

Audit of Complications in an Otolaryngology Led Skull-Base Surgical Practice

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Abstract

Objective This study was aimed to classify and study complications of surgery of the cranial base, primarily from an otorhinolaryngology perspective.

Design This study was designed with consecutive cohort of skull base surgical cases.

Setting Tertiary referral academic center.

Participants Patients having skull-base surgery at a otorhinolaryngology based skull-base unit, from 2002 to 2015.

Main Outcome Measures Enumeration of complications is the main outcome of this study. Surgical procedures, categorized for complexity as per a unified system, are applicable to endoscopic and open procedures. Complications were categorized as per the British Association of Otolaryngologists coding of surgical complications. Complication classified as major if life-threatening, causing permanent disability, or compromising the result of surgery.

Results A total of 342 patients ($n = 342$) were operated; 13 patients' records were excluded due to < 6 months posttreatment follow-up. The study group constituted 204 anterior skull-base (endoscopic, 120; open/external, 84) and 125 lateral skull-base procedures. Complication rates noted to increase in both groups with increasing complexity of surgical intervention. Anterior skull-base surgery (total complications, 11%; major, 3%; death, 0.5%) noted to have significantly less surgical complications than lateral skull-base surgery (total complications, 33%; major, 15%; death, 1.6%; $p < 0.001$). Among the anterior procedures no significant difference noted among endoscopic and external approaches when compared across similar surgical complexity.

Conclusion Despite improvement in surgical and perioperative care, the overall major complication rate in a contemporary otolaryngology led, primarily extradural, skull-base practice is noted at 8%. Perioperative mortality, though rare, was encountered in 1%. A standard method for categorization of surgical complexity and the grade of complications as reported here is recommended.

Keywords

- ▶ skull base
- ▶ complications
- ▶ skull-base surgery
- ▶ mortality

Introduction

Surgery of the skull-base forms is a challenging segment in otorhinolaryngology practice. Treatment is undertaken for complex and varied pathologies. Advances in diagnostic radiology, interventional radiology, neuronavigation, nerve

monitoring, surgical instrumentation, and postsurgical care have transformed both the scope and the safety of modern skull-base surgical practice. Nevertheless, complications are a frequent reality.

The exact definitions of what constitutes skull-base surgery and what should and should not be included under this label

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remain contentious. The gamut of complications can vary widely depending on the case mix in a particular practice. Previous reports have documented the individual complications of endoscopic, anterior external, lateral, and pediatric skull-base surgery.¹⁻⁷

This report attempts to standardize and compare surgical complexity and surgical complications across the entire surgical spectrum of skull base surgery (endoscopic anterior, open anterior, and open lateral) as encountered at a contemporary otolaryngology led skull-base surgery practice. Surgical procedures are classified as per approach and complexity^{8,9} and complications classified as per a patient oriented, standard reporting format.¹⁰

Methods

A retrospective chart review of all patients with skull-base procedures was undertaken at the Department of Otolaryngology and Head-Neck Surgery under the care of the senior author from January 2002 to March 2015. Appropriate Institutional permissions were obtained. Follow-up data were collated from chart review, follow-up records, follow-up reviews, and telephonic follow-ups.

The following criteria were used to define the study population:

Inclusion criteria: All patients of who underwent surgery for lesions of the skull-base were included. These included external, endoscopic as well as combined approaches.

Exclusion criteria: Patients with less than 6 months follow-up were excluded from the study.

The charts and follow-up records of patients in the study population were evaluated for demographic data, diagnosis, the site of lesion, surgical approach, surgery undertaken, and complications encountered.

Categorization of Surgical Procedures

Surgical approaches were categorized as endoscopic endonasal, external anterior, and external lateral.

