ORIGINAL CONTRIBUTION

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Endoscopic rhino-neurosurgical approach for non-adenomatous sellar and skull base lesions*

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SUMMARY

Objective: *Since endoscopic endonasal transsphenoidal surgery requires skills of both neurosurgeons and otorhinolaryngologists, and the nose is the primary corridor of approach, we favour the term "endoscopic rhino-neurosurgery" and report on our interdisciplinary experience treating non-adenomatous lesions with skull base extension.*

Methods: *Between 2004 and 2009, 58 patients with 21 different disease patterns underwent endoscopic rhino-neurosurgical procedures. Mean age was 39.9 years, 50% were female. Seven had undergone prior surgery. Clinically, 34.5% presented with visual field deficits and with nerve palsies. Preoperatively, 62.1% showed a normal pituitary function.*

Results: *Mean follow-up was 13.1 months. The surgical goal depended on type of lesion; the intended extent of resection was achieved in 81%. Recovery from visual field deficits occurred in 80%. Neither deteriorated nor new cranial nerve palsies were observed. A normal endocrinological function could be maintained in 94.4%. Permanent diabetes insipidus occurred in 7 patients. Surgical complications included cerebrospinal fluid (CSF) leaks in 6 patients and meningitis in 4. All complications were managed successfully. There was no surgery-related mortality.*

Conclusion: *The endoscopic rhino-neurosurgical approach is applicable for a wide variety of lesions comprising sella and skull base. As our data prove, this technique can be performed with satisfying results in non-adenomatous lesions as well.*

Key words: endoscopy, extended endonasal surgery, skull base lesion

INTRODUCTION

With the technical development of endonasal endoscopy, indications and applicability in this field have definitely expanded and evolved over the last several years. Tumours located in the sella and the adjacent skull base can be managed with an improved patient comfort [1-13]. Complication and treatment success rates appear to be comparable or even superior to standard transcranial approaches regarding extent of tumour removal and postoperative deficits [2,5,12,13,15].

The endonasal endoscopic approach to the skull base comprises skills, knowledge, and experience from both, the neurosurgical and the otorhinolaryngological disciplines. This team approach can be seen as role a model of interdisciplinary cooperation. As the nostrils and nose are always used as the primary corridor of approach, and the principles of neurosurgical microsurgery are applied, once the sella, skull base, and dura are reached or even crossed, we use the term "endoscopic rhino-neurosurgery" as it describes best what we achieve: endoscope-based neurosurgery, performed through the nose. We present our experiences with this technique for non-adenomatous skull base lesions involving a wide variety of different disease patterns over a five-year period.

PATIENTS AND METHODS

Patients

From February 2004 to April 2009, 245 patients underwent endoscopic skull base surgery in close cooperation with the Division of General Otorhinolaryngology (ORL), Head and Neck Surgery, Medical University, Graz, Austria; out of them, 58 had non-adenomatous lesions. All patient data were collected in a prospective database.

Clinical presentation is shown in Table 1. Gender distribution was balanced (50% female, 50% male), mean age was 39.9 years (range 4-78). Preoperative examination included routine clinical and neurological examination, and a full endocrinological evaluation in symptomatic patients or in patients with radiological involvement of pituitary/hypothalamic structures. Neuroophthalmological investigation was performed in case of radiological signs of chiasm compression and/or a history of visual disturbances. Neuroradiological studies included mag-

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Table 1. Presenting signs and symptoms in 58 patients with non-adenomatous sellar and skull base lesions.

Endocrinological disturbances	**Total (%)* n = 22 (37.9%)**	**Neuroophthal-mological signs**	**n = 24 (41.4%)**	**Nerve palsies**	**n = 7 (12.1%)**	**General symptoms**	**n=34 (58.6%)**
Adynamia	5 (8.6%)	Visual field deficiency	20 (34.5%)	V palsy UL	1 (1.7%)	Cephalea	17 (29.3%)
Amenorrhea, galactorrhea	5 (8.6%)	Diplopia	3 (5.2%)	VI palsy UL	2 (3.4%)	Nausea/vomitus	3 (5.2%)
Decreased libido and potency	3 (5.2%)	Papilledema BL	1 (1.7%)	VII palsy UL	1 (1.7%)	Vertigo	5 (8.6%)
Diabetes insipidus	2 (3.4%)			Phrenic nerve palsy UL	1 (1.7%)	TN	1 (1.7%)
Weight loss	3 (5.2%)			Recurrent laryngeal nerve palsy UL	1 (1.7%)	Hypacusis	2 (3.4%)
Growth retardation	3 (5.2%)			Dysesthesia V/2	1 (1.7%)	Spontaneous CSF leak	2 (3.4%)
Obesity	1 (1.7%)					Impaired nasal breathing	1 (1.7%)
						Spastic paresis, hyperreflexia	1 (1.7%)
						Somnolence, hydrocephalus	1 (1.7%)
						Neck pain	1 (1.7%)

Abbreviations: BL, bilateral; UL, unilateral; TN, trigrminal neuralgia; n = number.
*The numbers in parenthesis are percentages of the total number of 58 patients. Many patients had more than one sign or symptom.

netic resonance imaging (MRI) with intravenous gadolinium contrast application. MRI and computed tomography (CT) scan were routinely used for fusion image guidance during endoscopic surgery (ENTrak®, GE).

