

# Immediate and Delayed Complications Following Endoscopic Skull Base Surgery

Matthew R. Naunheim<sup>1,2</sup> Ahmad R. Sedaghat<sup>1,2</sup> Derrick T. Lin<sup>1,2</sup> Benjamin S. Bleier<sup>1,2</sup>  
Eric H. Holbrook<sup>1,2</sup> William T. Curry<sup>3,\*</sup> Stacey T. Gray<sup>1,2,\*</sup>

<sup>1</sup>Department of Otolaryngology - Head and Neck Surgery, Massachusetts Eye and Ear Infirmary, Boston, Massachusetts, United States

<sup>2</sup>Department of Otology and Laryngology, Harvard Medical School, Boston, Massachusetts, United States

<sup>3</sup>Department of Neurosurgery, Massachusetts General Hospital, Boston, Massachusetts, United States

Address for correspondence Stacey T. Gray, MD, Department of Otolaryngology, Massachusetts Eye and Ear Infirmary, 243 Charles Street, Boston, MA 02114, United States  
(e-mail: stacey\_gray@meei.harvard.edu).

J Neurol Surg B 2015;76:390–396.

## Abstract

**Objectives** To characterize the temporal distribution and resolution rate of postoperative complications from endoscopic skull base surgery.

**Design** Retrospective review of patients undergoing endoscopic resection of paranasal sinus or skull base neoplasm from 2007 to 2013.

**Setting** Massachusetts General Hospital/Massachusetts Eye and Ear Infirmary Cranial Base Center.

**Participants** Fifty-eight consecutive patients.

**Main Outcome Measures** Postoperative complications were categorized as cerebrospinal fluid (CSF) leak, pituitary, orbital, intracranial, or sinonasal. Complications were temporally categorized as “perioperative” (within 1 week), “early” (after 1 week and within 6 months), or “delayed” (after 6 months).

**Results** The most common perioperative complications were diabetes insipidus (19.0%), CSF leak (5.2%), and meningitis (5.2%), with resolution rates of 75%, 100%, and 100%, respectively. Overall, CSF leak occurred in 13.8% of patients and resolved in all cases. A total of 53.8% of all complications were evident within 1 week of surgery. Chronic rhinosinusitis was the most common delayed complication (3.4%). Hypopituitarism and delayed complications were less likely to resolve ( $p = 0.014$  and  $p = 0.080$ , respectively).

**Conclusions** Monitoring of complications after endoscopic skull base surgery should focus on neurologic complications and CSF leak in the early postoperative period and development of chronic rhinosinusitis in the long term. Late-onset complications and hypopituitarism are less likely to resolve.

## Keywords

- ▶ complications
- ▶ skull base surgery
- ▶ cerebrospinal fluid leak
- ▶ hypopituitarism
- ▶ diabetes insipidus

## Introduction

In the past decade, endoscopic endonasal approaches for the surgical management of skull base pathology have become

\* These authors contributed equally to the research and the preparation of the manuscript.

increasingly common. Initially, endoscopic techniques were applied solely to the surgical treatment of benign sinonasal inflammatory disorders, but as the understanding of endoscopic surgical anatomy improved so did the applications for endoscopic endonasal techniques. Endoscopic approaches have subsequently been applied to increasingly more complex disorders involving the skull base. Initially this technique was applied to benign processes, such as encephaloceles and pituitary neoplasms. However, recent evidence suggests that appropriately selected intracranial neoplasms as well as sinonasal malignancies can also be addressed with endoscopic approaches.<sup>1,2</sup> Endoscopic techniques offer several potential advantages to traditional open approaches including improved visualization of structures deep within the sinonasal cavity, the clivus, or the parasellar region. Endoscopic endonasal skull base surgery obviates the need to retract the frontal and/or temporal lobes of the brain to reach deep intracranial locations.<sup>3,4</sup> Recent studies also suggest that overall morbidity may also be reduced<sup>5-7</sup> and hospital stays may be shorter<sup>7,8</sup> with endoscopic approaches.

