Curr Oncol Rep (2014) 16:369
DOI 10.1007/s11912-013-0369-6

HEAD AND NECK (E HANNA, SECTION EDITOR)

Endoscopic Resection of Sinonasal Cancers

Shirley Y. Su · Michael E. Kupferman · Franco DeMonte · Nicholas B. Levine · Shaan M. Raza · Ehab Y. Hanna

Published online: 21 January 2014

Abstract Sinonasal malignancies, a rare group of tumors, are characterized by histological heterogeneity and poor survival. As improvements in image-guidance and endoscopic technologies became incorporated into head and neck oncologic and neurosurgical practice, the application of these technologies and techniques to the surgical management of sinonasal malignancy began. Over the past decade, there has been increasing evidence regarding the safety and oncological effectiveness of these techniques. Several institutions have reported their experience with endoscopic surgery and have shown reduced morbidity, better quality of life, and survival outcomes equivalent to those of open surgery in carefully selected patients. Endoscopic cranial base surgery is a rapidly evolving field. We review the literature on oncological outcomes, safety, quality of life, and recent technological advances.

Keywords Sinonasal malignancy · Endoscopic surgery · Skull base surgery · Skull base reconstruction · Head and neck cancer

Introduction

Sinonasal malignancies account for only 3-5 % of head and neck tumors [1, 2]. They are an aggressive and histologically heterogeneous disease group. Survival remains poor despite advances in treatment over the past 50 years. Ketcham et al. [3] first established the anterior craniofacial resection (ACFR) as the standard of care for sinonasal malignancies in the 1960s. The past decade has witnessed the introduction of endoscopic surgery as a complement to, and more recently at times an alternative to open surgery. Although it was initially met with concerns regarding oncological soundness and faced technical challenges such as adequate reconstruction, there is now increasing acceptance of its safety and oncological effectiveness in carefully selected patients. With endoscopic techniques as part of the surgical armamentarium, tailored surgical strategies can now be devised based on the target lesion, the goals of treatment, and the patient. Endoscopic surgery for sinonasal malignancies is a rapidly evolving field. The growing expertise of surgical teams has paralleled advances in technology and progress in medical and radiation oncology. The role of endoscopic surgery in the multidisciplinary management of sinonasal malignancies is being continually refined. We outline current indications for endoscopic resection of sinonasal malignancy, summarize recent developments, and propose areas for further research.

Anatomical Limits of Endoscopic Endonasal Surgery

Since the advent of endoscopic cranial base surgery, the limit of what is endoscopically resectable has been progressively expanded. Endoscopic resection of the anterior skull base and dura with reconstruction was first described in 2005 [4, 5]. The standard endoscopic endonasal "craniofacial" resection starts with debulking of the intranasal tumor, identifying the attachment of tumor origin, and resection of the sinonasal component. The lamina papyracea, cribriform plate, fovea ethmoidalis, planum sphenoidale, dura, and olfactory bulbs and tracts can be resected depending on the extent of tumor

This article is part of the Topical Collection on *Head and Neck*

S. Y. Su (✉) · M. E. Kupferman · E. Y. Hanna
Department of Head and Neck Surgery, University of Texas MD Anderson Cancer Center, 1515 Holcombe Blvd, Suite 1445, Houston, TX 77030-4009, USA
e-mail: sysu@mdanderson.org

F. DeMonte · N. B. Levine · S. M. Raza
Department of Neurosurgery, University of Texas MD Anderson Cancer Center, 1515 Holcombe Blvd, Suite 1445, Houston, TX 77030-4009, USA

involvement. Selected centers are now using the endoscopic technique to resect involved brain parenchyma, although extensive brain involvement remains a relative contraindication to endoscopic surgery alone and in most cases necessitates a combined craniotomy.

In recent years, “extended” transcribriform approaches have been described. “Transpterygoid approaches” provide access to the petrous temporal bone, Meckel’s cave, and middle cranial fossa [6]. “Transclival approaches” allow tumor clearance from the nasopharynx, clivus, and the odontoid, with the lower limit being the nasopalatine line [7]. Further extension of tumors into the oropharynx can be accessed with a combined transnasal and transoral approach. Superolaterally, the endoscopic approach can reach up to the midpoint of the orbit. Tumors extending to the maxillary sinus are cleared via an endoscopic medial maxillectomy or complete medial maxillectomy with resection of the lacrimal duct. Once the maxillary sinus has been opened, further access to the pterygopalatine fossa, parapharyngeal space, and infratemporal fossa is possible [8, 9]. Lateral access may be further improved with the addition of a Caldwell–Luc incision or a septal window that allows binareal access. A purely endoscopic approach is contraindicated where there is involvement of skin and subcutaneous tissue, nasolacrimal sac, anterior table of the frontal sinus, and carotid artery, and extensive dural and brain parenchymal involvement. In such cases, the addition of a transfacial or transcranial approach is warranted.