The patient population included highly heterogeneous pathological entities (Table 2); the aim of surgical resection varied according to the individual lesion: total resection, tumour mass/volume reduction, biopsy, cyst evacuation, optic nerve decompression, or odontoidectomy. Total tumour removal was defined as complete intraoperative resection confirmed by postoperative neuroimaging (CT and/or MRI). Subtotal tumour removal refers to more than 80% tumour reduction, and partial removal to less than 80% of tumour volume.

Seven patients (7/58, 12.1%) had undergone conventional surgery prior to the first endoscopic rhino-neurosurgical procedure. One patient with a widespread endo- and suprasellar meningioma with involvement of the sphenoid wing had been operated transcranially twice before. An endoscopic procedure was performed due to recurrent tumour and visual field deterioration. A patient with a craniopharyngioma had multiple interventions before endoscopy: 2 transcranial and 2 transsphenoidal microscope-based operations, as well as bleomycin treatment via an Ommaya reservoir, followed by a radiosurgical intervention. One patient with a squamous cell carcinoma involving the right orbit and paranasal sinuses had been treated with exenteration of the right orbit, radio- and chemotherapy, and 2 consecutive endoscopic procedures by ENT (ear, nose, and throat)-surgeons. A patient with an intra-, supra-, para-, and infra-sellar chordoma had undergone a transcranial approach, as well as another patient with a chondrosarcoma. A strongly vascularized neuroblastoma had to be removed in 2 steps endoscopically because of excessive bleeding; first approaching the intranasal part of the tumour and in a second procedure the intracranial part. In a case of a patient with fibrous dysplasia, a transsphenoidal biopsy and a transcranial operation had preceded endoscopic intervention.

Surgical technique

Total intravenous anaesthesia (TIVA) with propofol (5-8 mg/kg/h) as hypnotic agent and remifentanyl (0.15-0.4 µg/kg/minute) was used in all cases as anaesthetic. For ventilation, a mixture of oxygen and air were administered; no anaesthetic gases are generally applied.

Patients are placed in a supine position, head and upper part of the body slightly elevated for 5 - 15 degrees. An ENT-surgeon and a neurosurgeon stand or sit on either side of the patient, thus providing the best access to both nostrils. All procedures are routinely performed under CT-/MRI-fusion navigation.

Maximum topical vasoconstriction was achieved by applying cottonoids soaked in adrenalin 1:1000 to the mucosal surfaces for a minimum of 10 minutes.

We have adopted a four-hand, two nostril approach, modifying the techniques described by Sethi and Hong [14], using the sphenoid as primary source of access. This concept allows for a modular adaptation of approach to the individual patients needs. With this technique, turbinate resections can be avoided with the exception of malignant lesions affecting the inner nose and sinuses as well.

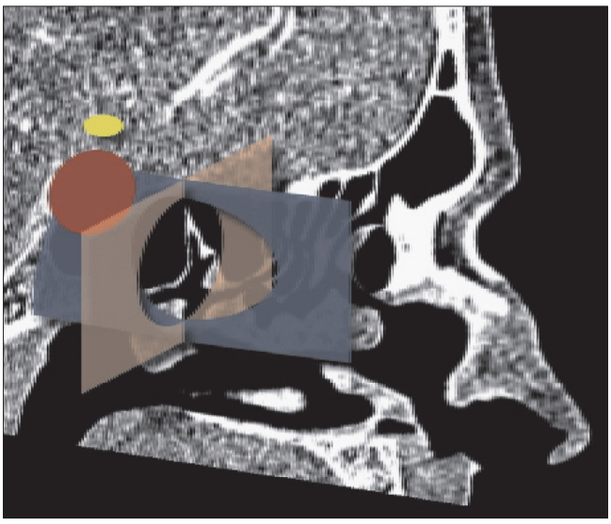

Figure 1. Schematic display of approach routes: Nasal and intersphenoidal septum, respectively (blue), anterior sphenoidal wall (pink), pituitary/sella (red), optic chiasm (yellow). Surgical defects in septa and anterior sphenoidal wall vary depending on indication.