The trend of utilizing endoscopic endonasal approaches to the skull base mirrors similar trends toward less invasive procedures across other surgical subspecialties.<sup>9,10</sup> Endoscopic skull base approaches also leverage the skill sets of multiple surgical specialties, and such surgical collaboration has also led to increasingly sophisticated procedures and cross-pollination between disciplines.<sup>11</sup>

As the development and evolution of endoscopic endonasal approaches to the skull base have been reported over the last decade, the associated complications have also been described. Complications of endoscopic skull base surgery most commonly reported include cerebrospinal fluid (CSF) leak, visual changes, and meningitis,<sup>8,12-14</sup> although series that focus on pituitary surgery also report high rates of electrolyte and hormone disturbances caused by pituitary dysregulation.<sup>15,16</sup> Most published reports of postoperative complications have focused primarily on immediate postoperative complications with a limited description of the temporality with which complications occur as well as the development of delayed complications.<sup>2,6,13,17</sup> We have reported that complications related to the treatment of sinonasal neoplasms, although rare, may manifest at a significant interval after skull base surgery itself.<sup>18</sup> Knowledge of the temporal distribution for postoperative complications of endoscopic endonasal techniques to address skull base pathology is not only important for counseling patients but also for planning appropriate postoperative follow-up and monitoring by the surgeon. We describe the temporal distribution of postoperative complications of endoscopic endonasal approaches for skull base neoplasms.

## Methods

### Study Subjects

Approval of this study was obtained through the Massachusetts Eye and Ear Infirmary institutional review board. Surgical records from six skull base surgeons (four otolaryngologists and two neurosurgeons) were interrogated for all

cases of endoscopic endonasal surgery performed for the indication of a skull base neoplasm from May 2007 through May 2013. Cases that used transfacial or combined endoscopic/open approaches to the skull base were excluded. Demographic information, medical history, comorbidities, and procedural data were collected from the hospital's electronic and paper medical records. Each patient record was manually reviewed for complications. Postoperative complications were broadly categorized as pituitary, orbital, intracranial, sinonasal, and CSF leak, and they were subdivided into specific diagnostic categories. Timing of complications was categorized as "perioperative" if occurring within 1 week of surgery, "early" if occurring between 1 week and 6 months, and "delayed" if > 6 months after surgery. The onset and resolution of each complication was defined by written documentation in clinician progress notes. Conditions for which there was preoperative documentation of symptoms were not considered complications of surgery.

### Analysis

Data were analyzed with Microsoft Excel and the statistical software R ([www.r-project.org](http://www.r-project.org)). Standard descriptive statistics are reported. Univariate associations were performed between predictor variables and resolution of complications using the Regression Modeling Strategies package of R.

## Results

Fifty-eight cases were included over the 6-year period from 2007 to 2013. Most of the cases were performed in the latter half of this time period, with 50 cases from May 2010 through May 2013. The mean age of the cohort was 54.3 years (range: 16-86 years). There were approximately even numbers of men and women (30 women and 28 men). Average time of follow-up was 1.4 years (range: 0.1-9.4 years).

► **Table 1** lists the pathologies of this cohort. The most common tumor pathology was pituitary adenoma (34.5%), followed by craniopharyngioma (19.0%), clival chordoma (13.8%), and meningioma (12.1%). Endoscopic approaches were categorized as transsellar (36.2%), transplanar (12.1%), transsellar/transplanar (20.7%), transclival (15.5%), transsellar/transclival (3.4%), transcribriform (8.6%), and infratemporal fossa resection (3.4%).

Skull base reconstruction was performed with a nasoseptal flap in 72.4% of cases and utilized a rigid underlay technique in 29.3%. Postoperative treatment consisted of adjuvant radiation therapy in 44.8% and adjuvant chemotherapy in 10.3% of patients. Notably, 6.9% of patients had undergone radiation preoperatively, either as a failed primary treatment or as neoadjuvant treatment before surgery. Lumbar drains were not routinely placed at the time of surgery, although they were occasionally utilized in the event of high-flow CSF leak encountered during surgery (8.6%). There were no documented deaths in the study period.