Surgical procedures were further graded as per the surgical complexity. Endoscopic endonasal procedures have been previously classified for degree of complexity by Snyderman et al.⁹ As per this classification, level I procedures are the initial sinus access procedures which are precursors to subsequent skull-base procedures (e.g., endoscopic sphenoid and frontal sinus access and sphenopalatine artery ligation). The specific skull-base procedures are classified as level II–V in graded degrees of complexity progressing along level II (skull-base bone exposure, minor dural leak closure, intrasellar pituitary), level III (significant dural exposure, extradural intracranial procedures, extrasellar pituitary), level IV (intradural procedures, major carotid exposure), and level V (vascular malformations and highly vascular tumors, aneurysms). Drawing on this above classification, a similar grading was undertaken for external anterior and external lateral procedures and the same is indicated in ► **Table 1**. Highly vascular tumors were classified as level V by Snyderman et al but highly vascular tumors with appropriate embolization have been classified as level IV in this analysis as the majority of such tumors (juvenile angiofibroma and glomus jugulare tumors) are currently managed with preoperative embolization prior to surgery.

Surgical Techniques and Approaches

The surgical procedure was tailored depending on the site and extent of lesion. Presurgical embolization, neuronavigation, cranial nerve monitoring, and postsurgical ventilation were undertaken as per requirement. All surgeries were undertaken under the care of the otolaryngology service and led by the senior author (A.T.). Collaboration with neurosurgery was undertaken as and when appropriate and particularly for level IV procedures. Level V procedures are routinely undertaken under the neurosurgery service and do not form part of this particular dataset.

Categorization of Complications

The complications were classified as minor, intermediate, major, and death as in accordance with the codes prepared

Table 1 Categorization of complexity of surgical procedure and severity of complication

Categorization of complexity of skull-base surgical procedure (applicable to all approaches, i.e., endonasal endoscopic, external anterior, and external lateral)	
Level I	Precursor surgical procedures preceding skull-base access
Level II	Skull-base bone exposure, minor dural exposure/dural leak closure; intrasellar pituitary
Level III	significant dural exposure, extradural intracranial procedures, extrasellar pituitary
Level IV	Intradural procedures, major carotid exposure, highly vascular tumors (appropriate embolization)
Level V	Vascular malformations, aneurysms, highly vascular tumors (no or inadequate embolization)
Categorization of surgical complications	
Minor complication	A complication which does not require treatment or delay discharge
Intermediate complication	A complication which delays discharge or which requires or prolongs treatment but does not cause permanent disability
Major complication	A life threatening complication or one which causes permanent disability or which compromises the result of surgery
Death	–

for the British Association of Otolaryngologists for reporting on surgical complications (►Table 1).¹⁰

Expected sequelae, such as anosmia, following a traditional anterior cranio–facial resection and grade III facial weakness following a facial nerve transposition for a glomus jugulare excision were not rated as complications. All patients who underwent planned facial nerve transposition in the infratemporal approaches were counseled about postoperative facial paralysis. Recovery to grade III or better by 9 months was classified as an expected sequelae and not a complication. A grade IV or worse status at the 9-month review was listed as a major complication.

New lower cranial nerve palsies inclusive of X nerve loss or section was corrected at surgery or in the early postsurgical period with a thyroplasty procedure.¹¹ In keeping with the criteria listed in ►Table 2, well rehabilitated speech and swallowing postsurgery was classified as an intermediate complication (i.e., requires treatment but does not cause permanent disability).

Results

Clinicosurgical Profile of Patients Undergoing Surgery

From January 2002 to March 2015, 342 patients were operated at our otorhinolaryngology and head–neck surgery referral centre for various lesions of the skull-base. Thirteen patients were excluded from this analysis as per the exclusion criteria and 329 patients constitute the final study group.

Details of Surgery

Of the 329 patients included in the study, 204 (62%) patients underwent surgery on the anterior skull-base and 125 (38%) on the lateral skull-base. Among the 204 anterior procedures 120 (59%) were purely endoscopic and 84 were open or external approaches. Endoscopic assistance was used in 17 of the 84 patients with external anterior approaches. There was intracranial intradural involvement in 21 cases (6.4%). The details of surgical procedures as per complexity of surgery are detailed at ►Table 2.

