European Archives of Oto-Rhino-Laryngology
https://doi.org/10.1007/s00405-019-05750-9

OTOLOGY

Role of endoscopy in lateral skull base approaches to the petrous apex

Daniele Marchioni[1] · Luca Gazzini[1] · Marco Bonali[2] · Nicola Bisi[1] · Livio Presutti[2] · Alessia Rubini[1]

Received: 26 October 2019 / Accepted: 28 November 2019

Abstract

Objective The aim of this article is to study the role and advantages of combined microscopic/endoscopic procedures or exclusive endoscopic approaches in the treatment of petrous apex pathologies.

Methods The study was designed as a retrospective case series analysis. We included patients affected by pathologies of the petrous apex, who underwent microscopic/endoscopic-assisted or exclusive endoscopic procedures. Patient and pathology characteristics and surgical data (focusing on the involvement of the internal carotid artery (ICA) and facial nerve by the disease) were collected. Residual disease, detected through the endoscopic check, and the feasibility of endoscopic residual tumor removal were also evaluated. Finally, facial nerve and hearing functions were assessed pre- and postoperatively.

Results The records of 75 patients undergoing lateral skull base surgery for petrous apex lesions, from May 2009 to March 2019, were collected. In 17 out of 75 patients, an exclusive endoscopic procedure was possible. The remaining 58 patients underwent a combined microscopic/endoscopic approach. In 15 cases, residual disease was found and removed endoscopically at the end of the microscopic procedure; in eight cases, the residual disease was medial and/or inferior to the horizontal segment of the ICA, while in two cases, it was located in the fundus of the internal auditory canal. In five cases, it involved the labyrinthine segment of the facial nerve.

Conclusion Petrous apex surgery remains a traditional microscopic-based surgery, but the recent advent of endoscopic surgery has permitted an improvement in radicality minimizing the manipulation of neurovascular structures.

Keywords Petrous apex · Lateral skull base approach · Endoscopic lateral skull base surgery

Introduction

Surgical approaches to the petrous apex are particularly challenging because of the complex anatomy of this region and the presence of important neurovascular structures. Several traditional lateral microscopic approaches have been described to reach diseases located in the petrous apex. Some approaches allow preservation of the optic capsule (middle cranial fossa, infralabyrinthic, retrolabyrinthic and infracochlear approaches), while other approaches require the sacrifice of the optic capsule and therefore, the loss of hearing function (transcochlear and transotic approaches). The choice of the best surgical approach for the surgeon is based on the location of the lesion at the level of the petrous apex, on the preoperative hearing and facial nerve functions, and on the characteristics of the lesion.

Regardless of the type of procedure adopted, this kind of surgery is always very complex, due to the frequent necessity to skeletonize noble anatomical structures such as the facial nerve, the internal carotid artery (ICA), and the trigeminal nerve (V3), to remove the pathology in the petrous apex. In the literature, some authors have suggested the 360° dissection of arterial structures (such as the ICA, to obtain mobilization of the vessel) and displacement of nerve structures (such as posterior rerouting of the facial nerve) to allow a complete and clear visualization and adequate surgical access to the petrous apex.

The progressive introduction of endoscopic approaches in oto-neurosurgery has increasingly allowed the classic microscopic techniques to be integrated with endoscopic procedures (assisted interventions), thus minimizing the manipulation and the consequent morbidity of neurovascular

✉ Luca Gazzini
lucagazzini100@gmail.com

[1] Otolaryngology-Head and Neck Surgery Department, University Hospital of Verona, Piazzale Aristide Stefani, 1, 37126 Verona, Italy

[2] Otorhinolaryngology-Head and Neck Surgery Department, University Hospital of Modena, Modena, Italy

Published online: 02 December 2019

structures. Moreover, recently, exclusive endoscopic corridors to the lateral skull base have been described to treat pathologies limited to the petrous apex [1, 2].

In this article, a large number of cases operated through traditional approaches are presented, evaluating when the contribution of endoscopy could be useful for the removal of the pathologies; exclusive endoscopic approaches to the petrous apex are also analyzed to better explain their role and indications.

Materials and methods

A retrospective study was conducted including all of the patients who underwent surgical approaches to the petrous apex in the period between May 2009 and March 2019 at the Otolaryngology Departments of the University Hospital of Verona and University Hospital of Modena, Italy.

Inclusion criteria

We included in this study patients affected by diseases arising from the petrous apex region, who underwent traditional microscopic surgery combined with an endoscopic approach (endoscopic-assisted procedures), or endoscopic surgery through the sole use of these tools (exclusive endoscopic procedures).