Oncological Outcomes

Several large studies published over the past decade have reported on the oncological outcomes of open ACFR. An international collaborative study of 1,307 patients treated with ACFR at 17 institutions reported 5-year overall survival (OS), disease-specific survival (DSS) and recurrence-free survival rates of 54, 60, and 53 %, respectively [10]. Howard et al. [11] reported on 259 patients treated by ACFR at a single institution with a mean follow-up of 63 months. The 5-, 10-, and 15-year disease-free survival (DFS) rates were 59, 40, and 33 %, respectively. Survival has improved over the past four decades [12]. In a retrospective medical record review of 282 patients treated at Memorial Sloane-Kettering Cancer Center and Tel Aviv Medical Center between 1973 and 2008, patients operated on after 1996 had better 5-year OS and DSS rates (66 % and 70 %) compared with patients operated on before 1996 (55 % and 57 %). Surgery after 1996 was an independent predictor of outcome on multivariate analysis, despite higher rates of comorbidity, dural and pterygopalatine invasion, and multicompartmental involvement [12].

When endoscopic endonasal surgery was first described for the treatment of sinonasal malignancies, concerns were raised regarding the oncological soundness of the procedure [13] Criticisms have centered on the inability of the endoscopic approach to perform an en bloc resection [14]. Proponents of the endoscopic technique argue that unless the tumor is small, en bloc resection is rarely achievable with open surgery [15]. Several studies have shown that en bloc resection does not positively impact on oncological outcomes [16, 17]. What is paramount, however, is achieving negative resection margins, regardless of the surgical approach. Multiple studies have demonstrated that a positive resection margin is an independent risk factor for recurrence and reduced survival [10, 12, 16–19]. Open ACFR has reported positive resection margin rates of 15.6–17 % [10, 18]. Endoscopic surgery, with its excellent visualization, has demonstrated a result equivalent to that of open surgery (10–19 %) in selected patients [20, 21•, 22].

The two largest series of recent times have demonstrated endoscopic resection to have oncological results comparable to those of open surgery. Hanna et al. [21•] reported on 120 patients treated at MD Anderson Cancer Center from 1992 to 2007. Seventy-seven percent were treated with an exclusive endoscopic approach (EEA) and 23 % were treated with the cranioendoscopic approach (CEA; defined as the transnasal endoscopic approach with the addition of a frontal or subfrontal craniotomy). Sixty-three percent of patients in the EEA group had T1–2 tumor stage, whereas 95 % of patients in the CEA group had T3–4 disease stage ($P<0.01$). Positive margins were reported in 15 % of patients. Fifty percent of patients received postoperative radiation therapy or chemotherapy and radiation therapy. With a mean follow-up of 37 months, the local, regional, and distant recurrence rates were 15, 6, and 5 %, respectively. The 5- and 10-year DSS rates were 87 and 80 %, respectively. Disease recurrence and survival did not significantly differ between the EEA and CEA groups. Hanna et al. emphasized the role of appropriate adjuvant or neoadjuvant therapy and treatment by expert multidisciplinary teams in the management of sinonasal malignancies. Nicolai et al. [23•] reported on 184 patients from the University of Brescia and the University of Pavia/Insubria-Varese treated from 1996 to 2006. The overall 5-year DSS rate was 82 %. At the mean follow-up of 34 months, the local, regional, and distant recurrence rates were 15, 1, and 7 %, respectively. Both study cohorts had similar distributions of T staging, adjuvant treatment, and proportion of EEA to CEA (Table 1). However, compared with the MD Anderson Cancer Center group, patients in the European group were older, predominantly male, less likely to have had prior treatment (28 % versus 58 %), and more likely to present with adenocarcinoma (37 % versus 14 %). Irrespective of these differences, the 5-year DSS rate for the two series is comparable to the rates reported in the open ACFR cohorts. Both groups concluded that in well-selected patients, endoscopic resection of sinonasal cancers results in acceptable oncological outcomes.

Table 1 Demographic, pathological, and treatment characteristics of the two largest endoscopic resection series to date

	Hanna 2009	*Nicolai 2008*
Number of cases, n	120	184
Reporting period	1992-2007	1996-2006
Mean age, years	53	59
Male sex, %	54	64
Surgical approach, %		
Exclusively endoscopic approach (EEA)	77	73
Cranioendoscopic approach (CEA)	23	27
Prior treatment, %		
Yes	58	28
No	42	72
T stage, %		
1	25	28
2	25	14
3	21	18
4	29	28
Histology, %		
Esthesioneuroblastoma	17	12
Adenocarcinoma	14	37
Squamous cell carcinoma	13	14
Melanoma	14	9
Adenoid cystic carcinoma	7	7
Other	29	19
Positive margins, %	15	Not reported
Adjuvant treatment, %	50	46.7
Complications, %	11	9
CSF leak	3	4
Mean follow up, months	37	34
Disease Specific Survival, %		
5 year	87	82
10 year	80	Not reported
Site of Recurrence, %		
Local	15	15
Regional	6	1
Distant	5	7

Esthesioneuroblastoma

Esthesioneuroblastoma is one of the most commonly reported diseases among the sinonasal malignancies. The gold standard treatment has traditionally been ACFR followed by postoperative radiation therapy. In a meta-analysis of 390 patients treated with open ACFR between 1990 and 2000, the 5-year DFS rate was 45 % [24]. MD Anderson Cancer Center recently reported on a cohort of 70 patients, most of whom who received definitive resection were treated with open surgery (42 of 50 patients) [25]. Their median OS was 126.3 months (10.5 years) and their median DSS was 139 months (11.6 years). Howard et al. [11] reported 5-, 10-, and 15-year DFS rates of 74, 50, and 40 %, respectively, for 56 patients treated at a single institution from 1978 to 2004. The University of Virginia Health System published its experience of 50 patients from 1976 to 2004. Its 5-, 15-, and 20-year DFS rates are 86.5, 82.6, and 81.2 %, respectively [14, 26].