► **Table 2** shows the nonpituitary postoperative complications associated with the surgical cohort. In the immediate perioperative period (0-7 days), the most common complications were CSF leak (5.2%), meningitis (5.2%), and decreased

**Table 1** Pathologies and respective prevalences

Pathology	Number (%)
Sellar masses	34 (58.6)
Pituitary adenoma	20
Craniopharyngioma	11
Rathke cleft cyst	3
Clival chordoma	8 (13.8)
Meningioma	7 (12.1)
Location	
Sellar	4
Suprasellar	1
Parasellar	1
Olfactory groove/Cribriform plate	1
Sinonasal malignancy	7 (12.1)
Esthesioneuroblastoma	2
Sinonasal undifferentiated carcinoma	2
Osteosarcoma	1
Renal cell carcinoma	1
Adenocarcinoma	1
Other	2 (3.4)
Juvenile nasopharyngeal angiofibroma	1
Germinoma	1

vision (3.4%). All perioperative CSF leaks resolved within 1 week of diagnosis. Of the three patients with perioperative CSF leak, one patient required revision endoscopic repair; the other two CSF leaks resolved with the placement of a lumbar drain. All patients with perioperative diminished vision had recovery of visual loss, although the time frame for recovery was over several months. Meningitis occurred in three patients in the perioperative period that resolved with antibiotic treatment within 11 days of diagnosis.

Early complications (1 week to 6 months) were less frequent. Interestingly, five patients developed a CSF leak > 1 week after surgery. In this group, the CSF leak was transient and resolved spontaneously in one patient, required the placement of a lumbar drain in one patient, and required revision endoscopic skull base repair in two patients. Additionally, one patient ultimately required placement of a ventriculoperitoneal (VP) shunt for communicating hydrocephalus and intracranial hypertension; risk factors in this patient included morbid obesity, poorly controlled type 1 diabetes, and previous sellar irradiation. Intracranial complications did occur infrequently, with one patient developing a stroke, and one patient with small subacute subdural hematomas incidentally noted on imaging studies that resolved without intervention.

Delayed complications (> 6 months) were even less frequent. Chronic rhinosinusitis (CRS) was the most common delayed complication, occurring in 3.4% of all patients. One patient did develop meningitis > 6 months after surgery

**Table 2** Complications occurring after surgery excluding pituitary complications<sup>a</sup>

Complication	Perioperative		Early		Delayed	
	<i>n</i>	Resolution	<i>n</i>	Resolution	<i>n</i>	Resolution
Vision/Orbital complications						
Diplopia ( <i>n</i> = 48) <sup>b</sup>	1	100.0% (150 d)	–	–	–	–
Epiphora ( <i>n</i> = 57)	–	–	1	0% (–)	–	–
Decreased vision ( <i>n</i> = 27)	2	100.0% (114 d)	1	100.0% (15 d)	–	–
CSF leak ( <i>n</i> = 58)	3	100.0% (5 d)	5	100.0% (12 d)	–	–
Intracranial complications						
Infection ( <i>n</i> = 58)	3	100.0% (11 d)	–	–	1	100.0% (15 d)
Hemorrhage ( <i>n</i> = 58)	–	–	1	100% (26 d)	–	–
Stroke ( <i>n</i> = 58)	–	–	1	0% (–)	–	–
Chronic rhinosinusitis ( <i>n</i> = 58)	–	–	–	–	2	0% (–)

<sup>a</sup>Perioperative complications are defined as those occurring up to one week after surgery, early complications are defined as those occurring between one week and six months after surgery and delayed complications are defined as those occurring beyond six months after surgery.

<sup>b</sup>The *n* value listed after each complication reflects the number of patients who had not experienced this complication preoperatively.

that resolved with antibiotic treatment. No CSF leaks were noted in a delayed fashion.

Pituitary complications were considered separately in those patients undergoing surgery for pituitary adenoma, craniopharyngioma, and Rathke cleft cyst (►Table 3). Diabetes insipidus (DI) was the most common perioperative complication, with 100% resolution in the pituitary adenoma group and 75% resolution in the craniopharyngioma group. In the early and delayed periods, hypopituitarism was more common (five patients), and resolution was rare (one patient).

