What is the Best Route to the Meckel Cave?

Anatomical Comparison between the Endoscopic Endonasal Approach and a Lateral Approach

Jason Van Rompaey¹ Carrie Bush¹ Eyad Khabbaz¹ John Vender² Ben Panizza³ C. Arturo Solares¹

¹ Department of Otolaryngology, Georgia Health Sciences University School of Medicine, Georgia Skull Base Center, Augusta, Georgia, United States

² Department of Neurosurgery, Georgia Health Sciences University School of Medicine, Augusta, Georgia, United States

³ Queensland Skull Base Unit, University of Queensland, Princess Alexandra Hospital, Brisbane, Queensland, Australia

Address for correspondence C. Arturo Solares, MD, Department of Head and Neck Surgery, Georgia Health Sciences University, Georgia Skull Base Center, 1120 15th Street BP 4109, Augusta, GA 30912, United States (e-mail: csolares@gru.edu).

J Neurol Surg B 2013;74:331–336.

Abstract

Background Traditionally, a pterional approach is utilized to access the Meckel cave. Depending on the tumor location, extradural dissection of the Gasserian ganglion can be performed. An endoscopic endonasal access could potentially avoid a craniotomy in these cases.

Methods We performed an endoscopic endonasal approach as well as a lateral approach to the Meckel cave on six anatomic specimens. To access the Meckel cave endoscopically, a complete sphenoethmoidectomy and maxillary antrostomy followed by a transpterygoid approach was performed. For lateral access, a pterional craniotomy with extradural dissection was performed.

Results The endoscopic endonasal approach allowed adequate access to the Gasserian ganglion. All the relevant anatomy was identified without difficulty. Both approaches allowed for a similar exposure, but the endonasal approach avoided brain retraction and improved anteromedial exposure of the Gasserian ganglion. The lateral approach provided improved access posterolaterally and to the superior portion.

Conclusion The endoscopic endonasal approach to the Meckel cave is anatomically feasible. The morbidity associated with brain retraction from the open approaches can be avoided. Further understanding of the endoscopic anatomy within this region can facilitate continued advancement in endoscopic endonasal surgery and improvement in the safety and efficacy of these procedures.

Keywords

- ▶ endonasal endoscopic
- ▶ Gasserian ganglion
- ▶ lateral approach
- ▶ maxillary antrostomy
- ▶ Meckel cave
- ▶ pterional craniotomy
- ▶ sphenoethmoidectomy

Introduction

Involvement of the Meckel cave by skull base pathology is relatively infrequent among all cranial tumors.¹ Anecdotally, in a primarily skull base practice, its involvement seems to be more frequent. Regardless, when the Meckel cave is involved

with disease, appropriate therapeutic intervention is required. The deep location and surrounding neurovasculature of the Meckel cave pose a challenge to complete tumor resection.² Over the years, many innovative treatments have been developed to address the clinical needs of the patient and minimize surrounding tissue damage. With the

received

May 10, 2011

accepted after revision

August 10, 2011

published online

April 5, 2013

© 2013 Georg Thieme Verlag KG
Stuttgart · New York

DOI <http://dx.doi.org/10.1055/s-0033-1342989>.
ISSN 2193-6331.

advent of stereotactic radiation, a more targeted approach has resulted in effective treatment with minimal damage to the delicate surrounding tissue.³ Even though this modality is effective, in many cases a surgical approach is the best option. In addition, it allows for tissue diagnosis in cases in which imaging is not definitive.