Since the advent of endoscopic endonasal surgery, several small series have reported 3- to 5-year DFS rates of between 89 and 100 % [23•, 27–30]. In a meta-analysis of 23 articles with 361 patients comparing endoscopic with open surgery, endoscopic surgery was associated with better survival (10-year OS rate of 90 % versus 65 % for open resection) [31]. However, most of the open surgery patients had Kadish C or D disease and there were more cases of long-term follow-up for the open surgery group. Hence, the current literature supports the use of endoscopic surgery for early-stage esthesioneuroblastoma.

Squamous Cell Carcinoma

Open surgical resection of squamous cell carcinoma (SCC) has a 5-year OS rate of 43–64 % [10, 18, 32–34]. Published studies on endoscopic resection of SCC consist of small series of between 11 and 25 patients, the largest of which reported a 5-year DSS rate of 61 % [15, 23•, 35]. The University of Pittsburgh Medical Center recently presented its experience of 34 patients treated with endoscopic surgery [22]. The cohort consisted of a majority (85 %) of stage T3–4 tumors. Seventy-four percent of patients were treated with the purely endoscopic endonasal approach (EEA) and 26 % were treated with combined transcranial/transfacial and endoscopic endonasal approaches. Twenty-seven patients had definitive resection and seven had debulking surgery. The definitive resection group had 5-year DFS and OS rates of 62 and 78 %, respectively. The positive margin rate was 19 % in the definitive resection group. Survival was comparable with that for open surgery.

Adenocarcinoma

Open ACFR with postoperative radiation therapy is associated with 3- and 5-year OS rates of 72 and 64 %, respectively [36]. In a series of 66 patients treated at MD Anderson Cancer Center from 1993 to 2009, the 5-year OS and DSS rates were 65.9 and 79.1 %, respectively [20]. Most patients were treated with surgery, and 50 % received adjuvant radiation therapy. Twenty-six percent of patients underwent endoscopic resection and 74 % underwent ACFR. For patients undergoing endoscopic resection, 57 % were staged as having T1–2 disease and 43 % were staged as having T3–4 disease. Ninety-one percent of surgical margins were negative. There was no difference in survival between endoscopic and open approaches across all T classifications. The authors of the study concluded that open procedures did not significantly improve survival compared with endoscopic surgical resections when outcomes were matched for T staging.

Nicolai et al. [37] reported on 76 patients treated from 1985 to 2009. There were 12 endoscopic resections, 17 endoscopic resections with transnasal craniectomy, nine cranioendoscopic resections, 11 external approaches to the ethmoid, and 18 ACFRs. The 3- and 5-year OS rates were 68.0 and 48.4 %, respectively. The 3-year OS rates were 92.88 % and an astonishing 33.33 % in patients treated with endoscopic techniques and ACFR, respectively. On multivariate analysis, previous treatment (hazard ratio 3.9, $P=0.01$) and ACFR (hazard ratio 5.16, $P=0.05$) were associated with poorer survival. While acknowledging the inherent bias of the endoscopic technique towards smaller lesions and a later treatment period, Nicolai et al. concluded that the endoscopic technique, in appropriately selected patients, was associated with favorable oncological outcomes and a reduction in the complication rate and hospitalization time.

Morbidity and Complications

Endoscopic surgery avoids craniofacial soft tissue dissection, skeletal disassembly, and brain retraction. Multiple studies have shown endoscopic surgery to be associated with lower morbidity, faster hospital recovery, and decreased hospital stay [21•, 23•, 27, 38, 39]. The two largest endoscopic series of recent years report an overall complication rate of 9–11 % and a mortality rate of 0–1 % [21•, 23•], compared with an overall complication rate of 36.3 % and mortality rate of 4.5 % for open ACFR [18]. The commonest complication was CSF leak (3-4 %), followed by a small percentage of infectious, CNS, and systemic complications. Both studies confirm that the complication rates and length of hospital stay (3.7 days versus 15.4 days) were higher in the CEA group than in the EEA group. The complication rates increased with T4 lesions and larger tumors and if an endoscopic craniectomy was added [39],

CSF Leak and Reconstructive Options

Early reconstructive experience at the University of Pittsburgh Medical Center was associated with CSF leak rates of 20-30 % for endoscopic anterior cranial base defects [40, 41]. The application of a nasoseptal flap placed extradurally has lowered leak rates to 5 % [42]. When there is tumor involvement of the superior nasal septum, the "extended nasoseptal flap" can be harvested from the lower septum and extended onto the floor and lateral wall of the nasal cavity [43]. Other vascularized reconstructive alternatives for the anterior skull base include the minimally invasive pericranial flap [44], the middle turbinate flap for small defects, and the transpterygoid temporoparietal fascia flap [45, 46]. The inferior turbinate flap, although robust, has limited reach and is best suited to clival defects [47]. Other flaps described in the literature such as the palatal flap [48], the buccinator myomucosal flap [49], and the occipital galeopericranial flap [50] may be considered.

Some investigators have used nonvascularized reconstructive options with favorable results. Gil et al. [51] described a double-layered tensor fascia lata repair with a CSF leak rate of 0.8 %. Histological examination of resected fascia lata in patients who underwent a second operation showed evidence of neovascularization of the fibrous tissue, even without the presence of a vascularized flap. Villaret et al. [52] proposed a three-layer reconstruction with the iliotibial tract. They reported postoperative CSF leak rates of around 4 % [23•, 52].