Both exclusive endoscopic procedures (supragenicular, transpromontorial and infracochlear approaches) and microscopic/endoscopic-assisted procedures (middle cranial fossa, transotic, translabyrinthine, infralabyrinthine, transcochlear and enlarged transcanal transpromontorial approaches) were analyzed.

Exclusion criteria

Patients who underwent removal of petrous apex lesions through an endoscopic endonasal transsphenoidal approach were excluded from this case series. Patients affected by pathologies in the petrous apex who underwent microscopic surgery, without endoscopic assistance, were also excluded from this study.

Method

The choice of the single-case surgical procedure depended on several criteria: the histopathological nature of the lesion, its extent and location, the involvement of the labyrinth and cochlea by the disease, and the relationship of the pathology with the intrapetrous ICA and facial nerve. Furthermore, other significant factors taken into account were the preoperative audiological status and the general medical condition and comorbidities of the patient. In the case of good preoperative hearing, we chose a surgical approach with preservation of hearing function (middle cranial fossa, infracochlear, infralabyrinthine approaches); in the case of a non-serviceable preoperative hearing function, we used a transotic or transcanal transpromontorial approach; in the case of a compromised preoperative facial nerve function, a transcochlear approach was performed.

The choice of procedure, namely a combined microscopic/endoscopic-assisted or exclusive endoscopic approach, varied according to the indications listed above [1, 2]. In combined endoscopic/microscopic surgical procedures, the intervention started as a traditional procedure, using a microscope, but after the microscopic excision of the lesion, an endoscope was used to check the surgical cavity and exclude the presence of residual disease. In the case of residual pathology, the endoscope was used operatively to remove the remnants and achieve radicality. It was also used to analyze the petrous apex anatomy, and evaluate the ICA, facial nerve and other noble structures.

Exclusive endoscopic procedures were performed solely with endoscopic tools, introduced through the external auditory canal (transcanal corridor) to reach the petrous apex region. The indications for this approach were limited to pathologies located in the petrous apex, at the level of the infracochlear, supragenicular and supralabyrinthine areas.

The rigid endoscopes used for all of the surgical procedures had a diameter of 3 mm or 4 mm and they were angled at 0° or 45° (Karl Storz, Tuttlingen, Germany). The 70° endoscope was only used in the case of evidence of residual disease, which was impossible to manage using a 45° endoscope.

Data examined

A retrospective review of charts and intraoperative videos was carried out to identify those patients in whom the endoscope was used during surgery. The aim was to assess the role of endoscopy in these approaches (exclusive or combined).

Pathological and histopathological characteristics were collected. The intraoperative data analysis focused on the type of surgical approach, and the involvement of the ICA and facial nerve by the disease. Moreover, the percentage of residual disease detected by the endoscopic tools after the microscopic excision, and the feasibility of residual tumor removal under angled endoscopic view were evaluated. The function of the facial nerve was also assessed pre- and postoperatively, using the House–Brackmann classification [3]. Intra- and postoperative complications were collected, as well as any adverse events during the follow-up period.

Informed consent was obtained from all individual participants included in the study.

Results

From May 2009 to March 2019, 75 patients underwent lateral skull base surgery for petrous apex lesions at the Otolaryngology Department of the University Hospital of Verona or University Hospital of Modena, Italy. Among these, 36 patients were male and 39 female, and the median age was 43.9 years.

In 17 out of 75 patients, an exclusive endoscopic procedure was feasible, while in 58 patients, a combined microscopic/endoscopic approach was necessary to remove the disease completely.

The histopathological classification of the lesions treated is summarized in Table 1.

Exclusive endoscopic approach to the petrous apex

In 8 of the 17 cases who underwent an exclusive endoscopic procedure, an infracochlear approach was performed, while 9 of the 17 procedures were supragenicular approaches. In all 17 cases (100%), the entire procedure was performed under endoscopic view, without the need for the microscope. In all of these patients, it was possible to achieve complete removal of the disease, performing a sensorineural hearing sparing procedure with preservation of the cochlea.

In only one case, treated with an infracochlear approach, intraoperative bleeding occurred from the jugular bulb, and it was managed endoscopically without the necessity to interrupt the surgery.

Microscopic/endoscopic-assisted approach to the petrous apex

The remaining 58 of the 75 patients underwent a combined microscopic/endoscopic-assisted approach to the petrous apex: 12 patients underwent a middle cranial fossa approach, 2 patients an enlarged transcanal transpromontorial approach, 27 patients a transotic approach, 3 patients an infralabyrinthine approach, 8 patients a transcochlear approach, and 6 patients underwent procedures with multiple combined approaches (transmastoid with middle cranial fossa approach).