Table 2 Listing of complications as per categorization skull-base surgical procedures

Surgical approach and complexity		Surgical complications	
Anterior skull base			
Endoscopic endonasal skull-base (n = 120)	Level II (n = 55)	<ul style="list-style-type: none"> • CSF rhinorrhea repair 	Intermediate graft donor site infection (2), postsurgical seizures (1), valproate toxicity (1)
	Level III (n = 53)	<ul style="list-style-type: none"> • Meningocele, encephalocele excision • Pituitary (extrasellar) and clival tumors • Optic nerve decompression • Posttraumatic • Skull-base fibrous dysplasia • Nose and PNS tumors • Mucocele with extensive dural exposure • Allergic fungal rhinosinusitis -intradural 	Minor transient CSF leak (1), Intermediate CSF leak requiring repair (1), postsurgical seizures (1), secondary hemorrhage (1), Major extradural hemorrhage (1)
	Level IV (n = 12)	<ul style="list-style-type: none"> • Clival chordoma/olfactory groove meningioma/olfactory Neuroblastoma (intradural) • Petrous cholesterol granuloma with major ICA exposure • Allergic fungal rhinosinusitis with major ICA exposure 	Minor secondary hemorrhage (1), Major meningitis (1), carotid blow-out and hemiparesis (1)
External anterior skull-base (n = 84)	Level II (n = 23)	<ul style="list-style-type: none"> • Osteoplastic flap • Frontal sinus CSF rhinorrhea • Maxillary swing • Nose, PNS, Infratemporal fossa tumors 	Minor transient CSF leak (1)
	Level III (n = 28)	<ul style="list-style-type: none"> • Ant craniofacial resection <ul style="list-style-type: none"> – Nose and PNS tumors – Orbital tumors, intracranial–extradural extension – Invasive fungal granuloma with intracranial–extradural extension • Maxillary swing <ul style="list-style-type: none"> – Juvenile angiofibroma Radkowski's IIIA 	Minor transient VI n palsy (2), transient III n palsy (1), Intermediate, medial canthus fistula (1), CSF leak requiring repair (1), Major palatal perforation (1)
	Level IV (n = 33)	<ul style="list-style-type: none"> • Maxillary swing/anterior craniofacial resection <ul style="list-style-type: none"> – Juvenile angiofibroma Radkowski's IIIB (ICA exposure/cavernous sinus involvement) – Nasal dermoid with intracranial extension – Nose and PNS malignancy with ICA exposure with intradural extn./ICA abutment 	Intermediate seizure (1), Major extradural hemorrhage (1), palatal perforation (1), death pulmonary thromboembolism (1)

Table 2 (Continued)

Surgical approach and complexity		Surgical complications	
Anterior skull base			
External lateral skull-base (n = 125)	Level II (n = 16)	<ul style="list-style-type: none"> • CSF otorrhoea–transmastoid repair/middle cranial fossa repair • CSF otorrhoea–subtotal petrosectomy • Skull-base osteomyelitis with medial extn. 	Minor, transient CSF leak (1), Intermediate postoperative CSF leak repair (1)
	Level III (n = 64)	<ul style="list-style-type: none"> • Infratemporal fossa approach of Fisch's types A/B <ul style="list-style-type: none"> – Middle ear meningioma – Jugular foramen nonparaganglioma tumors – Endolymphatic sac tumor • Anterior petrosectomy- <ul style="list-style-type: none"> – Cholesteatoma, skull-base osteomyelitis • Orbitozygomatic subtemporal-infratemporal approach <ul style="list-style-type: none"> – Infratemporal tumors – Invasive fungal granuloma – Juvenile angiofibroma IIC/IIIA 	Intermediate X nerve palsy (5), ^a seizures (1), Major extradural hemorrhage (1), VB/VC nerve section (3)
	Level IV (n = 45)	<ul style="list-style-type: none"> • Infratemporal fossa approach of Fisch's types A, B, and C <ul style="list-style-type: none"> – Tympanojugular paraganglioma • Orbitozygomatic subtemporal-infratemporal approach <ul style="list-style-type: none"> – Juvenile angiofibroma IIIB/ICA exposure – Nasopharynx malignancy (ACC) • Subtotal temporal bone resection <ul style="list-style-type: none"> – Temporal bone malignancy • Petrous apex drainage/debridement <ul style="list-style-type: none"> – Skull-base osteomyelitis extensively abutting petrous ICA • Extensive petrous apicitis/tuberculosis • Translabyrinthine/transotic approach <ul style="list-style-type: none"> – Vestibular schwannoma/petrous cholesteatoma/cerebellopontine angle tumors • Retrolabyrinthine presigmoid approach • Vestibular neurectomy • Vascular loop decompression 	Minor transient CSF leak (2), transient VI nerve palsy (1), Intermediate CSF leak (1), meningitis (1), transient III, IV,VI palsy (2), X–XII paresis/paralysis (5)*, Major VII n palsy HB grade IV–VI (6), weak breathy voice (2), encephalocoele (2), vision loss (1), cochleo-vestibular deficit (4), death carotid blow-out (2), amphotericin toxicity–renal failure (1) ^b