Vascular Injury

Internal carotid artery (ICA) injury during endoscopic resection of sinonasal malignancy is rare. However, with the ever-expanding indications for endoscopic surgery and the evolution of surgical techniques, resection of tumors near the carotid artery is becoming increasingly common. Gardner et al. [53] described their experience of seven ICA injuries in 2,015 endoscopic endonasal skull base cases over a 13-year period. The mortality rate was 17 % and the average blood loss was 1,600 mL (range 400–4,200 mL). There was one case of ICA injury in 256 sinonasal malignancies. This occurred during resection of a nasopharyngeal carcinoma after prior treatment, resulting in laceration of the ICA at the foramen lacerum. Gardner et al. concluded that the best strategy for managing ICA injury is prevention, "2 surgeon, 3- or 4-hand technique," anatomical knowledge, preemptive vascular control via a neck incision, careful preoperative assessment of imaging, and planning. Once ICA has occurred, they advocate early endovascular assessment with angiography. They identified neurophysiological monitoring to be a reliable predictor of cerebral hypoperfusion and this can guide the decision to perform intraoperative ICA sacrifice.

Valentine and Wormald [54] developed a sheep model to recreate and train surgeons in the management of ICA injury. A number of hemostatic techniques were tested, including muscle patch treatment (harvested sternocleidomastoid), Floseal (Baxter International, Deerfield, IL, USA), oxidized regenerated cellulose (Surgicel Nu-Knit, Ethicon, West Somerville, NJ, USA), MicroFrance Wormald vascular clamps (Medtronic, Jacksonville, FL, USA), and U-Clip anastomotic sutures (Medtronic) to suture the vascular defect. Muscle patch treatment was effective at achieving vascular control within 10 min, as was use of the MicroFrance Wormald vascular clamp and U-Clips. Other stratagems include active two-surgeon teamwork, the use of two large-bore suctions to direct blood flow away from the endoscope, strategic placement of the endoscope on the contralateral side with respect to the vascular injury to avoid excess soiling, and use of an endoscope lens-cleaning system.

Quality of Life

The only instrument validated for patients undergoing anterior skull base surgery is the anterior skull base quality-of-life questionnaire [55]. Although specific to patients undergoing extirpation of anterior skull base tumors, it was developed for open surgery [56]. It is a comprehensive multidimensional questionnaire comprising subscale scores for performance, physical function, vitality, pain, specific symptoms (taste, smell, appearance, epiphora, nasal secretions, and visual disturbance), and influence on emotions and a total score. A higher score indicates a better outcome, with a minimum of 1.0 and a maximum of 5.0.

The current available literature supports endoscopic resection having favorable long-term quality-of-life outcomes. Castelnuovo et al. [57] reported on a retrospective series of 153 patients treated with the endoscopic approach for sinonasal malignancies using the anterior skull base quality-of-life questionnaire. They found that quality-of-life scores sharply decreased 1 month after surgery from 4.68 to 4.03. However, the scores recovered to 4.59 over the course of 1 year after treatment. Patients older than 60 years, those who had had postoperative radiation therapy, and those for whom an expanded surgical approach with transnasal craniectomy had been undertaken had lower scores. In a meta-analysis of 273 patients undergoing skull base tumor resection, malignancy and less than 6 months from surgery are associated with worse quality-of-life scores [58]. Patients undergoing endoscopic surgery scored better with regard to physical function and impact on emotions than patients in the open surgery group [58, 59].

Technical Developments

Since the introduction of endoscopic endonasal surgery, specialized operating suites, intraoperative navigational devices, endonasal instrumentation, and Doppler sonography for identifying major vessels have become widely used by skull base surgeons [60]. In the past few years, some centers have introduced the use of microdebriders for fibrous lesions and ultrasonic dissectors as an alternative to the high-speed drill for bone removal [61–64]. Even as high-definition endoscopes have become the norm, depth perception, afforded by the microscope, is lost. The 3D endoscope is a possible alternative but is limited by problems with peripheral image distortions during narrow space exploration, reduced level of sharpness and contrast compared with high-definition 2D endoscopes, and the inability to visualize around corners [65–67].

A localized intraoperative virtual endoscopy image guidance system combines real-time instrument tracking with 3D virtual endoscopic views, intraoperative image updates, and critical structure proximity alerts [68]. Compared with standard image guidance systems, it was found to reduce scores for mental demand, effort, and frustration in cadaveric studies. Localized intraoperative virtual endoscopy image guidance systems may have a role in technically challenging cases where there are compromised visual landmarks and critical structures are nearby. The system is ready for a clinical trial but one major drawback is the addition of visual and auditory stimuli, which can be unnecessarily distracting.

Robotic surgery is used extensively in head and neck transoral surgery. It offers 3D depth perception, excellent visualization, and 360° rotational arms allowing small, precise, tremor-free movements in enclosed spaces. Several early studies have explored the feasibility of robotic-assisted skull base surgery [69–71]. The main constraint appears to be crowding of instruments in a confined space, but various solutions have been proposed. Hanna et al. [72] reported a robotic transantral approach to the anterior skull base by introducing instruments through large bilateral antrostomies combined with a transnasal camera. O'Malley and Weinstein [70] used a combined cervical and transoral robotic approach to dissect the median skull base, sella, and parasellar and suprasellar regions of the anterior skull base. Ozer et al. [73] compared transoral, transcervical, transnasal, and transpalatal corridors using cadaveric specimens to assess the optimal route of the camera and instrument placement without using transcervical trocars. They found that a transoral camera provided good instrumentation but visualization over the roof of the nasopharynx and posterior choana was poor. A transnasal camera provided excellent visualization but poor instrumentation. The transpalatal approach was the best compromise but necessitated removal of the posterior aspects of the hard palate.

