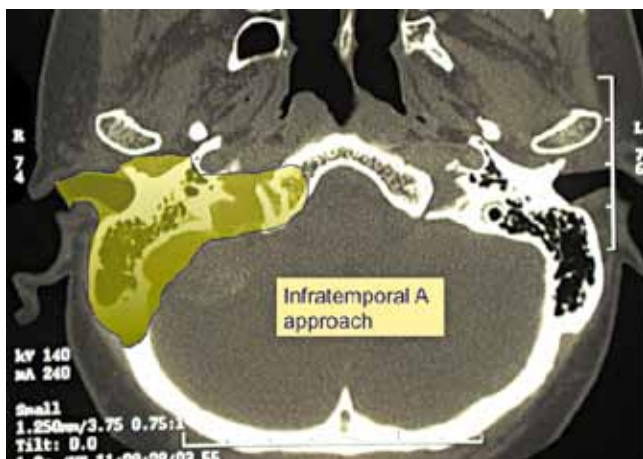
Petro-occipital-transigmoid approach

The petro-occipital-transigmoid (POTS) approach has been recently described [5 6]. POTS is a posterolateral route to the jugular foramen, upper neck and CPA. Its entry is composed of posterolateral conservative petrosectomy combined with suboccipital craniotomy. The surgical corridor is oblique in an anterior-medial direction and leaves the outer and middle ear, VII cranial nerve and labyrinth in place. It extends both to the upper neck through the mastoid and jugular foramen, and the CPA. The shape of the bone field allows safe closure with a fat plug and a single intra-extradural procedure. The surgical corridor is created with mastoidectomy to the posterior labyrinth, exposure and closure of the sigmoid sinus and suboccipital craniotomy (Fig. 9). In the extradural procedure, the occipital dura is depressed to increase the angle of view to the lower skull base. For intra-extradural lesions, the dura is opened to enter the CPA. The parapharyngeal space communicates through the inferior aspect of the mastoid, which is drilled out, and the jugular fossa. There is only limited control of the carotid artery.

The infratemporal approach type A [26] and POTS [5 6] are two different surgical corridors to the jugular foramen. As seen in Figure 9, the infratemporal approach runs through the temporal bone from lateral to medial, with a lateral petrosectomy sacrificing the external and middle ear, and transposition of the facial nerve. POTS is more respectful of surrounding structures and runs posterior to the external and middle ear, reaching the jugular foramen and inferior area from a postero-lateral perspective, but allows only limited control of the carotid artery on its posterior aspect.

Infratemporal + suboccipital approach

Adding suboccipital craniotomy to the infratemporal A approach entails posterior enlargement of the surgical field [26] (Fig. 10). The cerebellum can be depressed and a wider portion of the CPA can be reached. This is the case when removal of a large intradural portion of the lesion is required,
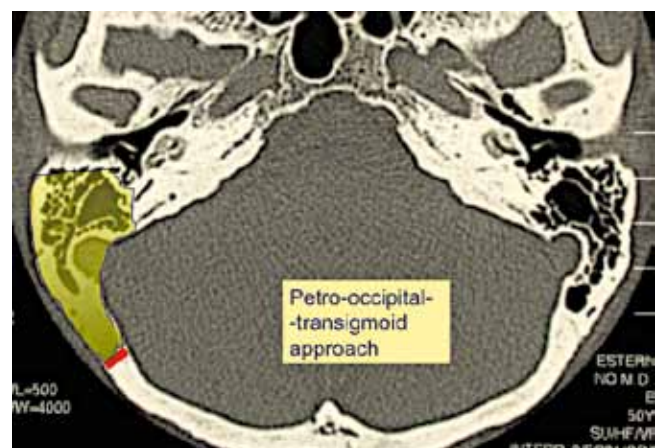

Fig. 8. Infratemporal A approach.

Fig. 9. Petro-occipital-transigmoid-approach (POTS).

and the entire procedure is staged. The first step is an infratemporal approach to remove the extradural part of the lesion at the jugular foramen. The suboccipital step is secondarily added to remove the intradural part of the lesion.

Transtemporal approaches or subtemporal extradural approaches

Subtemporal approach (subtemporal-extradural-transapex approach, middle cranial fossa approach)
The gate of entry of this approach is a temporal craniotomy of about 4 x 5 cm. The surgical corridor runs below the temporal lobe, above the petrous bone, and the target is the anterior and posterior aspect of the petrous bone and apex [9 21 26]. The temporal floor is visualized from above. Elevation of dura from the anterior side of the petrous bone proceeds from posterior to anterior. Structures such as the labyrinth and internal auditory canal are not visible, but are uncovered from the overlying bone. The internal auditory canal lies at about 45° from the blue line of the semicircular canal.
To enlarge the approach, the tentorium is transected and the sub-temporal approach is referred to as a transtemporal-subtemporal-transtentorial approach, and can be combined with a pre-sigmoid-retrolabyrinthine approach [27] (Fig. 11).