Abbreviations: ACC, Adenoid cystic carcinoma; CSF, cerebrospinal fluid; extn. extension; ICA, Internal Carotid Artery; inv., Involvement; plum., not present in the document; PNS, Paranasal sinus.

^aWell rehabilitated speech and swallowing postsurgery was classified as an intermediate complication.

^bDeath due to amphotericin B nephrotoxicity, classified as a nonsurgical complication.

Complications Encountered

Among the 204 anterior skull-base procedures, a total of 23 surgical complications were noted (11%). The endoscopic anterior skull-base group had 12 complications in 120 patients (10%) with three major complications and no deaths. The external anterior skull-base group had 11 complications in 84 patients (13%) with three major complications and one death.

Among the 125 lateral skull-base (external) procedures, a total of 41 surgical complications were encountered (33%). The 41 complications included 4 minor, 16 intermediate, 19 major complications, and 2 surgical related deaths. One other death was classified as nonsurgical related (amphotericin B toxicity related acute renal failure) and not included in the analysis of surgical related complications. A significantly lower complication rate was noted in the anterior skull-base approaches (endoscopic + external) than in the lateral skull-base approaches ($p < 0.001$).

Deficits which were anticipated and expected prior to surgery were classified as sequelae rather than complications. Fifteen out of 18 cases with juvenile angiofibroma (IIIB) excised by the lateral subtemporal–infratemporal approach had section of the maxillary nerve, and were so classified.

Among 21 patients with normal presurgical facial nerve function and facial nerve transposition as part of a Fisch's type A excision, 15 recovered to grade III by the 9-month follow-up, and six had residual function worse than grade IV. The 15 patients with recovery to grade II and III were classified as sequelae rather than a complication.

12 patients had deterioration of lower cranial nerve function following surgery on the jugular foramen. Of them, 10/12 recovered function with compensation, speech, and swallowing therapy and a thyroplasty ($n = 9$). No patient required long-term tube feeds or a long-term tracheotomy. Two patients had residual weak voices, one of these despite a thyroplasty. Transient speech and swallowing

Table 3 Surgical complications as per surgical approach and complexity

	Level II		Level III		Level IV	
	Minor/ intermediate	Major/ death	Minor/ intermediate	Major/ death	Minor/ intermediate	Major/ death
Anterior skull-base						
Anterior endoscopic endonasal, <i>n</i> = 120	4/55	0/55	4/53	1/53	1/12	2/12
Anterior external, <i>n</i> = 84	1/23	0/23	5/28	1/28	1/33	3/33
Anterior endoscopic vs. anterior external Chi-square test, <i>p</i> -value	0.63	–	0.16	0.64	0.46	0.47
Lateral skull-base						
Lateral external <i>n</i> =125	2/16	0/16	6/64	4/64	12/45	17/45
Anterior external vs. at external Chi-square test, <i>p</i> -value	0.35	–	0.25	0.60	0.006	0.004
Anterior (endoscopic + external) vs. lateral Chi-square test, <i>p</i> -value	0.40	–	0.73	0.26	0.004	0.003

dysfunction which was ultimately well rehabilitated was classified as an intermediate complication (requires treatment but does not cause permanent disability)

Carotid blowouts occurred on three occasions, one intraoperative, and two in the first postoperative week. The intraoperative blow out was successfully treated with limited final morbidity but both patients with postoperative blow outs died.

Analysis of Complications Depending on Surgical Approach and Surgical Complexity

►Table 3 and ►Fig. 1 depict the quantum of complications for differing surgical approaches and complexity of surgery (surgical levels). Level II procedures (endoscopic/anterior external/lateral external) were associated with occasional minor and intermediate complications but no major com-

plications or deaths. Level III procedures led to some major complications but no deaths. All three deaths were associated with level IV procedures.