The goal of a surgical approach is the resection of a tumor with negative margins using sound oncological principles. Direct visualization of the tumor is essential to obtaining this goal.⁴ Various methods of skull base surgery have arisen to create an adequate corridor for surgical resection. A common method of directly visualizing the skull base is the use of a craniotomy. Open cranial surgery necessitates the creation of a sufficient window proximal to the tumor with retraction of the brain to reveal the skull base.⁵ The most common approach for accessing the Meckel cave is anterolateral using a pterional craniotomy.^{6–8}

With advancements in optical technology, new avenues of visualization have been made available to the surgeon.^{9,10} The development of the endoscope enabled the ability to peer deep into the corpus. This clear view of previously obstructed anatomy created the capability of minimizing the surgical window with tissue preservation. Recognizing this benefit, surgical disciplines have applied the endoscope to create a wide array of minimally invasive techniques. With the intention of lessening neurologic damage, neurosurgeons have utilized the endoscope to assist in the visualization of structures in the skull base during open procedures. These endoscopic-assisted procedures are able to maintain oncologic principles and minimize neurovascular damage.^{10,11} However, brain manipulation is still required in some cases to access the tumor.

The need to reduce brain retraction and minimize cosmetic damage motivated the development of a procedure to allow endonasal endoscopic access to the skull base.⁵ The anatomy of the nasal cavity and surrounding sinuses provide a unique corridor for accessing the entire ventral skull base.¹² Originally, the endonasal endoscopic approach (EEA) was utilized to access the sella and cavernous sinus via the sphenoid sinus. The EEA was expanded from the sphenoid sinus to include access from the cribriform plate to the odontoid process.¹³ The expanded EEA also opens the possibility of accessing the parasellar region, including the Meckel cave.^{5,10,14}

The expanded EEA is relevant to tumors in the Meckel cave, because it provides a unique anteromedial access to the base of the Gasserian ganglion.¹³ Utilizing this approach to the Meckel cave could possibly increase the maintenance of negative margins while minimizing brain retraction. Accessing this region using an open approach would require significant brain manipulation.^{5,8,10,15} The purpose of this article is to draw a comparison between the two approaches in an anatomical cadaveric model.

Methods

Specimens

Six anatomic specimens were selected based on patent vasculature and closeness to time of death. After being preserved

in formalin, the specimens were injected with colored latex to highlight the arterial and venous vasculature. The procedure for head injection followed the guidelines set by Sanan et al.¹⁶

Endoscopic Dissection Technique

Both 0-degree and 45-degree endonasal rod endoscopes were used. The endoscope was placed on a stand, allowing a bimanual technique. This microdissection technique was similar to those used in open approaches.

The EEA utilized a combined transpterygoid, transsphenoidal corridor. The initial step was to create an adequate corridor of visualization within the nasal cavity. To achieve this, the middle turbinate was removed using endoscopic scissors. Removal of the posterior third of the nasal septum followed, allowing binasal instrumentation use and expanding the corridor of visualization. The sphenoid sinus os was then identified and the anterior wall was excised using angled through cut nasal forceps. The mucosa was removed from the posterior wall of the sphenoid sinus to obtain a clear view of the optic and carotid prominence, and the optic carotid recess.

The focus was then directed on the transpterygoid approach, starting with the identification of the uncinate process and os of the maxillary sinus. The medial wall of the maxillary sinus was dissected to the posterior surface, and the posterior wall was removed medially to the pterygoid prominence, exposing the sphenopalatine fossa and contents. This revealed the maxillary, sphenopalatine, nasal, and greater palatine arteries and allowed identification of the sphenopalatine ganglion, greater descending palatine, and vidian nerves. V2 was then observed running medially through the sphenopalatine fossa and was followed to the foramen rotundum (►Fig. 1). Exposure of V2 medioposteriorly to the Gasserian ganglion was accomplished using a high-speed drill. This necessitated the removal of the anteromedial portion of the Meckel cave. After exposing the Gasserian ganglion, we removed the carotid prominence of the posterior wall of the sphenoid sinus to reveal the internal carotid artery (ICA). This facilitated adequate visualization of V1. Further dissection of V1 exposed cranial nerve VI and the sympathetic division of V1. With use of the high-speed drill, we removed the pterygoid prominence posteriorly to the Meckel cave, allowing clear visualization of V3 and the petrous portion of the ICA. Microsurgical instruments were used to remove epineural fascia and clear the corridor of debris, allowing clear visualization of the Meckel cave and contents (►Fig. 2).