CSF leaks (seen in 13.8%) were more common in the early postoperative period than in any other time frame. Notably, all but one CSF leak occurred within the first 2 postoperative weeks. ►Table 4 details the eight patients who had CSF leaks. Of these cases, most CSF leaks resolved with placement of a lumbar drain, although three patients ultimately required revision endoscopic surgical repair, and one patient required placement of a VP shunt because of underlying intracranial hypertension. CSF leaks that developed after the first postoperative week were more likely to require operative intervention for control.

Resolution of complications was less likely if the complication was hypopituitarism ( $p = 0.014$ ; odds ratio [OR]: 0.06). Additionally, complications that developed after the perioperative period were less likely to resolve ( $p = 0.080$ ; OR: 0.09).

### Discussion

With advances in image guidance technology, surgical instrumentation, and skull base reconstructive techniques over the past decade, endoscopic endonasal skull base surgery has emerged as an alternative approach for the treatment of many skull base lesions.<sup>3,19,20</sup> As endoscopic endonasal ap-

proaches continue to gain popularity, reports have suggested that the complication rate is less than that seen with open approaches.<sup>2,3,7,13,21,22</sup> The overall complication rate for endoscopic endonasal skull base surgery is reported from 10 to 20%,<sup>2,4,6,7,17,21</sup> although there is significant heterogeneity in the research cohorts in the literature. Given the rarity of skull base tumors, varying pathologies and different endoscopic approaches are usually included in the same cohort, which can confound the results. For example, endoscopic repair of skull base defects such as CSF leaks and encephaloceles are associated with a much lower incidence of complications than endoscopic resection of tumors.<sup>23–25</sup> With respect to skull base tumors, benign lesions often require less aggressive surgical resection and are therefore less likely to result in complications.<sup>12</sup> Although previous reports have detailed the frequency of postoperative complications from endoscopic endonasal skull base surgery, the temporality of postoperative complications, as well as their subsequent resolution, has not been described. Such knowledge is not only useful for patient counseling but also for postoperative monitoring and follow-up by the surgeon.

In the present study, we characterize the temporal distribution of complications from endoscopic endonasal approaches for resection of skull base neoplasms. In addition, we also reviewed the resolution of these complications. In our cohort, the most common perioperative complication, defined as occurring within the first postoperative week, was DI at 19.0%, which happened only in cases with sellar pathology; most of these cases resolved. This is consistent with reported rates published in several studies (range: 19–39%).<sup>15,16,26</sup> Transient vision changes were also noted within 1 week of surgery (5.2%). The vast majority of CSF leaks occurred within 2 weeks of surgery, and all resolved, with three requiring operative repair and one requiring placement of a VP shunt (►Table 4). Early (1 week to 6 months) and delayed (6 months

**Table 3** Pituitary complications occurring after surgery for sellar masses<sup>a</sup>

Complication	Perioperative		Early		Delayed	
	<i>n</i>	Resolution	<i>n</i>	Resolution	<i>n</i>	Resolution
Pituitary adenoma ( <i>n</i> = 20) <sup>b</sup>						
Diabetes insipidus ( <i>n</i> = 20)	3	100%(79 d)	0	–	0	–
Hypopituitarism ( <i>n</i> = 14)	1	0% (–)	1	0% (–)	0	–
Craniopharyngioma ( <i>n</i> = 11)						
Diabetes insipidus ( <i>n</i> = 9)	8	75% (13 d)	1	100% (15 d)	0	–
Hypopituitarism ( <i>n</i> = 5)	0	–	2	0% (–)	1	100% (236 d)
Rathke cleft cyst ( <i>n</i> = 3)						
Diabetes insipidus ( <i>n</i> = 3)	0	–	0	–	0	–
Hypopituitarism ( <i>n</i> = 2)	0	–	1	0% (–)	0	–

<sup>a</sup>Perioperative complications are defined as those occurring up to 1 week after surgery, early complications are defined as those occurring between 1 week and 6 months after surgery, and delayed complications are defined as those occurring beyond 6 months after surgery.