In 15 cases, residual disease was found endoscopically at the end of the microscopic procedure; in 8 cases, the residual disease was medial and/or inferior to the horizontal segment of the ICA, and in 2 cases, it was located in the fundus of the internal auditory canal; in 5 cases, it involved the labyrinthine segment of the facial nerve as summarized in Table 2.

In all of these 15 patients, the assistance of the endoscope, combined with traditional microscopic surgery, was necessary to completely remove the residual disease, which was not visible under microscopic view. Posterior facial nerve rerouting or 360° skeletonization of the ICA with mobilization of this vessel were not necessary to reach and remove the disease in any of these patients.

Table 1 Pathologies and surgical approaches for the 75 patients included in this study

Surgical approach	Pathology
Middle cranial fossa	Six cholesterol granuloma
	Four supralabyrinthine cholesteatoma
	One facial nerve schwannoma
	One chondrosarcoma
Enlarged transcanal transpromontorial approach	Two vestibular schwannoma with petrous apex extension
Transcochlear	Seven petrous apex cholesteatoma
	One mycotic petrositis
Transotic	Seventeen petrous apex cholesteatoma
	Five cholesterol granuloma
	One epidermoid cyst
	Three mycotic petrositis/osteoradionecrosis
	One acoustic schwannoma
Infralabyrinthine	Three infralabyrinthine cholesteatoma
Infracochlear	Five cholesteatoma with infracochlear extension
	Three cholesterol granuloma
Supragenicular	Six supralabyrinthine cholesteatoma
	Two facial nerve schwannoma
	One facial nerve hemangioma
Combined procedures: Transmastoid with middle cranial fossa approach	Five supralabyrinthine cholesteatoma
	One facial nerve schwannoma

Table 2 Sites of residual disease in patients who underwent a combined microscopic/endoscopic procedure

Approach	Sites of residual disease
Middle cranial fossa	Two medial and inferior to the horizontal tract of ICA
	One fundus of IAC
Enlarged transcanal transpromontorial	One medial to the horizontal tract of ICA
Transcochlear	One medial to the horizontal tract of ICA
Transotic	Four medial and inferior to the horizontal tract of ICA
Infralabyrinthine	0
Combined transmastoid and middle cranial fossa	Five labyrinthine tract of facial nerve
	One fundus of IAC

ICA internal carotid artery, *IAC* internal auditory canal

Table 3 Intraoperative and postoperative complications

Exclusive endoscopic approach ($n=17$)	Microscopic endoscopic-assisted approach ($n=58$)
Intraoperative	
One jugular bulb bleeding	One internal carotid artery bleeding
Postoperative	
	One cerebrospinal fluid (CSF) leakage
	One monocular diplopia
	One surgical wound dehiscence

Table 4 Facial nerve outcomes

Facial nerve function (House–Brackmann scale)	Preoperative	Postoperative
I, *n* (%)	52 (69.3)	49 (65.3)
II, *n* (%)	5 (6.7)	9 (12)
III, *n* (%)	7 (9.3)	6 (8)
IV, *n* (%)	3 (4)	4 (5.3)
V, *n* (%)	1 (1.3)	0 (0)
VI, *n* (%)	7 (9.3)	7 (9.3)

Regarding intraoperative complications, in one case, a self-limited bleeding from the jugular bulb was observed intraoperatively and in one case, the ICA was injured during a transotic approach (Table 3). In the latter case, this major complication was promptly treated by closing the small defect with Gelitacel (hemostat absorbable material) and Paladur resin (thermopolymerizable resin) with a satisfactory control of the bleeding. This patient underwent a postoperative magnetic resonance angiography that showed no aneurysm of the vessel or presence of contrast extravasation, and the patient did not present postoperative complications during the 3-year follow-up.

Regarding postoperative complications, there was one case of cerebrospinal fluid wound leakage after a transotic approach, which was treated conservatively with spontaneous resolution. In one case, a dehiscence of the surgical wound occurred in the postoperative period requiring surgical suturing of the defect (located at the cul-de-sac suture of the external auditory canal) under local anesthesia. One patient suffered mild monocular diplopia after a transotic approach, which was successfully corrected by using corrective prisms on lenses (Table 3).

Facial nerve outcomes

Anatomic preservation of the facial nerve was achieved in 68/75 cases in which the nerve function was normal preoperatively. Facial nerve outcome is summarized in Table 4. In summary, facial nerve function remained unchanged in 62 patients, an improvement was achieved in 4 cases, and in 9 cases, facial nerve function worsened in the postoperative period.