It is important to note that an alternate approach to access the Meckel cave could be used. This involves dissecting the Vidian nerve and associated canal to the petrous portion of the ICA in close proximity to the foramen rotundum. This may provide a useful landmark for accessing the Meckel cave.

Lateral Dissection Technique

The pterional approach began with an incision starting at the level of the zygomatic arch just in front of the tragus, extending superiorly and curving anteriorly, staying just behind the hairline to slightly medial of the supraorbital

Fig. 1 Removal of the posterior wall of the maxillary sinus, exposing the contents of the sphenopalatine fossa. AwSS, anterior wall of the sphenoid sinus; DPA, descending palatine artery; GPN, greater palatine nerve; IMA, internal maxillary artery; ION, inferior optic nerve; LPN, lesser palatine nerve; PwMS, posterior wall of the maxillary sinus; SPA, sphenopalatine artery; SPG, sphenopalatine ganglion.

notch. The skin was then retracted inferiorly, revealing the temporalis muscle. This was separated from the skull using a periosteal elevator and reflected inferiorly over the zygomatic process. The zygomatic arch was removed using a high-speed cutting drill at the malar process and the articular joint of the mandible. This allowed greater reflection of the temporalis muscle for improved visualization of the temporal fossa. Using a high-speed drill, a keyhole was made at the suture of the frontal and sphenoid bones. The tip was exchanged

Fig. 2 Removal of the anterior, posterior, and lateral walls of the sphenoid sinus along with partial resection of the pterygoid prominence, exposing the anteromedial contents of the Meckel cave. DPA, descending palatine artery; GG, Gasserian ganglion; GPN, greater palatine nerve; IMA, internal maxillary artery; ION, inferior optic nerve; PwSS, posterior wall of the sphenoid sinus; SPA, sphenopalatine artery; SPG, sphenopalatine ganglion.

with a cutting tool, and a bone flap was created superiorly around the pterion and extending inferiorly to the infratemporal fossa. Care was taken to preserve the dura. A Kerrison rongeur bone punch was also applied to expand the pterional incision. A microscope was utilized to aid in the microsurgical dissection of the contents of the Meckel cave. Clear visualization of the Gasserian ganglion, the branches of the trigeminal nerve, and the middle meningeal artery was achieved.

Dry Skull Measurements

To approximate the amount of exposure created by the endonasal endoscopic approach, measurements were completed on 15 dry skulls bilaterally. In the middle cranial fossa, a line was drawn from the anterolateral border of foramen ovale to the inferolateral border of the superior orbital fissure. This forms the lateral boundary for exposure in the endonasal approach. From the inferolateral border of the superior orbital fissure, a line was drawn to the superolateral portion of the opening to the carotid canal as it enters the middle cranial fossa. This forms the medial border of the endonasal exposure. To obtain the posterior border, a line was drawn from the superolateral border of the carotid canal to the starting point at the anterolateral border of foramen ovale.

Results

Access to the Meckel cave was completed with both the EEA and the open anterolateral approach. Both approaches provided adequate surgical access to the Meckel cave and contents. However, the anteromedial access was achieved by the EEA without brain retraction (→Fig. 3). Even though brain retraction was required in the pterional craniotomy, this approach provided improved access to the posterolateral

Fig. 3 Anatomical contents of the anteromedial portion of the Meckel cave. GG, Gasserian ganglion; ICA, internal carotid artery; PwSS, posterior wall of the sphenoid sinus.

Fig. 4 Exposure of the posterolateral portion of the Meckel cave in an open pterional craniotomy. GG, Gasserian ganglion; ICA, internal carotid artery; MMA, middle meningeal artery.

area of the Meckel cave (►Fig. 4), the superior portion of the Gasserian ganglion, and the cavernous sinus (►Fig. 5).

The approximated endonasal endoscopic exposure was measured bilaterally in 15 dry skulls totaling 30 individual samples. The mean area exposed was 123 mm². There was a standard deviation of 19 mm². At a 95% confidence interval, the lower and upper limits were 117 mm² and 130 mm².