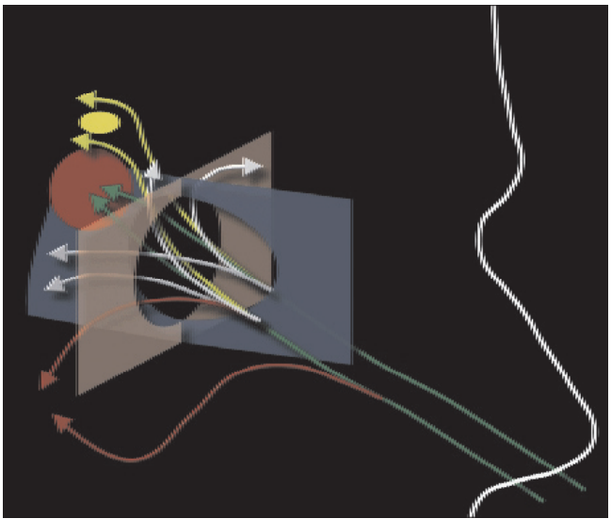

Figure 2. Selection of surgical routes: To sella and pituitary (green arrows), supra- and infrachiasmatic approach (yellow arrows), transsphenoidal approach to clivus (grey arrows), transsphenoidal and transmaxillary approach to lateral recess of sphenoid sinus, pterygopalatine fossa, retromaxillary and infratemporal region (red arrows), approach to planum sphenoidale and olfactory fossa/ethmoidal roof, respectively (white arrows).

For the initial steps, a 0-degree, 4 mm endoscope (Karl Storz, Tuttlingen, Germany) is used. Depending on the individual situation, 30-degree and 45-degree endoscopes can be applied. We do not use any endoscope holders; the endoscope is guided manually through the entire procedure. Thus, anatomical overview and detailed display of individual structures can be achieved. Irrigation, if required, is performed manually as well. After removal of the decongesting adrenalin swaps, the nose is inspected with a 0-degree endoscope and the natural ostium of the sphenoid sinus is identified bilaterally. Once the ostia are enlarged on both sides, the nasal septum is transsected 0.5-1.0 cm anterior to the rostrum and then resected posteriorly towards the sphenoid and superiorly towards the skull base. The ostia now are connected. Next, the sphenoidal septum is resected and depending on the individual situation, further incomplete subsegmentations and septations can be taken care of as well. Also depending on the individual situation, the anterior third of the sphenoid sinus floor has to be lowered or completely resected to enable a sufficient range of motility for the various instruments required in the following surgical steps. At this stage, normally an excellent identification and overview of key anatomical structures like optic nerve tubercles, course of carotid arteries, infraoptical recess, sella floor/bulge, clivus, vidian and maxillary nerves can be obtained. Unaffected by the actual course of the intersphenoidal septum, identification of the midline is never a problem with this technique. Using navigational devices, a final evaluation is made to see whether the approach created is sufficient to reach the targets margins (Figure 1).

All further steps depend on the individual lesion (Figure 2): for sellar lesions, the sella floor is identified and opened. If the bone is thinned out, it can gently be infractured and removed in appropriate dimensions; drills and – in very rare cases – chisels can serve its purpose as well. Exposure of sellar dura can be extended both dorsally inferiorly onto the clivus, laterally to the internal carotids – cranially to the siphon and inferiorly, to the horizontal portion of the carotid at skull base. If the craniocervical junction needs to be approached, C1-C2 can be reached in the midline either transnasally, transorally (after elevation of the soft palate) or in a combined way. Depending on the degree of pneumatisation, the lateral recess of the sphenoid sinus may extend to the temporal lobe. For manipulations in this area, structures of the pterygopalatine fossa have to be dissected and/or the posterior wall of the maxillary sinus, thus giving access to retromaxillary pterygopalatine and infratemporal fossa processes.

If a lesion extends anterior to the sella, the bone of the planum sphenoidale is resected in a retrograde fashion using drills and punches. Maximum exposure of dura via this approach includes the planum sphenoidale, the ethmoidal roofs, and the cribiform plate up to the posterior wall of the frontal sinuses. Especially in malignancies, all sinuses and cells can be opened endoscopically simultaneously and if required, resected. Frontal sinuses can be drilled open (the so-called median drainage according to Draf et al. [15]), inspected and treated if required.

If dura at planum needs to be opened, a transverse incision is made and – depending on the tumour entity – either a flap is created or dura resected. In malignant lesions, dural margins are resected and evaluated in frozen sections.