Sub-occipital approach

Suboccipital or retrosigmoid approach
This approach is the classical "neurosurgical" approach: a direct surgical corridor to the CPA through sub-occipital craniotomy or craniectomy [1 2 23]. The occipital bone removed, the opening of the dura gives access to the posterior CPA and to the posterior aspect of the temporal bone.
The opening is a craniotomy extending from the sigmoid and the transverse sinus to the occipital squama at various widths (Fig. 12). Opening of the dura and retraction of cerebellum gives access to the CPA. Retrolabyrinthine meatotomy allows exposure of the full length of the internal auditory canal without sacrificing the labyrinth [1].
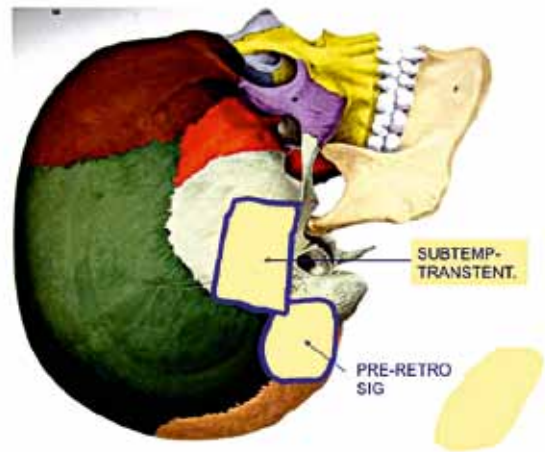

Fig. 10. Infratemporal-suboccipital approach.

Fig. 11. Sub-temporal (transtentorial) approach, retrosigmoid approach.
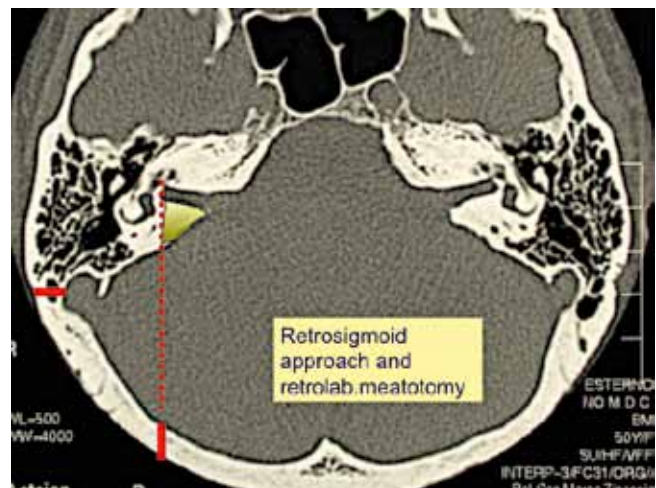
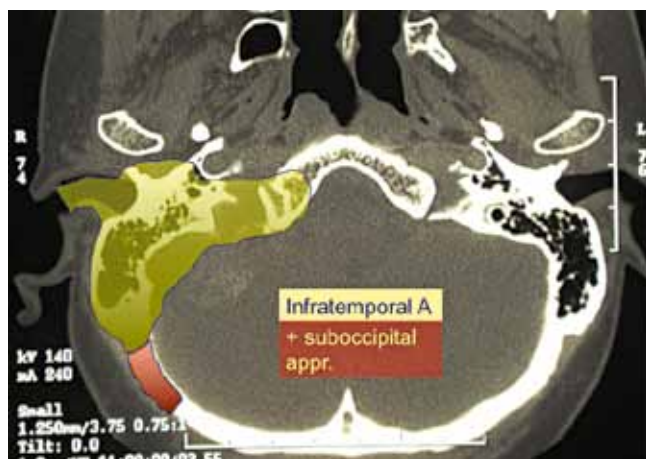**Fig. 12.** Sub-occipital (retrosigmoid) approach (+ retrolabirynthine meatotomy).

Discussion and conclusions

The different approaches to be considered are distinct tools in the hands of the surgeon. It is not the approach that has to be forced to the individual case, but the pathology dictates its own approach. In other words, it means that when choosing the route of entry into the lateral skull base to reach the target in the CPA, the advantages and disadvantages of each approach must be apparent, and the best approach suited to each individual case. The compendium of approaches to the CPA that we presented all follow the principle of entry door, target and surgical corridor connecting the two.
The petrous bone, with the addition of free contiguous structures, is the mainstay of lateral skull base surgery. The approaches described are typical, and are commonly used alone or two adjacent approaches can be combined. Rarely, the target can be reached through two separate techniques. Moreover, a single approach can recruit a few steps of the contiguous approach.

Selection of the approach is dictated by histology and extent of the lesion, and the approaches are flexible enough to fit every lesion. The often cited "individualized" or tailored approach is unreal and misinforms on how the lesion is handled.

In addition to the questions " Where do we want to go? What is our target?" and "Which route to go there?", "What is our goal? Do we want to be radical? What is the morbidity the patient is going to tolerate?" should also be added. Only within this frame, can each approach or combination of approaches be flexible enough to be suited to the individual case.

After answering these preliminary questions, the next step to select and plan the approach is represented by imaging. Preoperative bone-window CT and contrast-enhanced MRI are basic mandatory exams. Knowledge of the anatomy and structures that are crossing the surgical corridor are to be considered in preoperative imaging, to plan the surgical tactic and foresee which structures can be saved or sacrificed. The aim of in-depth understanding of the lateral skull base and its approaches is to keep simple things in mind, and drive difficult problems into simple, logical steps.

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