Discussion

Johann Friedrich Meckel was the first anatomist to describe the bony recess that provides the seat for the Gasserian ganglion in the mid 1700s.¹⁷ The Meckel cave is located in the parasellar region adjacent to the cavernous sinus in the middle cranial fossa. This bony indentation of the sphenoid

Fig. 5 Exposure of the Gasserian ganglion and cavernous sinus in an open pterional approach. GG, Gasserian ganglion; ICA, internal carotid artery; SOF, superior orbital fissure.

forms the base of the Gasserian ganglion.^{1,6} Extending out from the ganglion are the ophthalmic, maxillary, and mandibular branches of the trigeminal nerve. These three branches exit the Meckel cave via the superior orbital fissure, foramen ovale, and the foramen rotundum, respectively.

The deep location and the surrounding neurovascular structures make accessing the Meckel cave challenging.^{2,11,13,15} The possibility of damaging surrounding tissue is high, and attempts to operate in the Meckel cave have been associated with cranial nerve morbidity.^{18,19} Consequently, an approach to surgery was required that allowed adequate visualization and a sufficiently open corridor to perform tumor resection. The complex nature of the anatomy has led to the development of various methods of accessing this area with the least amount of damage to surrounding structures.

The most commonly used approach for accessing the Meckel cave is the anterolateral. This requires a pterional incision, temporal lobe retraction, and transection of the Gasserian ganglion to reach the Meckel cave. Although at times the trigeminal nerve needs to be sacrificed for complete tumor resection, it is not always necessary.¹⁸ The pterional approach has been effective for removing tumors of the middle fossa; however, the access to the anteromedial portion of the Meckel cave and related structures has proved to be limiting.¹³ These observations are consistent with our findings in this study.

The challenging anatomy has provided impetus for developing alternative surgical techniques. With the improvement in endoscopic technology, endoscopic-assisted surgery has been utilized with a reasonable degree of success.¹¹ This has allowed increased visualization and limited unintended disruption of sensitive tissue. The endonasal endoscopic approach has evolved to become an innovative method of accessing the entire ventral skull base.²⁰ It has arisen out of an increasing understanding of anatomy and advancement of technology.¹⁰ Even though surgical microscopes were originally used to visualize internal nasal anatomy, they only allowed viewing of midline structures.²¹ Accessing the surrounding area requires the use of an endoscope. The rod lens of the endoscope allows the camera to penetrate deep into the nasal cavity and directly visualize anatomy beyond the midline. This has allowed the endonasal endoscope to incorporate access to the anterior, middle, and posterior fossa and has opened the complete ventral skull base for surgical access.¹² Visualization and the overall ability to perform endoscopic skull base surgery have been augmented with concurrent development of angled endoscopes, specific skull base instrumentation, image guidance, and Doppler and ultrasound probes.^{10,14,19}

Greater visualization of the ventral skull base has generated interest in the use of EEA. However, EEA also overcomes other limitations associated with the open approach. The advantage of EEA is that it avoids brain retraction. The near midline location of the Meckel cave necessitates significant manipulation of the temporal lobe, inevitably resulting in morbidity. Accessing the skull base with this technique comes at the cost of possible brain contusion, edema, and bleeding.^{10,11,22}

EEA also lessens the cosmetic impact of skull base surgery when compared with a pterional craniotomy. The removal of a pterional bone flap requires a large incision to the head and potentially altering the aesthetic appearance.^{7,15,22} With EEA there are no externally visible incisions, as all of the surgery is done within the nasal cavity. The minimally invasive nature of the surgery leaves the face and head without the need for cosmetic repair.^{22–24}

A less-invasive approach can allow for shortened healing time. This means that the patient spends less time in the hospital recovering from postsurgical wounds.^{10,23,25} As a result, adjunct therapy such as radiation can commence in a shorter amount of time and improves the possibility of better outcomes.²⁴