<sup>b</sup>The *n* value listed after each complication reflects the number of patients who had not experienced this complication preoperatively.

**Table 4** Cerebrospinal fluid leak complications

Time	Tumor characteristics		Stage	Surgical management <sup>a</sup>		CSF leak characteristics		
	Pathology	Location		Initial skull base repair	Lumbar drain	Time to CSF leak	Time to definitive resolution	Management
Perioperative	Pituitary adenoma	Sella	NA	<ul style="list-style-type: none"> <li>Abdominal fat graft</li> <li>Vascularized nasoseptal flap</li> </ul>	Yes	2 d	7 d	<ul style="list-style-type: none"> <li>Lumbar drain</li> </ul>
	Pituitary adenoma	Sella and suprasellar	NA	<ul style="list-style-type: none"> <li>Abdominal fat graft</li> <li>Middle turbinate free mucosal graft</li> </ul>	No	2 d	7 d	<ul style="list-style-type: none"> <li>Lumbar drain</li> <li>Endoscopic repair</li> </ul>
	Clival chordoma	Clivus	NA	<ul style="list-style-type: none"> <li>Abdominal fat graft</li> <li>Septal cartilage underlay</li> <li>Vascularized nasoseptal flap</li> </ul>	No	1 d	2 d	<ul style="list-style-type: none"> <li>Lumbar drain</li> </ul>
Early	Pituitary adenoma	Sella	NA	<ul style="list-style-type: none"> <li>Abdominal fat graft</li> <li>AlloDerm underlay</li> <li>Middle turbinate free mucosal graft</li> <li>Vascularized nasoseptal flap</li> </ul>	Yes	14 d	37 d	<ul style="list-style-type: none"> <li>External ventriculostomy</li> <li>Ventriculoperitoneal shunt</li> </ul>
	Meningioma	Sella	NA	<ul style="list-style-type: none"> <li>Abdominal fat graft</li> <li>DuraMatrix overlay</li> <li>Vascularized nasoseptal flap</li> </ul>	No	8 d	9 d	<ul style="list-style-type: none"> <li>Lumbar drain</li> </ul>
	Craniopharyngioma	Suprasellar with extension to third ventricle	NA	<ul style="list-style-type: none"> <li>AlloDerm underlay</li> <li>Septal cartilage overlay</li> <li>Vascularized nasoseptal flap</li> </ul>	No	10 d	8 d	<ul style="list-style-type: none"> <li>Lumbar drain</li> <li>Endoscopic repair</li> </ul>
	Craniopharyngioma	Suprasellar	NA	<ul style="list-style-type: none"> <li>DuraMatrix underlay</li> <li>Middle turbinate free mucosal graft</li> </ul>	No	11 d	3 d	<ul style="list-style-type: none"> <li>Lumbar drain</li> <li>Endoscopic repair</li> </ul>
	Esthesioneuroblastoma	Paranasal sinuses and skull base	Kadish B	<ul style="list-style-type: none"> <li>AlloDerm underlay</li> <li>Vascularized nasoseptal flap</li> </ul>	Yes	32 d	5 d	<ul style="list-style-type: none"> <li>Self-resolved</li> </ul>

Abbreviations: CSF, cerebrospinal fluid; NA not applicable.

<sup>a</sup>All patients underwent an entirely endoscopic surgical approach and resection.

onward) complications were notable for a 10% rate of hypopituitarism that was less likely to resolve than other complications ( $p = 0.014$ ) and two cases of CRS that developed in a delayed fashion. Predictably, certain complications (DI, hypopituitarism) were associated only with sellar masses, but many other complications (visual changes, CSF leak, intracranial complications, CRS) are general to all endoscopic skull base procedures. Notably, there were no wound complications in our series; this is a potential advantage compared with transfacial approaches that carry a risk of delayed wound complications including nasocutaneous fistula.<sup>18</sup>

Special attention should be paid to the intracranial complications of endoscopic skull base surgery that can be devastating. In our cohort, although rare, intracranial complications were noted to occur in all time periods but were more likely to occur in the perioperative and early time period (►Table 2). One case was complicated by small bilateral subdural hematomas seen on postoperative scans that were managed conservatively. Stroke occurred in one patient, which was unrelated to the surgical approach or tumor manipulation. This case was a delayed infarct after endoscopic craniopharyngioma resection, believed to be related to vasospasm secondary to aseptic meningitis in the early postoperative period. Three other cases of meningitis resolved with antibiotic treatment including one case that presented 8 months after surgery. Although intracranial complications are rare, early identification and treatment is essential.