Dealing with intraoperative bleeding is an important consideration. Preoperative strategies include evaluation for bleeding disorders, appropriate reduction of antiplatelet and anticoagulants medications, and judicious use of preoperative embolization for vascular tumors [74•]. Intraoperative measures include control of hypertension, patient positioning in the reverse Trendelenburg position, and use of topical vasoconstrictors and hemostatic agents. Hot water irrigation was originally described for the treatment of epistaxis [75] and is now used routinely in some centers to decrease ooze from sinonasal mucosa. The development of endoscopic bipolar cautery and intranasal CO_2 laser technology [76], and the adaptation of coblators for intranasal use can potentially reduce intraoperative blood loss during resection of highly vascular tumors [77, 78].

Areas for Further Research

We have increasing evidence of the oncological soundness and safety of endoscopic resection for appropriately selected patients. This evidence provides us with a critical understanding of the types of lesions amenable to endoscopic resection. Nevertheless, there are no published studies of followup beyond 10 years and there is a paucity of pathology-specific survival data. The challenge is to define the role of endoscopic surgery within a multidisciplinary oncological strategy that includes rapidly evolving modalities such as proton beam radiation therapy, neoadjuvant chemotherapy, and targeted therapy. Although endoscopic surgery offers better functional and quality-of-life outcomes than open surgery, prospective studies that evaluate and propose solutions to address the impact of the overall treatment strategy, including the effects of adjuvant treatments, are required. Technical limitations in endoscopic skull base surgery include the inability to suture, difficulty accessing around corners, and control of large vessels. The future decade will bring advances in technology that will require thoughtful integration with current practice, balancing innovation, efficacy, and value.

Conclusion

Advances in technique and instrumentation have allowed safe and effective endoscopic resection of tumors in the sinonasal cavity and skull base. Endoscopic surgery offers an oncologically sound alternative to open surgery in selected patients with sinonasal malignancies. It offers the advantages of lower morbidity, faster recovery, and better quality-of-life outcomes. Pathology-specific and long-term follow-up survival data are required to further define the role of endoscopic surgery in the setting of multidisciplinary care.

Compliance with Ethics Guidelines

Conflict of Interest Shirley Y. Su, Michael E. Kupferman, Franco DeMonte, Nicholas B. Levine, Shaan M. Raza, and Ehab Y. Hanna declare that they have no conflict of interest

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:

- Of importance

1. Le QT, Fu KK, Kaplan M, Terris DJ, Fee WE, Goffinet DR. Treatment of maxillary sinus carcinoma: a comparison of the 1997 and 1977 American joint committee on cancer staging systems. Cancer. 1999;86:1700–11.
2. Tiwari R, Hardillo JA, Mehta D, Slotman B, Tobi H, Croonenburg E, et al. Squamous cell carcinoma of maxillary sinus. Head Neck. 2000;22:164–9.
3. Ketcham AS, Wilkins RH, Vanburen JM, Smith RR. A combined intracranial facial approach to the paranasal sinuses. Am J Surg. 1963;106:698–703.
4. 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:E3.
5. Jho HD, Ha HG. Endoscopic endonasal skull base surgery: part 1—the midline anterior fossa skull base. Minim Invasive Neurosurg. 2004;47:1–8.
6. Van Rompaey J, Suruliraj A, Carrau R, Panizza B, Solares CA. Meckel's cave access: anatomic study comparing the endoscopic transantral and endonasal approaches. Eur Arch Otorhinolaryngol. 2013. doi:10.1007/s00405-013-2581-2.
7. de Almeida JR, Zanation AM, Snyderman CH, Carrau RL, Prevedello DM, Gardner PA, et al. Defining the nasopalatine line: the limit for endonasal surgery of the spine. Laryngoscope. 2009;119:239–44.
8. Hosseini SM, Razfar A, Carrau RL, Prevedello DM, Fernandez-Miranda J, Zanation A, et al. Endonasal transpterygoid approach to the infratemporal fossa: correlation of endoscopic and multiplanar CT anatomy. Head Neck. 2012;34:313–20.
9. Rivera-Serrano CM, Terre-Falcon R, Fernandez-Miranda J, Prevedello D, Snyderman CH, Gardner P, et al. Endoscopic endonasal dissection of the pterygopalatine fossa, infratemporal fossa, and post-styloid compartment. Anatomical relationships and importance of eustachian tube in the endoscopic skull base surgery. Laryngoscope. 2010;120 Suppl 4:S244.
10. Patel SG, Singh B, Polluri A, Bridger PG, Cantu G, Cheesman AD, et al. Craniofacial surgery for malignant skull base tumors: report of an international collaborative study. Cancer. 2003;98:1179–87.
11. Howard DJ, Lund VJ, Wei WI. Craniofacial resection for tumors of the nasal cavity and paranasal sinuses: a 25-year experience. Head Neck. 2006;28:867–73.
12. Gil Z, Fliss DM, Cavel O, Shah JP, Kraus DH. Improvement in survival during the past 4 decades among patients with anterior skull base cancer. Head Neck. 2012;34:1212–7.
13. Snyderman CH, Kassam AB. Endoscopic techniques for pathology of the anterior cranial fossa and ventral skull base. J Am Coll Surg. 2006;202:563.
14. Levine PA. Would Dr. Ogura approve of endoscopic resection of esthesioneuroblastomas? An analysis of endoscopic resection data versus that of craniofacial resection. Laryngoscope. 2009;119:3–7.
15. Lund VJ, Stammberger H, Nicolai P, Castelnuovo P, Beal T, Beham A, et al. European position paper on endoscopic management of tumours of the nose, paranasal sinuses and skull base. Rhinol Suppl. 2010:1-143.
16. Wellman BJ, Traynelis VC, McCulloch TM, Funk GF, Menezes AH, Hoffman HT. Midline anterior craniofacial approach for malignancy: results of en bloc versus piecemeal resections. Skull Base Surg. 1999;9:41–6.
17. Feiz-Erfan I, Suki D, Hanna E, DeMonte F. Prognostic significance of transdural invasion of cranial base malignancies in patients undergoing craniofacial resection. Neurosurgery. 2007;61:1178–85. discussion 1185.
18. Ganly I, Patel SG, Singh B, Kraus DH, Bridger PG, Cantu G, et al. Complications of craniofacial resection for malignant tumors of the skull base: report of an international collaborative study. Head Neck. 2005;27:445–51.
19. Suarez C, Llorente JL, Fernandez De Leon R, Maseda E, Lopez A. Prognostic factors in sinonasal tumors involving the anterior skull base. Head Neck. 2004;26:136–44.