Although EEA does allow for improved visualization of the skull base, the surgical corridor it creates is smaller than a pterional craniotomy. In certain cases, this can eliminate the possibility of en bloc excision of the tumor.^{10,22} To avoid seeding of the cancer to the surrounding tissue, en bloc tumor removal has been preferred in malignant cases.²² However, 31% of surgical cases of the skull base have tumors with margins that are either positive or close to neurovascular structures.²⁵ Even in a pterional approach, en bloc resection could be challenging. It is possible that piecemeal removal of a tumor may be required in either approach. However, the endoscope provides direct visualization, thereby facilitating thorough removal.²⁴ Piecemeal elimination may even be advantageous. Recent developments in piecemeal tumor extirpation such as Mohs have become treatments of choice with good patient outcomes.¹⁰ Even if the tumor cannot be removed en bloc, the possibility of debulking could provide relief from compressive symptoms. Lastly, the majority of tumors in this region necessitating resection are histologically benign and are routinely removed in a piecemeal fashion with internal debulking followed by capsular dissection.

In our experience the macroscopic tumors in the Meckel cave tend to occlude the venous sinuses in the surrounding area. When the malignancy extends into these sinuses, excessive hemorrhaging can be a complication. For example, in perineural disease the perineurium provides an adequate barrier. The protective effects of the perineurium extend from the dermis to the Gasserian ganglion.^{26,27} However, once the metastasis extends past this point it may involve the dura or extend further back toward the brainstem. Although en bloc resection of the disease up to the Gasserian ganglion is possible, bleeding from the sinuses can be problematic.

One potential drawback of using EEA is a presumed higher rate of cerebrospinal fluid (CSF) leakage.^{5,10,28,29} Initial reports had unacceptably high CSF leak rates, and for this reason there has been an aversion to increased use of EEA procedures.³⁰ However, recent developments in reconstruction have greatly reduced the occurrence of this complication. Particularly, the use of vascularized skull base reconstruction, most commonly with the use of a pedicled nasoseptal flap, has been shown to significantly reduce CSF leak rates.^{10,23,31} Another impediment is the potential for cavernous sinus bleeding. In our experience, this can be managed adequately

with the use of a bimanual technique and Surgifoam paste (Ethicon, Somerville, New Jersey, USA).

EEA with its unique visualization and access provides an additional tool to the expanding armamentarium of the surgeon. It is not necessarily a replacement for an open approach to the Meckel cave and should be considered either an alternative or adjunct. Tumors can be complex, spanning large regions of the skull base and necessitating a combined approach.^{9,15} For this reason it is recommended that the surgeon be familiar with both approaches.⁹ This allows increased options for surgical resection and comprehensive tumor extirpation. Also, manipulation of the vasculature with underlying pathology can create a hemorrhagic emergent condition in EEA. This may necessitate the conversion of an endoscopic to an open approach to obtain adequate hemostatic control.⁹ Having training in both approaches could be advantageous in this scenario.

Current data show that EEA has been successful in the removal of tumors with negative margins.^{4,10,13} As with any surgical procedure, there are complications. This procedure is relatively new, and there are limited data of its long-term effect. Further studies are needed to evaluate the impact of the outcomes and overall effectiveness.

In this study the anterolateral approach provided adequate access laterally to the cavernous sinus. However, tumors located anteromedial and inferior to the Gasserian ganglion would require removal of neural structures to obtain access. The open approach allows for unimpeded admission, proceeding medially until the border of the foramen ovale has been reached. Removing pathology that extends more medially increases the possibility of iatrogenic trauma from working between the branches of the trigeminal nerve. Hence, the endonasal approach to the Meckel cave is uniquely suited for gaining access to the anteromedial location while maintaining minimal damage to surrounding neurovasculature.

The use of the endonasal versus open approach should be determined based on tumor location. Anteromedial location of the neoplasm could indicate removal via endoscopy, thereby preserving the functioning of the Gasserian ganglion. A tumor located lateral to the foramen ovale or in the posterolateral portion of the ganglion would be beyond the reach of an endoscope. In this case, a pterional craniotomy would be better suited, as this would provide adequate access with minimal damage to surrounding structures.