In summary, these data suggest that earlier complications tend to be more likely to resolve than later ones, although the association between late-onset complications and lack of resolution did not reach clinical significance in our study ( $p = 0.080$ ). These findings nonetheless serve a practical benefit to surgeons, who should monitor for transient electrolyte disturbances, CSF leak, and neurologic status immediately after surgery, and evaluate for permanent pituitary or sinonasal complications in the long term.

This study had several limitations. First, only joint otolaryngology-neurosurgery cases were included. This was done by design to reflect the multidisciplinary approach to skull base surgery, but it likely biased our cohort toward cases with more complicated pathology and surgical approaches. We excluded patients who underwent repair of CSF leaks, encephaloceles, and sinonasal neoplasms that did not necessitate intracranial dissection, instead focusing on patients with skull base neoplasms that required a two-team approach for resection. Because endoscopic repair of CSF leaks and encephaloceles are reported to have a very low complication rate,<sup>23-25,27</sup> we believed that inclusion of these cases would skew the complication profile for this more complicated subset of patients. Thus the sample size is small, and the ability to detect associations and perform more extensive multivariate analysis is limited. In addition, both malignant and benign neoplasms were included in this series, and the planned surgical goals are often different in these two groups. The intent of this review was to focus solely on the endoscopic surgical approach and the associated com-

plications, rather than disease outcomes. There is a chance that complication rates will be higher in patients who have recurrent or residual disease. Several patients had a short period of follow-up, although the average time was 1.4 years, limiting the conclusions that can be drawn about long-term complications. Minor complications like nasal crusting and intranasal adhesions were not recorded; such complications have been shown to occur at a low level after endoscopic skull base surgery but were not characterized in this study.<sup>28</sup>

## Conclusion

Endoscopic endonasal approaches for skull base neoplasms can be safely performed but have a distinct complication profile. Early-onset complications tend to consist of CSF leak and visual disturbances, and DI in patients with sellar pathologies. Complications that develop in a delayed fashion include CRS and hypopituitarism. Intracranial complications (e.g., hemorrhage, stroke) are rare. Early complications have a greater tendency to resolve, whereas later complications tend to be persistent. Although longer follow-up is required, these findings highlight the importance of vigilant long-term follow-up for patients undergoing endoscopic skull base surgery.

## References

- 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(12):1219-1224
- Nicolai P, Battaglia P, Bignami M, et al. Endoscopic surgery for malignant tumors of the sinonasal tract and adjacent skull base: a 10-year experience. *Am J Rhinol* 2008;22(3):308-316
- Snyderman CH, Pant H, Carrau RL, Prevedello D, Gardner P, Kassam AB. What are the limits of endoscopic sinus surgery?: the expanded endonasal approach to the skull base *Keio J Med* 2009;58(3):152-160
- Lund VJ, Stammberger H, Nicolai P, et al; European Rhinologic Society Advisory Board on Endoscopic Techniques in the Management of Nose, Paranasal Sinus and Skull Base Tumours. European position paper on endoscopic management of tumours of the nose, paranasal sinuses and skull base. *Rhinol Suppl* 2010;(22):1-143
- Kasemsiri P, Prevedello DMS, Otto BA, et al. Endoscopic endonasal technique: treatment of paranasal and anterior skull base malignancies. *Braz J Otorhinolaryngol* 2013;79(6):760-779
- Batra PS, Citardi MJ, Worley S, Lee J, Lanza DC. Resection of anterior skull base tumors: comparison of combined traditional and endoscopic techniques. *Am J Rhinol* 2005;19(5):521-528
- Suh JD, Ramakrishnan VR, Chi JJ, Palmer JN, Chiu AG. Outcomes and complications of endoscopic approaches for malignancies of the paranasal sinuses and anterior skull base. *Ann Otol Rhinol Laryngol* 2013;122(1):54-59
- 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
- Wickham JE. Minimally invasive surgery. Future developments. *BMJ* 1994;308(6922):193-196
- Mack MJ. Minimally invasive and robotic surgery. *JAMA* 2001;285(5):568-572
- Snyderman C, Carrau R, Kassam A. Who is the skull base surgeon of the future? *Skull Base* 2007;17(6):353-355