20. Bhayani MK, Yilmaz TA, Sweeney A, Calzada G, Roberts DB, Levine NB, et al. Sinonasal adenocarcinoma: a 16-year experience at a single institution. Head Neck. 2013. doi:10.1002/hed.23485.
21.• Hanna E, DeMonte F, Ibrahim S, Roberts D, Levine N, Kupferman M. Endoscopic resection of sinonasal cancers with and without craniotomy: oncologic results. Arch Otolaryngol Head Neck Surg. 2009;135:1219–24. *This article reports on one of the two largest cohorts studies with regard to oncological outcomes for endoscopic resection of sinonasal malignancies*.
22. De Almeida JR, Su S, Koutourousiou M, Vaz Guimaraes Filho F, Fernandez Miranda J, Gardner P, et al. Endoscopic endonasal surgery for squamous cell carcinoma of the sinonasal cavity and skull base. J Neurol Surg Part B. 2013;74.
23.• Nicolai P, Battaglia P, Bignami M, Bolzoni Villaret A, Delu G, Khrais T, et al. Endoscopic surgery for malignant tumors of the sinonasal tract and adjacent skull base: a 10-year experience. Am J Rhinol. 2008;22:308–16. *This article reports on one of the two largest cohorts studied with regard to oncological outcomes for endoscopic resection of sinonasal malignancies*.
24. Dulguerov P, Allal AS, Calcaterra TC. Esthesioneuroblastoma: a meta-analysis and review. Lancet Oncol. 2001;2:683–90.
25. Ow TJ, Hanna EY, Roberts DB, Levine NB, El-Naggar AK, Rosenthal DI, et al. Optimization of long-term outcomes for patients with esthesioneuroblastoma. Head Neck. 2013. doi:10.1002/hed.23327.
26. Loy AH, Reibel JF, Read PW, Thomas CY, Newman SA, Jane JA, et al. Esthesioneuroblastoma: continued follow-up of a single institution's experience. Arch Otolaryngol Head Neck Surg. 2006;132:134–8.
27. Castelnuovo PG, Delu G, Sberze F, Pistochini A, Cambria C, Battaglia P, et al. Esthesioneuroblastoma: endonasal endoscopic treatment. Skull Base. 2006;16:25–30.
28. Folbe A, Herzallah I, Duvvuri U, Bublik M, Sargi Z, Snyderman CH, et al. Endoscopic endonasal resection of esthesioneuroblastoma: a multicenter study. Am J Rhinol Allergy. 2009;23:91–4.
29. Lund V, Howard DJ, Wei WI. Endoscopic resection of malignant tumors of the nose and sinuses. Am J Rhinol. 2007;21:89–94.
30. Unger F, Haselsberger K, Walch C, Stammberger H, Papaefthymiou G. Combined endoscopic surgery and radiosurgery as treatment modality for olfactory neuroblastoma (esthesioneuroblastoma). Acta Neurochir. 2005;147:595–601. discussion 601–2.
31. Devaiah AK, Andreoli MT. Treatment of esthesioneuroblastoma: a 16-year meta-analysis of 361 patients. Laryngoscope. 2009;119:1412–6.
32. Kermer C, Poeschl PW, Wutzl A, Schopper C, Klug C, Poeschl E. Surgical treatment of squamous cell carcinoma of the maxilla and nasal sinuses. J Oral Maxillofac Surg. 2008;66:2449–53.
33. Lee CH, Hur DG, Roh HJ, Rha KS, Jin HR, Rhee CS, et al. Survival rates of sinonasal squamous cell carcinoma with the new AJCC staging system. Arch Otolaryngol Head Neck Surg. 2007;133:131–4.
34. Mine S, Saeki N, Horiguchi K, Hanazawa T, Okamoto Y. Craniofacial resection for sinonasal malignant tumors: statistical analysis of surgical outcome over 17 years at a single institution. Skull Base. 2011;21:243–8.
35. Shipchandler TZ, Batra PS, Citardi MJ, Bolger WE, Lanza DC. Outcomes for endoscopic resection of sinonasal squamous cell carcinoma. Laryngoscope. 2005;115:1983–7.
36. Choussy O, Ferron C, Vedrine PO, Toussaint B, Lietin B, Marandas P, et al. Adenocarcinoma of ethmoid: a GETTEC retrospective multicenter study of 418 cases. Laryngoscope. 2008;118:437–43.
37. Nicolai P, Villaret AB, Bottazzoli M, Rossi E, Valsecchi MG. Ethmoid adenocarcinoma–from craniofacial to endoscopic resections: a single-institution experience over 25 years. Otolaryngol Head Neck Surg. 2011;145:330–7.