The type of pathology is common to both the anteromedial and posterolateral areas of the Meckel cave. As in other cranial base procedures, the pathology is not usually used as a criterion for approach. Tumor extirpation should be determined by criteria allowing a sufficient surgical corridor while minimizing iatrogenic damage to surrounding tissue.

Conclusion

The endoscopic endonasal approach to the Meckel cave is anatomically feasible and compares well with a lateral approach. The morbidity associated with brain retraction from the open approaches can be avoided. Further understanding

of the endoscopic anatomy within this region can continue to allow for advances in endoscopic endonasal surgery and improvement in the safety and efficacy of these procedures.

References

- Furtado S, Hegde A. Trigeminal neuralgia due to a small Meckel's cave epidermoid tumor: surgery using an extradural corridor. *Skull Base* 2009;19:353–357
- Mechtler L. Pain due to tumors of the skull base. In: de Leon-Casasola OA, ed. *Cancer Pain: Pharmacologic, Interventional, and Palliative Approaches*. Philadelphia: Saunders; 2007:55–68
- Chamoun RB, DeMonte F. Management of skull base metastases. *Neurosurg Clin N Am* 2011;22(1):61–66, vi–ii
- Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL. Expanded endonasal approach: the rostrocaudal axis. Part I. Crista galli to the sella turcica. *Neurosurg Focus* 2005;19(1):E3
- Cavallo LM, Messina A, Cappabianca P, et al. Endoscopic endonasal surgery of the midline skull base: anatomical study and clinical considerations. *Neurosurg Focus* 2005;19(1):E2
- Muto J, Kawase T, Yoshida K. Meckel's cave tumors: relation to the meninges and minimally invasive approaches for surgery: anatomic and clinical studies. *Neurosurgery* 2010;67(3, Suppl Operative):ons291–ons298, discussion ons298–ons299
- Park HS, Park SK, Han YM. Microsurgical experience with supra-orbital keyhole operations on anterior circulation aneurysms. *J Korean Neurosurg Soc* 2009;46(2):103–108
- Bai ZQ, Cai EY, Wang SQ, Li ZJ, Wang SB. Nasal cavity-maxillary sinus-pterygopalatine fossa-Meckel's cave: a preliminary anatomic study of an endoscopy-based operative approach. *Neurosci Bull* 2009;25(6):376–382
- Snyderman C, Carrau R, Kassam A. Who is the skull base surgeon of the future? *Skull Base* 2007;17(6):353–355
- Ong YK, Solares CA, Carrau RL, Snyderman CH. New developments in transnasal endoscopic surgery for malignancies of the sinonasal tract and adjacent skull base. *Curr Opin Otolaryngol Head Neck Surg* 2010;18(2):107–113
- Faleiro LC, Faleiro RM, Barroso LF, Gripp DA. Endoscopic assisted microneurosurgery for gasserian portion of trigeminal neuroma: two cases. *Arq Neuropsiquiatr* 2006;64(3A):650–653
- Snyderman CH, Carrau RL, Kassam AB, et al. Endoscopic skull base surgery: principles of endonasal oncological surgery. *J Surg Oncol* 2008;97(8):658–664
- Kassam AB, Prevedello DM, Carrau RL, et al. The front door to meckel's cave: an anteromedial corridor via expanded endoscopic endonasal approach- technical considerations and clinical series. *Neurosurgery* 2009; 64(3, Suppl):ons71–ons82, discussion ons82–ons83
- Prevedello DM, Thomas A, Gardner P, Snyderman CH, Carrau RL, Kassam AB. Endoscopic endonasal resection of a synchronous pituitary adenoma and a tuberculum sellae meningioma: technical case report. *Neurosurgery* 2007;60(4, Suppl 2):E401, discussion E401