- 12 Kassam AB, Prevedello DM, Carrau RL, et al. Endoscopic endonasal skull base surgery: analysis of complications in the authors' initial 800 patients. *J Neurosurg* 2011;114(6):1544–1568
- 13 Tabaei A, Anand VK, Barrón Y, et al. Endoscopic pituitary surgery: a systematic review and meta-analysis. *J Neurosurg* 2009;111(3):545–554
- 14 Halvorsen H, Ramm-Petersen J, Josefsen R, et al. Surgical complications after transsphenoidal microscopic and endoscopic surgery for pituitary adenoma: a consecutive series of 506 procedures. *Acta Neurochir (Wien)* 2014;156(3):441–449
- 15 Sudhakar N, Ray A, Vafidis JA. Complications after trans-sphenoidal surgery: our experience and a review of the literature. *Br J Neurosurg* 2004;18(5):507–512
- 16 Kristof RA, Rother M, Neuloh G, Klingmüller D. Incidence, clinical manifestations, and course of water and electrolyte metabolism disturbances following transsphenoidal pituitary adenoma surgery: a prospective observational study. *J Neurosurg* 2009;111(3):555–562
- 17 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
- 18 Gray ST, Lin A, Curry WT, et al. Delayed complications after anterior craniofacial resection of malignant skull base tumors. *J Neurol Surg B Skull Base* 2014;75(2):110–116
- 19 Cohen MA, Liang J, Cohen JJ, 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
- 20 Wood JW, Eloy JA, Vivero RJ, et al. Efficacy of transnasal endoscopic resection for malignant anterior skull-base tumors. *Int Forum Allergy Rhinol* 2012;2(6):487–495
- 21 Ransom ER, Chiu AG. Prevention and management of complications in intracranial endoscopic skull base surgery. *Otolaryngol Clin North Am* 2010;43(4):875–895
- 22 Komotar RJ, Starke RM, Raper DMS, Anand VK, Schwartz TH. The endoscope-assisted ventral approach compared with open microscope-assisted surgery for clival chordomas. *World Neurosurg* 2011;76(3–4):318–327; discussion 259–262
- 23 Komotar RJ, Starke RM, Raper DMS, Anand VK, Schwartz TH. Endoscopic endonasal versus open repair of anterior skull base CSF leak, meningocele, and encephalocele: a systematic review of outcomes. *J Neurol Surg A Cent Eur Neurosurg* 2013;74(4):239–250
- 24 Lopatin AS, Kapitanov DN, Potapov AA. Endonasal endoscopic repair of spontaneous cerebrospinal fluid leaks. *Arch Otolaryngol Head Neck Surg* 2003;129(8):859–863
- 25 Lee D-H, Lim S-C, Joo Y-E. Treatment outcomes of endoscopic repairs of sinonasal cerebrospinal fluid leaks. *J Craniofac Surg* 2011;22(4):1266–1270
- 26 Schreckinger M, Walker B, Knepper J, et al. Post-operative diabetes insipidus after endoscopic transsphenoidal surgery. *Pituitary* 2013;16(4):445–451
- 27 Jones V, Virgin F, Riley K, Woodworth BA. Changing paradigms in frontal sinus cerebrospinal fluid leak repair. *Int Forum Allergy Rhinol* 2012;2(3):227–232
- 28 Gallagher MJ, Durnford AJ, Wahab SS, Nair S, Rokade A, Mathad N. Patient-reported nasal morbidity following endoscopic endonasal skull base surgery. *Br J Neurosurg* 2014;28(5):622–625