38. Eloy JA, Vivero RJ, Hoang K, Civantos FJ, Weed DT, Morcos JJ, et al. Comparison of transnasal endoscopic and open craniofacial resection for malignant tumors of the anterior skull base. Laryngoscope. 2009;119:834–40.
39. Nicolai P, Castelnuovo P, Bolzoni Villaret A. Endoscopic resection of sinonasal malignancies. Curr Oncol Rep. 2011;13:138–44.
40. Snyderman CH, Kassam AB, Carrau R, Mintz A. Endoscopic reconstruction of cranial base defects following endonasal skull base surgery. Skull Base. 2007;17:73–8.
41. Kassam A, Carrau RL, Snyderman CH, Gardner P, Mintz A. Evolution of reconstructive techniques following endoscopic expanded endonasal approaches. Neurosurg Focus. 2005;19:E8.
42. Kassam AB, Thomas A, Carrau RL, Snyderman CH, Vescan A, Prevedello D, et al. Endoscopic reconstruction of the cranial base using a pedicled nasoseptal flap. Neurosurgery. 2008;63:ONS44–52. discussion ONS52–3.
43. Pinheiro-Neto CD, Paluzzi A, Fernandez-Miranda JC, Scopel TF, Wang EW, Gardner PA, et al. Extended dissection of the septal flap pedicle for ipsilateral endoscopic transpterygoid approaches. Laryngoscope. 2013. doi:10.1002/lary.24256.
44. Zanation AM, Snyderman CH, Carrau RL, Kassam AB, Gardner PA, Prevedello DM. Minimally invasive endoscopic pericranial flap: a new method for endonasal skull base reconstruction. Laryngoscope. 2009;119:13–8.
45. Fortes FS, Carrau RL, Snyderman CH, Kassam A, Prevedello D, Vescan A, et al. Transpterygoid transposition of a temporoparietal fascia flap: a new method for skull base reconstruction after endoscopic expanded endonasal approaches. Laryngoscope. 2007;117:970–6.
46. Bolzoni Villaret A, Nicolai P, Schreiber A, Bizzoni A, Farina D, Tschabitscher M. The temporo-parietal fascial flap in extended transnasal endoscopic procedures: cadaver dissection and personal clinical experience. Eur Arch Otorhinolaryngol. 2013;270:1473–9.
47. Fortes FS, Carrau RL, Snyderman CH, Prevedello D, Vescan A, Mintz A, et al. The posterior pedicle inferior turbinate flap: a new vascularized flap for skull base reconstruction. Laryngoscope. 2007;117:1329–32.
48. Oliver CL, Hackman TG, Carrau RL, Snyderman CH, Kassam AB, Prevedello DM, et al. Palatal flap modifications allow pedicled reconstruction of the skull base. Laryngoscope. 2008;118:2102–6.
49. Rivera-Serrano CM, Oliver CL, Sok J, Prevedello DM, Gardner P, Snyderman CH, et al. Pedicled facial buccinator (FAB) flap: a new flap for reconstruction of skull base defects. Laryngoscope. 2010;120:1922–30.
50. Rivera-Serrano CM, Snyderman CH, Carrau RL, Durmaz A, Gardner PA. Transparapharyngeal and transpterygoid transposition of a pedicled occipital galeopericranial flap: a new flap for skull base reconstruction. Laryngoscope. 2011;121:914–22.
51. Gil Z, Abergel A, Leider-Trejo L, Khafif A, Margalit N, Amir A, et al. A comprehensive algorithm for anterior skull base reconstruction after oncological resections. Skull Base. 2007;17:25–37.
52. Villaret AB, Yakirevitch A, Bizzoni A, Bosio R, Bignami M, Pistochini A, et al. Endoscopic transnasal craniectomy in the management of selected sinonasal malignancies. Am J Rhinol Allergy. 2010;24:60–5.
53. Gardner PA, Tormenti MJ, Pant H, Fernandez-Miranda JC, Snyderman CH, Horowitz MB. Carotid artery injury during endoscopic endonasal skull base surgery: incidence and outcomes. Neurosurgery. 2013. doi:10.1227/01.neu.0000430821.71267.f2.
54. Valentine R, Wormald PJ. Controlling the surgical field during a large endoscopic vascular injury. Laryngoscope. 2011;121:562–6.
55. de Almeida JR, Witterick IJ, Gullane PJ, Gentili F, Lohfeld L, Ringash J, et al. Quality of life instruments for skull base pathology: systematic review and methodologic appraisal. Head Neck. 2013;35:1221–31.