The maximum extent of dura resection with this approach includes sellar dura, planum sphenoidale, and dura of olfactory and anterior cranial fossa between both orbital roofs and

Table 2. Pathological entities, tumour extension, individual surgical goal, and extend of resection after endoscopic rhino-neurosurgical approach in 58 patients.

Lesion	No of cases	Previous surgery	Tumour extension/location
Rathke's cleft cyst	12	none	10 IS, SS 1 IS, SS, PS 1 IS, SS, IV
Meningioma	10	2 TC	8 TS, 1 SP, 1 OG
Craniopharyngioma	9	2 TC, 2 TMS, 1 GK	3 IS, SS 3 SS, IV 3 SS
Carcinoma (nasopharyngeal, paranasal sinus)	4	2 EC	1 IS, SS, PS 1 PS, SB, CL 1 PS, SB, SSI, CL, PSI 1 SP, EB, PSI
Chordoma	4	1 TC	1 SB, SPS, IS, SS, CS 1 SB, SPS, CL 1 SB, CL, CS 1 CL, C0/C1
Hypophysitis (2 lymphocytic, 1 granulomatous)	3	none	1 IS 2 IS, SS
Neuroblastoma	2	3 EC, 1GK	1 SP, EB, ETC 1 OR
Schwannoma	2	2 TC	1 IFT, MS 1 IS, PS, EB, PB, ITF, MS
Astrocytoma (pilocytic, fibrillary)	2	none	1 SS 1 IS, SS
Cholesterol granuloma	1	none	1 CL, PB
Fibrous dysplasia	1	1 TC, 1 TMS	1 IS, SS, PS, CS, SB, CL, OB
Osteoblastoma	1	none	1 SB, SP, SPS, CS
Chondrosarcoma	1	1 TC	1 IS, SS, CS
Plasma cell myeloma	1	none	1 CS, SPS, CL
Colloid cyst	1	none	1 IS, SS
Pituitary carcinoma	1	none	1 IS, SS, CS
Metastasis (carcinoma)	1	none	1 IS, SS, CS
Basilar invagination (Chiari II)	1	decompression posterior fossa	odontoid process
PNET	1	none	1 IS, SS, CL, spinal

Abbreviations: No = number

1. **Anatomy:** sphenoid bone = SB, sphenoid plane = SP, petrous bone = PB, occipital bone = OB, ethmoidal bone = EB, suprasellar = SS, intrasellar = IS, parasellar = PS, sphenoid sinus = SPS, clivus = CL, cavernous sinus = CS, infratemporal fossa = ITF, maxillary sinus = MS, intraventrivular = IV, paranasal sinuses = PSI, orbit = OR, ethmoidal cells = ETC, cervical vertebrae = C0/C1
2. **Meningiomas:** TS = tuberculum sellae meningioma, OG = olfactory groove meningioma, SP = sphenoid plane meningioma
3. **Approaches/Surgery:** Transsphenoidal transsellar = TS, Transsphenoidal transtuberculum = TT, Transsphenoidal transplanum = TTP, Transcribriform = TCR, Lateral approach to petrous apex = LPA, Transclival = TCL, Transmaxillary = TM, Approach to the craniocervical junction and foramen magnum = CCJ/FM, Optic nerve decompression = OND, Biopsy = BI, transcranial approach = TC, transsphenoidal microscopic approach = TMS, Gamma knife radiosurgery = GK, previous endoscopic endonasal procedure = EC

the posterior table of the frontal sinuses. In the so exposed area, crista galli can be resected if required, as can the olfactory bulbs in case of infiltration.

Angled endoscopes can be used to visualize areas unlikely or impossible to be seen with the microscope, like the hypothalamic region, the third ventricle, and even the lateral ventricles. Navigation in many cases provides additional confirmation and enhances the surgeons´ confidence of having removed a lesion completely – or of stopping and reconsidering the approach if vital or otherwise eloquent areas are affected.

Intracranial preparation corresponds to general microsurgical principles and surgical instruments are used according to the individual approach.

Dural defects are generally covered with fascia lata in an "underlay-overlay-technique" and sealed with fibrin glue