Among the patients belonging to the exclusive endoscopic group, and with normal preoperative facial function (grade I in the House–Brackmann scale), all of them maintained a normal facial nerve function, even postoperatively.

On the other hand, among the patients with normal facial nerve function preoperatively in the microscopic/endoscopic-assisted group, four of them presented a worsening of facial nerve function postoperatively: three patients had a grade II and 1 had a grade III deficiency (HB scale evaluation) during the follow-up; however, this difference between the two groups was not statistically significant (Chi-squared test = 2.104, $p=0.3491$).

Discussion

The first factor to analyze preoperatively in petrous apex lesions is whether a pathology's origin is extradural (cholesterol granuloma, clivus chordoma or chondrosarcoma) or intradural (meningioma, epidermoid or dermoid tumors), as this single factor provides clues to both the pathology's etiology and which kind of neural and vascular elements may be involved [4]. The choice of surgical approach used to treat the lesions in the petrous apex must necessarily be based

also on preoperative facial function, hearing function, and the location, dimensions, and histology of the lesion.

Pathologies of the petrous apex can be reached and removed surgically through an anterolateral transpetrosal route or through an anterior endoscopic transnasal route depending on the location of the disease. Van Gompel et al. provided a volumetric study of the resectable bone volumes of the petrous apex for the endoscopic endonasal approach and for the anterior transpetrosal approach for epidural lesions. They concluded that the endoscopic endonasal approach is suitable for inferior-anterior petrosectomy, and the anterior transpetrosal approach is suitable for superior-anterior petrosectomy [4].

In our case series, we have only considered the anterior and posterior transpetrosal approaches, and then we have analyzed them one by one. In our study, the majority of the surgical approaches have been performed using the microscope. Despite the spread of the endoscopic technique in middle ear surgery in the last few decades, lateral skull base surgery is still microscope-based because the pathologies located in this region often have huge dimensions, so to remove them, significant dissection and bony drilling are mandatory to reach the lesion in this area and preserve the neurovascular structures as much as possible.

Even the transcanal transpromontorial approach, developed thanks to our increased transcanal endoscopic anatomical knowledge [2, 5] has seen a progressive evolution over the years to a combined endoscopic/microscopic technique [6]. In our opinion, this characteristic to change from an endoscopic to a microscopic technique and vice versa, depending on the pathology to treat, is one of the most important concepts to bear in mind.

There are only a few studies in the literature concerning the exclusive endoscopic approach to the inner ear and lateral skull base [1, 2, 6]. This is due to the relatively recent introduction of these approaches and to the limited indications for only selected cases; these approaches are also performed in only a few oto-neurosurgical clinics because they require an adequate endoscopic learning curve, with significant surgical experience in middle ear surgery before approaching the petrous apex.

The exclusive endoscopic approaches to the lateral skull base consist of three techniques: infracochlear, supragenicular, and transpromontorial routes. The infracochlear approach is indicated for lesions located underneath the internal auditory canal, between the jugular bulb, ICA and cochlea. The supragenicular approach is indicated in the case of lesions located above the internal auditory canal and the cochlea, reachable by dissecting between the geniculate ganglion, the lateral semicircular canal, and the dura of the middle cranial fossa. The transpromontorial approach requires dissection between the tympanic and posterior segments of the facial nerve, the jugular bulb, and ICA through the cochlea, so postoperative total hearing loss is expected. This approach is indicated for lesions located mainly in the fundus of the internal auditory canal, cochlea, and/or vestibule [1, 2, 7–9].

Even though the exclusive endoscopic surgical approach for petrous apex pathologies is a technique characterized by limited indications, use of the endoscope during microscopic-based surgery is highly recommended as it allows residual pathology to be detected located in the petrous apex around the labyrinthine tract of the facial nerve and medial and under the ICA without the need for facial nerve rerouting or skeletonizing the ICA for a full 360°, thus avoiding mobilization of this vessel.

Analyzing our case series, facial nerve rerouting was never necessary to reach the lesion in the petrous apex and mobilization of the ICA was not performed in any of the patients. In one case, we experienced an ICA injury during the microscopic manipulation of the vessel, so this was not related to the endoscopic surgical steps.

Another kind of analysis concerns the use of the endoscope during the different microscopic/endoscopic-assisted approaches. The transotic approach is suitable for patients with no preoperative serviceable hearing. This approach is ideally suited to those tumors with a larger and anterior extension toward the petroclival junction, the petrous apex, or into the cochlea. One of the disadvantages of this approach is that the microscopic visualization of the petrous apex is obstructed by the presence of the facial nerve canal and the ICA. For this reason, the use of endoscopic-assisted surgery may help to achieve a complete anatomical control of the petrous apex using angled endoscopes, which would otherwise only possible in many cases with a posterior rerouting of the facial nerve (Fig. 1).