A trend is noted for major complications to be more manifest with increasing levels of surgical complexity (level II–IV; *p* < 0.05). Anterior skull-base endoscopic and external approaches did not differ in terms of complication rates across all levels of surgical complexity (►Table 3). Lateral approaches are noted to have similar complication rates as anterior approaches for level II and level III procedures but to have a greatly increased complication rate for level IV procedures.

Discussion

Surgical procedures on the skull-base have significant implications for the patient and there are occasions when some surgical morbidity is considered near-inevitable. It is naturally vital that surgical morbidity to be minimized and numerous individual advances in pretreatment radiology, adjuvant embolization, surgical instrumentation, anesthesia, and postsurgical intensive care have all contributed to cumulatively improve surgical care very significantly.¹² The present evaluation from a contemporary practice includes all these individual aids and reports on the quantum of complications in the current era of skull-base surgery. Complications have been categorized by a clear and unambiguous classification system¹⁰ (►Table 1) which is oriented toward patient outcomes rather than surgical procedures and is easily applied to diverse surgical procedures. Additionally, the large spectrum of skull-base procedures is categorized as per complexity and complication rates quantified for each subcategory.

The complication rate with anterior skull-base surgery is noted to be relatively lesser (11%, total complications; 3%, major complications; 0.5%, death). Lateral skull-base surgery is noted to have a significantly higher complication rate (33%, total complications; 15%, major complications, 1.6%, death; *p* < 0.001). The vast majority of lateral skull-base complications are consequent to level IV procedures and level II and III

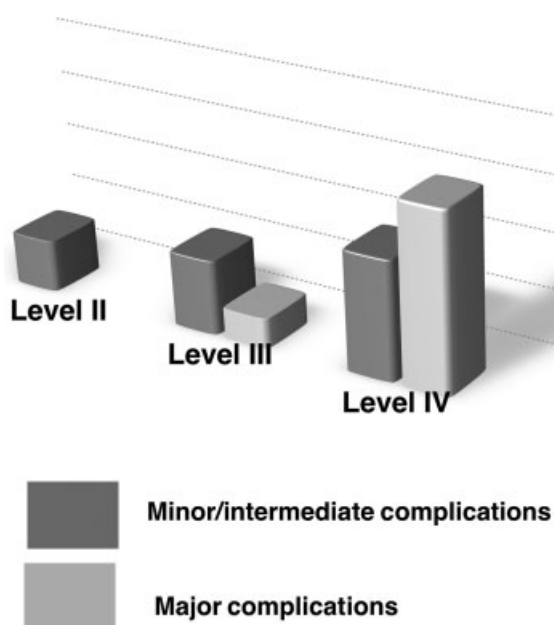


Fig. 1 Quantum of complications with increasing levels of surgical complexity.

procedures of the lateral skull-base are noted to be no more morbid than similarly categorized anterior skull-base procedures.

An integrated and unified grading of the complexity of skull-base surgical procedures is proposed (►Table 1). The classification is inspired from the widely quoted classification for endoscopic skull-base procedures from the Pittsburgh's group⁹ and is adapted to be applied to the entire spectrum of skull-base procedures (endoscopic, open anterior, open lateral). Progressing from level II to level IV, a statistically significant progression is noted across all three surgical approaches of an increasing incidence of major complications and mortality (►Table 3). The progressive increase in complication rates are noted along increasing surgical levels in validation of the strength and appropriateness of the proposed categorization.

The original principle of skull-base surgery at its initiation was to "remove bone and so spare the brain." The initially developed transtemporal and infratemporal fossa procedures were developed as per this guiding principle.¹³⁻¹⁵ Wide bony dissection in the skull-base enabled excellent access to the dura and adjoining neurovascular structures with negligible brain retraction. Wide exposure further enabled closer access to the surgical site with shorter and proximally held instruments, thus leading to more precise and tremor free surgical work on the critical skull-base.