Surgical approaches	Surgical goal	Extend of resection	Result (%)
TS, TT	CE	8 TR, 4 CE	12/12 (100%)
TS, TT, TTP, TCR	TR	8 TR, 1 STR, 1 PR	8/10 (80%)
TS, TT	TR	7 TR, 1 STR, 1 CE	7/9 (77.8%)
TS, TT, TTP, OND, TCR	TR	1 STR, 3 PR	1/4 (25%)
TT, TTP, TCL, CCJ/FM	TR	2 TR, 1 STR, 1 PR	2/4 (50%)
TS, TT	BI	2 TR, 1 BI	3/3 (100%)
TTP, OND	TR	2 TR	2/2 (100%)
TM, TS, TT, LPA, TCL	TR PR	1 TR, 1 PR	2/2 (100%)
TS, TT	BI, PR	1 BI, 1 PR	2/2 (100%)
TCL, LPA	CE	1 CE	1/1
TC, OND	OND, PR	1 OND, PR	1/1
TTP, TT, OND	OND, PR	1 OND, PR	1/1
TS,TT	TR	STR	0/1
TS, TCL	BI	PR	1/1
TS, TT	TR	TR	1/1
TT	TR	STR	0/1
TT	BI	PR	1/1
odontoidectomy	odontoidectomy	odontoidectomy	1/1
TS, TT	BI	BI	1/1

(Tissucol Duo Quick®, Baxter). While opening endoscopically the skull base, care is taken to preserve as much mucosa as possible to cover up the borders of the fascia in the end of the procedure. Several large skull base defects are additionally reconstructed using a vascularised nasoseptal pedicled flap [16]. Exclusively autologous materials are used for closure. Finally, the restored defect is lined with a haemostatic agent (oxidized regenerated cellulose, Tabotamb®, Johnson&Johnson, Gateway) and RapidRhino® tampons (ArthroCare ENT) are placed into the nasal cavity. Bed rest is ordered individually in case of large dural defects for 2-3 days or while a lumbar drainage is in place. Our established criteria for insertion of a lumbar drainage are the following: large dural defects, reoperations with prior cerebrospinal fluid (CSF) leaks, malignant lesions, radio-and/or chemotherapy, and occasionally according to the surgeons' personal assessment.

Follow-up

Patients harbouring benign lesions were followed in the outpatient clinic with neurological examination scheduled three months postoperatively and then annually. Neuroradiological evaluation with MRI was made in either case at the same intervals. Malignant processes were followed in shorter intervals according to treatment protocols. All patients underwent endonasal endoscopic follow-up examination four weeks postoperatively. Neuroophthalmological and full endocrinological evaluation was carried out individually at varying intervals.

RESULTS

The mean follow-up period was 13.1 months (range 3-48). Fifty-eight patients with non-adenomatous lesions demonstrated a variety of total 21 different disease patterns. Tumour extension, location, and the surgical goal depending on the specific pathological entity are summarized in Table 2. As

illustrated, almost all lesions showed extensive skull base involvement and required extended endoscopic procedures. The aim of surgery was total removal and/or cyst evacuation in the 3 largest patient groups (Rathke cleft cysts, meningiomas, craniopharyngiomas). Focusing on these patients, meningiomas could be removed totally in 80% (8/10) and craniopharyngiomas in 77.8% (7/9). Rathke cleft cysts could be treated successfully in 100% (12/12), 66.7% (8/12) had totally disappeared on postoperative MRI. Overall, the intended extent of resection was achieved in 81% (47/58).

There were 5 deaths during the follow-up period; none of which was related to the surgical procedure: 1 patient with a craniopharyngioma died unrelated to disease due to heart failure 3 months postoperatively. Two with infiltrating carcinomas and 1 with plasma cell myeloma died of disease 14 to 23 months after the surgical procedure. One chordoma patient presented with an additional metastasized rhabdomyosarcoma, which was the cause of death in this case after two years.

In the cumulative patient population, 36 patients (36/58, 62.1%) had no preoperative endocrinological disturbances. More than a third (37.9%, 22/58) showed any kind of hormonal deficiency at presentation in this heterogeneous patient group. At the last evaluation, 34 patients (34/36, 94.4%) had a normal pituitary function, thus the normal endocrinological status could be preserved in the majority. All 9 patients with craniopharyngiomas including 2 with a preoperatively normal function required postoperatively variable hormonal replacement from one to five-axis substitution. Endocrinological complications were transient diabetes insipidus (DI) in 2 patients (2/58, 3.4%) and permanent DI in 7 (7/58, 12.1%). All 7 have successful hormonal replacement therapy with vasopressin. Out of the 7 patients with permanent DI, 3 had a craniopharyngioma and in favour of total tumour removal the intra-operatively unidentifiable pituitary stalk could not be preserved. The pituitary stalk could be preserved in 6 patients with craniopharyngiomas. The remaining 4 patients showed suprasellar tumour extension with pituitary stalk involvement.