This is consistent with the literature. Patron et al. described the use of 0° or 30° endoscopes held by an assistant introduced either laterally or medially to the mastoid segment of the facial nerve [10]. Moreover, Sugimoto et al.

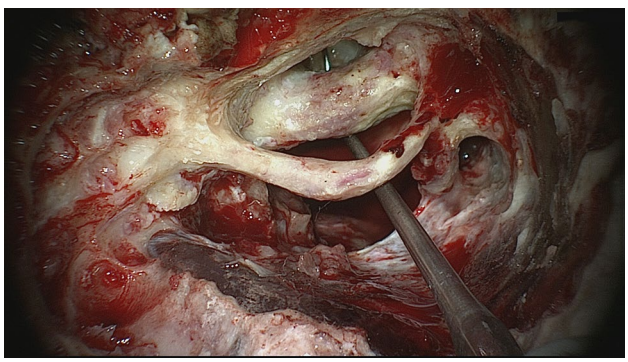

Fig. 1 Surgical field after transotic approach to the petrous apex. The angled instrument shows how the region medial to the internal carotid artery and facial nerve remains hidden to the microscopic view

applied the transotic approach in two patients affected by petrous apex cholesteatoma. Despite much bone removal and soft-tissue dissection, they could not achieve complete operative visualization of the petrous apex under microscopic view and therefore used the endoscopic approach to obtain a total view of the petrous apex area without mobilizing the ICA [11].

Recently, the enlarged transcanal transpromontorial approach has been developed as an evolution of the exclusive endoscopic transcanal transpromontorial approach, for patients with non-serviceable preoperative hearing function. It is a mainly microscopic approach indicated for removal of lesions located in the internal auditory canal, even with extension to the petrous apex, medial to the ICA.

In the case of patients affected by lesions in the petrous apex with a good preoperative hearing function, hearing preservation surgery is, of course, preferable (middle cranial fossa approach, infracochlear approach or infralabyrinthine approach). The middle cranial fossa approach provides exposure of the entire petrous bone to the upper half of the clivus and in Meckel's cave.

Kumral and colleagues described the role of oto-endoscopy during the middle cranial fossa approach, analyzing the surgical procedures for 14 petrous apex cholesteatomas. They found that endoscopic-assisted surgery is useful in removing the remnants of the cholesteatoma around the ICA (especially in the medial aspect of the ICA), the dura and facial nerve in the petrous apex resulting in less invasive surgery and less residual disease in blind spots [12]. Even in our experience, blind spots in the middle cranial fossa approach are represented by the area located medially to the horizontal and vertical segments of the ICA of the petrous apex and the fundus of the internal auditory canal. For this reason, endoscopic assistance to explore this area is suggested by many authors [12, 13].

Another hearing-sparing approach is the infralabyrinthine approach which requires drilling of the infralabyrinthine air cell tract, followed antero-medially along the long axis of the temporal bone towards the petrous apex. The limits of the dissection are the facial nerve anteriorly, the posterior semicircular canal superiorly, and the jugular bulb inferiorly. The indications are limited to lesions involving the posterior and inferior parts of the petrous apex. It is instead contraindicated in patients with a high jugular bulb, which is present in a variable percentage of cases. Microscopically, this approach does not allow good visualization of the petrous apex and it is necessary to use endoscopic assistance with different angled endoscopes (45°, 70°) to obtain a better view under the cochlea, facial nerve and ICA [14–16].

In the neurosurgical literature, the use of endoscopic assistance is also described for better intraoperative visualization during the retrosigmoid approach for petrous apex cholesteatoma [17]. Moreover, other modifications of the classic retrosigmoid approach have been reported using the endoscopic approach for some petroclival and Meckel's cave lesions [18].

In conclusion, an exclusive endoscopic approach has very limited indications in the treatment of lesions located in the petrous apex, and its role depends on some factors such as the dimensions of the pathology and the anatomical area involved. Petrous apex surgery remains a traditional microscopic-based surgery, but the advent of endoscopic-assisted surgery allows an improvement in radicality during the removal of lesions in the petrous apex, minimizing the manipulation of neurovascular structures such as the facial nerve and ICA.

Funding This research was not funded.

Compliance with ethical standards

Conflict of interest Authors have no conflict of interest to declare.

Ethical statement All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional (Comitato etico delle province di Verona e Rovigo) and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was collected from all the patients involved in the study.

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