The advent of the endoscope with its illumination, magnification, and angled telescopes has added a new dimension to skull-base surgery. The endoscope provides for superior access and illumination but the surgical field is deeper and surgical dissection with longer instruments and narrow corridors can be technically challenging. Innovations in techniques, such as the "two surgeons-four hands" technique, the routine use of a vascularized nasoseptal flap for augmenting dural repairs, and new instrumentation (neuronavigation, intraoperative Doppler, endoscope holders, microdebrider, coblation, cavitron ultrasonic surgical aspirator [CUSA]) have enabled the development of a safe and effective procedure.¹⁶⁻¹⁹ Centers with significant experience have noted of reduced morbidity and reduced duration of hospital stay with the endoscopic approach as compared with the external approach²⁻⁴ but apprehensions have been expressed of a higher rate of cerebrospinal fluid (CSF) leaks with endoscopic procedures than with open procedures, especially so with procedures with higher grades of complexity.^{2,20}

As is noted in this analysis, approximately 42% of our throughput in skull-base today is either totally endoscopic or endoscopic assisted. On initial evaluation, endoscopic procedures seem to have lower complication rates than external procedures (9 vs. 35%, $p < 0.001$) but this is a consequence of endoscopic procedures being limited to the safer areas of the anterior skull-base. When looking at the anterior skull-base in isolation and evaluating complications, specifically with regard to the complexity of surgery, comparable complication rates are noted for endoscopic and external procedures of comparable surgical complexity (►Table 3).

A distinction has to be made between sequelae and complications. As a simple distinction, sequelae are expected

adverse events, while complications are adverse events which can be potentially prevented. The differentiation between the two would probably be contentious. It would be expected that the informed consent would include a discussion of both but especially emphasize the inevitability/near-inevitability of the sequelae.

This analysis finds a much greater incidence of complications with lateral skull-base surgery. Additionally, this subgroup has a significant morbidity classified as sequelae rather than complications. Surgery on the jugular foramen is often associated with facial nerve dysfunction consequent to its surgical rerouting, and also lower cranial nerve dysfunction. Similarly, it is our experience that in patients with Radkowski's stage IIIB juvenile angiofibroma surgically accessed by the orbitozygomatic subtemporal-infratemporal approach, the VB nerve in its canal is an invariable casualty in the attempt to access tumor positioned medial to it in the Vidian canal complex, inferior and superior orbital fissures, paracavernous area, and sphenoid. In our practice, patients are specifically counseled regarding these deficits, and these are, therefore classified as sequelae rather than complications.

Rehabilitation and correction of residual deficits is an important part of skull-base practice. Such rehabilitation is best if undertaken immediately. In situations of facial nerve paralysis, our preference is to undertake immediate partial rehabilitation by upper eyelid loading (gold weight implantation) but nerve repair procedures take longer to be effective. Swallowing and speech rehabilitation in our practice is primarily undertaken by unilateral cricothyroid approximation (type IV thyroplasty) on the paralysed side.¹¹ The deficits of a "high" vagal paralysis consequent to jugular foramen lesions include not only the horizontal vocal fold misalignment consequent to recurrent laryngeal nerve (RLN) paralysis but also additional deficits of vertical vocal fold misalignment, vocal fold hypotonia, and sensory loss consequent to superior laryngeal nerve paralysis (SLN). In this situation of a high vagal paralysis, cricothyroid approximation is noted to better correct these deficits than a type I thyroplasty as it better corrects the deficits of vocal fold hypotonia and vertical misalignment and also partially corrects for the horizontal plane glottic gap.¹¹ Early interventions with cricothyroid approximation have contributed to minimizing swallowing morbidity in this report, with it being downgraded in many instances from being a major complication to an intermediate complication (i.e., a complication which requires treatment but does not cause permanent disability).

Conclusions

Many advances, surgical and nonsurgical, have contributed to the decreasing trends toward complications with skull-base surgery. Attention to rehabilitative procedures has further contributed toward this trend. In a contemporary otolaryngology led and primarily extradural skull-base practice, the overall total complication rate is currently noted at 19%, and the major complication rate at 8%. Mortality continues to be a reality and is noted at 1%. Much greater complication rates are noted with lateral

than with anterior skull-base surgery, particularly so with level IV procedures.

The categorization of surgical procedures and complications as proposed here enables an estimation of surgical morbidity and complication rates as per the complexity of the procedure. These should prove useful for informed consent and also in informed decisions regarding the risk-benefit of surgical procedures in individual situations.