Neuroophthalmological evaluation preoperatively showed visual field deficits in 20 patients (20/58, 34.5%). Eleven patients (11/20, 55%) experienced full recovery of their visual acuity, further 5 patients (5/20, 25%) showed significant amelioration, and 4 patients (4/20, 20%) remained unchanged. The latter included patients with a long-term history of optic nerve compression. Out of the group with unchanged postoperative visual field deficits, there was 1 transient visual deterioration (1.7%, 1/58) occurring 53 days after the endoscopic intervention in a patient operated for recurrent craniopharyngioma. At endoscopic tumour removal and cyst evacuation, an Ommaya reservoir drain from a prior bleomycin treatment had to be left untouched; over the following weeks the cyst obliterated and consequently the drain pushed against the optic nerve. The drain was removed via a transcranial approach and visual disturbances recovered again to the preoperative status.

Seven patients (7/58, 12.1%) presented with phrenical, recurrent laryngeal, and cranial nerve palsies preoperatively. One ocular cranial nerve palsy improved, one remained unchanged. No new or deteriorated cranial nerve palsy was observed in the study group.
A lumbar drainage was inserted in 8 patients (8/58, 13.8%) directly after the endoscopic procedure without complications.

Surgical complications consisted of CSF leaks in 6 patients (6/58, 10.3%) occurring 2 to 20 days after the first endoscopic intervention. This complication was treated in 5 cases by endoscopic revisions using a fascia lata patch followed in 4 by a lumbar drainage, in 1 by a simple further endoscopic packing. In one case, rhinorrhea stopped with insertion of a lumbar drainage alone. Postoperative CSF leaks occurred in the following pathological entities: craniopharyngioma (n = 2), Rathke cleft cyst (n = 1), fibrous dysplasia (n = 1), schwannoma (n = 1), and neuroblastoma (n = 1). The rate of postoperative meningitis was 6.9% (4/58 patients); treatment was successful in all with intravenous administration of fosfomycine and cefpirome over a mean of 7 days. One patient with a planum sphenoidale meningioma developed hydrocephalus requiring the insertion of a ventriculoperitoneal shunt 2 months after the endoscopic procedure. To note, this patient had already preoperatively dilated ventricles.

There was a wide range of adjunctive therapies due to the various different disease patterns. Carcinomas, PNET, plasma cell myeloma, and chordomas obtained radiotherapy and/or chemotherapy according to the corresponding therapeutic protocols. One patient underwent a subsequent transcranial approach with the aim of further tumour removal of an extended schwannoma; the endoscopic procedure was part of a staged treatment. A second endoscopic optic nerve decompression was performed in 2 patients with fibrous dysplasia and osteoblastoma after 30 and 35 months, respectively, resulting again in visual improvement. One subtotal resected craniopharyngioma was approached endoscopically for a second time and total removal could be achieved reflecting our endoscopic learning curve. Carcinomas and chordomas underwent further rhino-neurosurgical procedures in case of tumour progression or recurrence. A total of 10 endoscopic reinterventions were performed without additional morbidity or surgical mortality.

DISCUSSION

The endoscopic endonasal transsphenoidal technique constitutes by now a well-established method for treating effectively sellar and suprasellar lesions [1-3,5-9,12,13,17,18]. Taking advantage of the endoscopic view and the higher patient comfort involved with this technique, indications widened associated with a personal learning curve for parasellar up to extensive skull base lesions [19-34].

Craniopharyngiomas

Surgical management is still controversial and depends on tumour extension, consistency/ calcification, and grade of invasion. A variety of transcranial approaches are used to achieve as far as possible tumour removal [35,36]. None of these approaches seems to be superior in protecting delicate vascular structures supplying the hypothalamus, chiasm, and the pituitary stalk. It may be speculated that endoscopy provides a safer and more frequently a total resection by direct visualization, thus avoiding severe endocrinological or hypothalamic disturbances [21,22,27,30,31]. However, surgical manipulation or occasionally a severed pituitary stalk will result in new or deteriorated endocrinological deficits as demonstrated in our craniopharyngioma patient group. With traditional approaches, the surgical mortality is clearly increasing for repeated surgery and the average time for recurrence is 33 months [36]. The questions whether recurrences after a total endoscopic removal occur less frequently or surgical mortality can be reduced in case of recurrent endoscopic surgery definitely require long-term observations and larger study groups.

Osseous skull base lesions

Fibrous dysplasia or osteoma/osteoblastoma may present with visual deterioration requiring optic nerve decompression. Restoring or preserving visual acuity by endoscopic decompression is certainly less invasive and less disabling for the individual patient. Hospital stay is shortened (maximum 5 days) and complication rate for this indication is very low when compared with traditional transcranial approaches [37]. Our results seem to confirm the value of using the endoscopic approach to recover visual acuity in a heterogeneous patient group in overall 80% and only one indirect transient postoperative deterioration. However, an experienced team is required for both traditional and endoscopic approaches.