56. Gil Z, Abergel A, Spektor S, Shabtai E, Khafif A, Fliss DM. Development of a cancer-specific anterior skull base quality-of-life questionnaire. J Neurosurg. 2004;100:813–9.
57. Castelnuovo P, Lepera D, Turri-Zanoni M, Battaglia P, Bolzoni Villaret A, Bignami M, et al. Quality of life following endoscopic endonasal resection of anterior skull base cancers. J Neurosurg. 2013. doi: 10.3171/2013.8.JNS13296.
58. Amit M, Abergel A, Fliss DM, Gil Z. The clinical importance of quality-of-life scores in patients with skull base tumors: a meta-analysis and review of the literature. Curr Oncol Rep. 2012;14:175–81.
59. Abergel A, Cavel O, Margalit N, Fliss DM, Gil Z. Comparison of quality of life after transnasal endoscopic vs open skull base tumor resection. Arch Otolaryngol Head Neck Surg. 2012;138:142–7.
60. 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;18:107–13.
61. Cappabianca P, Cavallo LM, Esposito I, Barakat M, Esposito F. Bone removal with a new ultrasonic bone curette during endoscopic endonasal approach to the sellar-suprasellar area: technical note. Neurosurgery. 2010;66:E118; discussion E118.
62. McLaughlin N, Ditzel Filho LF, Prevedello DM, Kelly DF, Carrau RL, Kassam AB. Side-cutting aspiration device for endoscopic and microscopic tumor removal. J Neurol Surg Part B. 2012;73:11–20.
63. Lubbe DE, Fisher-Jeffes N, Semple P. Endoscopic resection of skull base tumours utilising the ultrasonic dissector. J Laryngol Otol. 2012;126:625–9.
64. Patel SK, Husain Q, Kuperan AB, Eloy JA, Liu JK. Utility of a rotation-suction microdebrider for tumor removal in endoscopic endonasal skull base surgery. J Clin Neurosci. 2013. doi:10.1016/j.jocn.2013.02.031.
65. Castelnuovo P, Battaglia P, Bignami M, Ferreli F, Turri-Zanoni M, Bernardini E, et al. Endoscopic transnasal resection of anterior skull base malignancy with a novel 3D endoscope and neuronavigation. Acta Otorhinolaryngol Ital. 2012;32:189–91.
66. Villaret AB, Battaglia P, Tschabitscher M, Mattavelli D, Turri-Zanoni M, Castelnuovo P, et al. A three-dimensional transnasal endoscopic journey through the paranasal sinuses and adjacent skull base: a practical and surgery-oriented perspective. Neurosurgery. 2013. doi:10.1227/NEU.0000000000000172.
67. Wasserzug O, Margalit N, Weizman N, Fliss DM, Gil Z. Utility of a three-dimensional endoscopic system in skull base surgery. Skull Base. 2010;20:223–8.
68. Dixon BJ, Daly MJ, Chan H, Vescan A, Witterick IJ, Irish JC. Augmented real-time navigation with critical structure proximity alerts for endoscopic skull base surgery. Laryngoscope. 2013. doi: 10.1002/lary.24385.
69. O'Malley Jr BW, Weinstein GS. Robotic skull base surgery: preclinical investigations to human clinical application. Arch Otolaryngol Head Neck Surg. 2007;133:1215–9.
70. O'Malley Jr BW, Weinstein GS. Robotic anterior and midline skull base surgery: preclinical investigations. Int J Radiat Oncol Biol Phys. 2007;69:S125–8.
71. Ozer E, Waltonen J. Transoral robotic nasopharyngectomy: a novel approach for nasopharyngeal lesions. Laryngoscope. 2008;118: 1613–6.
72. Hanna EY, Holsinger C, DeMonte F, Kupferman M. Robotic endoscopic surgery of the skull base: a novel surgical approach. Arch Otolaryngol Head Neck Surg. 2007;133:1209–14.
73. Ozer E, Durmus K, Carrau RL, de Lara D, Ditzel Filho LF, Prevedello DM, et al. Applications of transoral, transcervical, transnasal, and transpalatal corridors for robotic surgery of the skull base. Laryngoscope. 2013;123:2176–9.
74.• Thongrong C, Kasemsiri P, Carrau RL, Bergese SD. Control of bleeding in endoscopic skull base surgery: current concepts to improve hemostasis. ISRN Surg. 2013;2013:191543. *This is a comprehensive summary of hemostatic strategies in endoscopic endonasal skull base surgery*.
75. Stangerup SE, Dommerby H, Lau T. Hot-water irrigation as a treatment of posterior epistaxis. Rhinology. 1996;34:18–20.
76. Agarwal G, Kupferman ME, Holsinger FC, Hanna EY. Sinonasal and nasopharyngeal applications of the hand-held CO2 laser fiber. Int Forum Allergy Rhinol. 2011;1:109–12.
77. Ye L, Zhou X, Li J, Jin J. Coblation-assisted endonasal endoscopic resection of juvenile nasopharyngeal angiofibroma. J Laryngol Otol. 2011;125:940–4.
78. Ruiz JW, Saint-Victor S, Tessema B, Eloy JA, Anstead A. Coblation assisted endoscopic juvenile nasopharyngeal angiofibroma resection. Int J Pediatr Otorhinolaryngol. 2012;76: 439–42.