Conflicts of Interest

None declared.

References

- 1 Svider PF, Baredes S, Eloy JA. Pitfalls in sinus surgery: an overview of complications. *Otolaryngol Clin North Am* 2015;48(05):725–737
- 2 Fu TS, Monteiro E, Muhanna N, Goldstein DP, de Almeida JR. Comparison of outcomes for open versus endoscopic approaches for olfactory neuroblastoma: A systematic review and individual participant data meta-analysis. *Head Neck* 2016;38(Suppl 1):E2306–E2316
- 3 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(02):330–337
- 4 Meccariello G, Deganello A, Choussy O, et al. Endoscopic nasal versus open approach for the management of sinonasal adenocarcinoma: a pooled-analysis of 1826 patients. *Head Neck* 2016;38(Suppl 1):E2267–E2274
- 5 Cunningham CD III, Friedman RA, Brackmann DE, Hitselberger WE, Lin HW. Neurotologic skull base surgery in pediatric patients. *Otol Neurotol* 2005;26(02):231–236
- 6 Patel SG, Singh B, Stambuk HE, et al. Craniofacial surgery for esthesioneuroblastoma: report of an international collaborative study. *J Neurol Surg B Skull Base* 2012;73(03):208–220
- 7 Miller JD, Taylor RJ, Ambrose EC, Laux JP, Ebert CS, Zanation AM. Complications of open approaches to the skull base in the endoscopic era. *J Neurol Surg B Skull Base* 2017;78(01):11–17
- 8 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(06):1544–1568
- 9 Snyderman C, Kassam A, Carrau R, Mintz A, Gardner P, Prevedello DM. Acquisition of surgical skills for endonasal skull base surgery: a training program. *Laryngoscope* 2007;117(04):699–705
- 10 Moffat DA. *Recent Advances in Otolaryngology*. Edinburgh: Churchill Livingstone; 1995:27–40
- 11 Thakar A, Sikka K, Verma R, Preetam C. Cricothyroid approximation for voice and swallowing rehabilitation of high vagal paralysis secondary to skull base neoplasms. *Eur Arch Otorhinolaryngol* 2011;268(11):1611–1616
- 12 Casteluovo P, Dallan I, Battaglia P, Bignami M. Endoscopic endonasal skull base surgery: past, present and future. *Eur Arch Otorhinolaryngol* 2010;267(05):649–663
- 13 Zanoletti E, Martini A, Emanuelli E, Mazzoni A. Lateral approaches to the skull base. *Acta Otorhinolaryngol Ital* 2012;32(05):281–287
- 14 Kong J, Yang HY, Wang YF, Yang HJ, Shen SY, Wang F. Surgical management and follow-up of lateral skull base tumors: an 8-year review. *Mol Clin Oncol* 2017;6(02):214–220
- 15 Sanna M, Mancini F, Saleh E, Piazza P, Khrais T, Russo A, Taibah A. Approaches to infratemporal fossa. In: *Atlas of Microsurgery of the Lateral Skull Base*, 2nd ed. Stuttgart: Thieme; 2008:206–246
- 16 Wong GK, Poon WS, Lam MK. The impact of an armless frameless neuronavigation system on routine brain tumor surgery: a prospective analysis of 51 cases. *Minim Invasive Neurosurg* 2001;44(02):99–103
- 17 Casteluovo P, Pistochini A, Locatelli D. Different surgical approaches to the sellar region: focusing on the “two nostrils four hands technique”. *Rhinology* 2006;44(01):2–7
- 18 Casteluovo P, Battaglia P, Bignami M, et al. Endoscopic transnasal resection of anterior skull base malignancy with a novel 3D endoscope and neuronavigation. *Acta Otorhinolaryngol Ital* 2012;32(03):189–191
- 19 Tang H, Zhang H, Xie Q, et al. Application of CUSA excel ultrasonic aspiration system in resection of skull base meningiomas. *Chin J Cancer Res* 2014;26(06):653–657
- 20 Zoli M, Guaraldi F, Pasquini E, Frank G, Mazzatenta D. The endoscopic endonasal management of anterior skull base meningiomas. *J Neurol Surg B Skull Base* 2018;79(Suppl 4):S300–S310