Cholesterol granuloma of the petrous apex

A variety of surgical approaches is reported: infracochlear, infralabyrinthine, middle fossa, translabyrinthine, or transotic depending on the hearing status. The transsphenoidal approach is supposed to achieve unlikely permanent aeration resulting in recurrent lesions [38]. In contrast to this point, we have not observed a recurrence in our patient over a meanwhile 2.5-year follow-up (Figure 3); a further report with an even longer follow-up confirms the viability of the endoscopic technique [39].

Neoplastic skull base lesions

No new or deteriorated cranial nerve palsy occurred postoperatively in patients harbouring neoplastic processes of the clivus such as chordomas, chondrosarcomas, and carcinomas [25,28,31,33]. Achieving acceptable resection rates and at least maintenance of quality of life is of considerable interest to this special patient group.

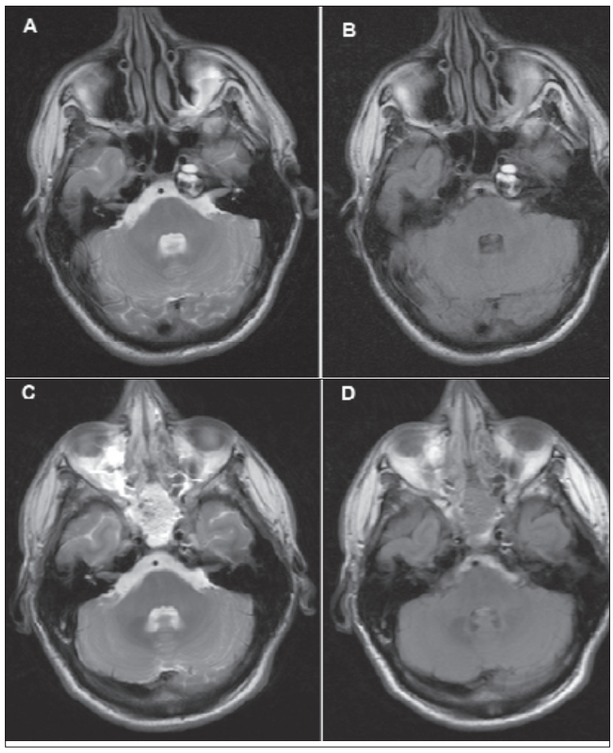

Figure 3. A 34-year-old man presented with vertigo and intermittent left-sided facial and abducens palsy. Axial T2- (A) and T1- (B) weighted MRI demonstrating a petrous apex lesion characterized by a central region of increased intensity and a peripheral rim of markedly decreased signal intensity on both sequences corresponding to a cholesterol granuloma. Axial T2- (C) and T1- (D) weighted MRI obtained 1 year postoperatively revealing a clear resolution of the lesion and absent central hyperintensity. Endoscopic inspection depicted a complete epithelial-layered cyst cavity, no secretion.

Meningiomas

When comparing endoscopic removal of anterior cranial base meningiomas with transcranial approaches, the significant advantage of the endoscopic technique is because the lesion is approached from below, thus removing the basal originating parts with its vascular supply first. An almost restricted blood supply facilitates further tumour removal under optimal microsurgical conditions without the need of brain retraction [24,34,40]. However, a higher incidence of postoperative CSF leaks up to 40% is reported on the endoscopically treated lesions [24,29,34,40,41]. In our study group, no postoperative CSF leakage occurred in this patient group. This result may be related to a careful patient selection for the endoscopic approach. Anterior skull base meningiomas may invade bony structures and show growth into the nasal cavity (Figure 4). In this particular case, tumour removal will require closure of the resulting skull base defect in either case independent of the selected route. Recent studies recommend endoscopic surgery for small- and medium-sized anterior cranial base meningiomas located in the midline and laterally to the region of the midorbit [34,41]. Again, larger