- Schwartz TH, Fraser JF, Brown S, Tabaei A, Kacker A, Anand VK. Endoscopic cranial base surgery: classification of operative approaches. *Neurosurgery* 2008;62(5):991–1002, discussion 1002–1005
- Sanan A, Abdel Aziz KM, Janjua RM, van Loveren HR, Keller JT. Colored silicone injection for use in neurosurgical dissections: anatomic technical note. *Neurosurgery* 1999;45(5):1267–1271, discussion 1271–1274
- Tubbs RS, Salter EG, Oakes WJ. Bony anomaly of Meckel's cave. *Clin Anat* 2006;19(1):75–77
- Ziyal IM, Sekhar LN, Ozgen T, Söylemezoğlu F, Alper M, Beşer M. The trigeminal nerve and ganglion: an anatomical, histological, and radiological study addressing the transtrigeminal approach. *Surg Neurol* 2004;61(6):564–573, discussion 573–574
- Nakamura M, Krauss JK. Image-guided resection of small lesions in the cavernous sinus and Meckel's cave. *Eur J Surg Oncol* 2010;36(2):208–213
- Barges-Coll J, Fernandez-Miranda JC, Prevedello DM, et al. Avoiding injury to the abducens nerve during expanded endonasal endoscopic surgery: anatomic and clinical case studies. *Neurosurgery* 2010;67(1):144–154, discussion 154
- Catapano D, Sloffer CA, Frank G, Pasquini E, D'Angelo VA, Lanzino G. Comparison between the microscope and endoscope in the direct endonasal extended transsphenoidal approach: anatomical study. *J Neurosurg* 2006;104(3):419–425
- Dave SP, Bared A, Casiano RR. Surgical outcomes and safety of transnasal endoscopic resection for anterior skull tumors. *Otolaryngol Head Neck Surg* 2007;136(6):920–927
- Eloy JA, Vivero RJ, Hoang K, et al. Comparison of transnasal endoscopic and open craniofacial resection for malignant tumors of the anterior skull base. *Laryngoscope* 2009;119(5):834–840
- Buchmann L, Larsen C, Pollack A, Tawfik O, Sykes K, Hoover LA. Endoscopic techniques in resection of anterior skull base/paranasal sinus malignancies. *Laryngoscope* 2006;116(10):1749–1754
- Cohen MA, Liang J, Cohen IJ, Grady MS, O'Malley BW Jr, Newman JG. Endoscopic resection of advanced anterior skull base lesions: oncologically safe? *ORL J Otorhinolaryngol Relat Spec* 2009;71(3):123–128
- Patel SG, Singh B, Polluri A, et al. Craniofacial surgery for malignant skull base tumors: report of an international collaborative study. *Cancer* 2003;98(6):1179–1187
- Solares CA, Brown I, Boyle GM, Parsons PG, Panizza B. Neural cell adhesion molecule expression: no correlation with perineural invasion in cutaneous squamous cell carcinoma of the head and neck. *Head Neck* 2009;31(6):802–806
- Solares CA, Boyle GM, Brown I, Parsons PG, Panizza B. Reduced alphaB-crystallin staining in perineural invasion of head and neck cutaneous squamous cell carcinoma. *Otolaryngol Head Neck Surg* 2010;142(3, Suppl 1):S15–S19
- Zimmer LA, Theodosopoulos PV. Anterior skull base surgery: open versus endoscopic. *Curr Opin Otolaryngol Head Neck Surg* 2009;17(2):75–78
- Hofstetter CP, Singh A, Anand VK, Kacker A, Schwartz TH. The endoscopic, endonasal, transmaxillary transpterygoid approach to the pterygopalatine fossa, infratemporal fossa, petrous apex, and the Meckel cave. *J Neurosurg* 2010;113(5):967–974
- Kassam AB, Thomas A, Carrau RL, et al. Endoscopic reconstruction of the cranial base using a pedicled nasoseptal flap. *Neurosurgery* 2008;63(1, Suppl 1):ONS44–ONS52, discussion ONS52–ONS53