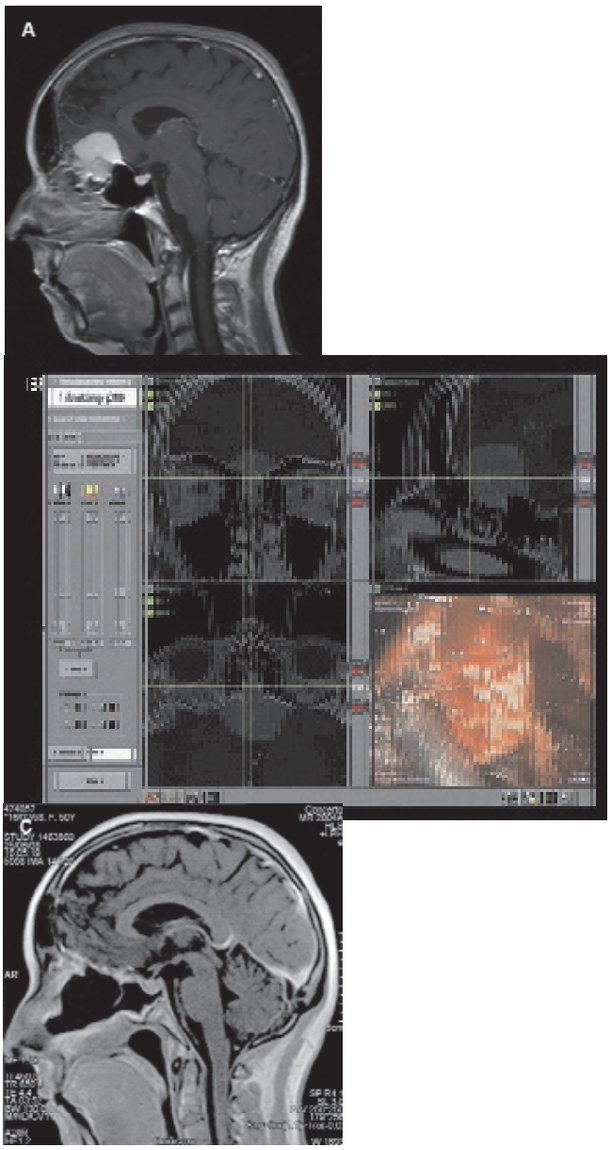

Figure 4. A 50-year-old woman presented with a history of spontaneous intermittent CSF rhinorrhea and anosmia. A) Sagittal gadolinium-enhanced T1-weighted MRI demonstrating an olfactory groove meningioma with infiltration of the cribriform plate and endonasal expansion into the middle and posterior ethmoidal cells. B) Intraoperative navigation image showing tumour removal via transcribriform approach. C) Sagittal gadolinium-enhanced T1-weighted MRI obtained 3 months postoperatively depicting no residual tumour.

study groups are required to objectify risks and benefits of the endoscopic procedure for anterior cranial base meningiomas, especially in comparison to other minimal invasive approaches as the supraorbital route [41].

Closure techniques

A safe closure of the skull base defect is the main challenge of endoscopic approaches. The current study has a rate of 10.3% postoperative CSF leaks and is thus within the range of that reported in other studies in which a rate of 3 to 40% was reported [5,10,21,24,25,29]. This wide range can be explained by the fact that extended approaches may be generally associated with a higher risk of postoperative CSF leakage than approaches to pure sellar lesions. This has been demonstrated, especially for endoscopically removed chordomas and meningiomas. Recently, a growing number of different techniques for skull base reconstruction following endoscopic transnasal approaches have been published [16,42-50]. The common feature of all is the use of a layered technique to accomplish closure, but there are different views and preferences regarding the materials used. In principle, one can choose between autologous and heterologous material for closure. Heterologous grafts such as bone substitutes, any kind of dural grafts, or dermal allografts may be associated with a certain risk of incompatibility, particularly in patients undergoing further radio- and/or chemotherapy impairing healing process or immunocompetence. A variety of possibilities harvesting autologous material has been reported [16,43,46,50]. The use of fascia lata and intranasal materials such as pedicled mucoperiosteal flaps or grafts, septal cartilage, ethmoid plate has shown to be highly effective for skull base reconstruction. Harvesting autologous material has a potential risk of donor-side morbidity such as bleeding, scar formation, infection, and intranasal complications. However, we have used exclusively autologous grafts for skull base closure in our series without associated donor-side morbidity. In case of intraoperative CSF leak, we have adopted the following procedure: meticulous repair of the defect, management to reduce CSF pressure (bed rest, instructions to avoid sneezing and coughing, insertion of a lumbar drainage according to our above-mentioned guidelines), and administration of prophylactic perioperative antibiotics.

Corresponding to our strategy, all endoscopic skull base operations are performed routinely by an experienced team consisting of 1 ENT-surgeon and 1 neurosurgeon. We regard this close collaboration as a key point to achieve optimal operative results with maximum patients' comfort.

CONCLUSION

This paper has given an account of the wide applicability of endoscopic rhino-neurosurgical procedures for non-adenomatous skull base lesions. Our results show that the individual surgical goal can be achieved in more than 80% in a heterogeneous patient group using this technique. Hormonal balance could be preserved in the majority of those presenting with normal pituitary function preoperatively and pre-existing visual field deficits recovered in 80%. Endoscopic reoperations in case of tumour recurrence or progression could be performed without additional morbidity. The current study adds to a growing body of literature on endoscopic endonasal surgery for skull base lesions. However, with a short follow-up, caution must be applied, as findings are difficult to compare to those reported on traditional approaches.

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