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Challenges, Learning Curve, and Safety of Endoscopic Endonasal Surgery of Sellar-Suprasellar Lesions in a Community Hospital

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■ BACKGROUND AND OBJECTIVE: **Endoscopic endonasal surgery (EES) for the management of sellar, suprasellar, and anterior skull base lesions is gaining popularity. Our aim was to analyze and present the clinical outcomes of EES for the management of these lesions in a community hospital setting.**

■ METHODS: **We retrospectively reviewed the charts of 56 patients with sellar, suprasellar, and anterior skull base lesions who underwent EES between 2010 and 2018.**

■ RESULTS: **There was male predominance (53.6%) with a mean age of 54.9 ± 13.7 years. Lesions were 45 pituitary adenomas, 5 meningiomas, 3 metastatic, 1 craniopharyngioma, 1 Rathke cyst, and 1 mucocele. Gross total excision was achieved in 57.1%, subtotal excision occurred in 37.5%, and decompression and biopsy were achieved in 5.4% patients. Postoperative vision normalized or improved in 27 patients (86.1%) and was stable in 4 patients (13.9%). Recovery of a preexisting hormonal deficit occurred in 13 (23.2%) patients, and a new hormonal deficit occurred in 9 patients (16.1%). The mean hospital stay was 6.1 ± 4.9 days. Postoperative complications included cerebrospinal fluid leak in 8 patients (14.3%). Four patients (7.1%) had meningitis. Diabetes insipidus was present in 19 patients (33.9%), and postoperative intracranial hematoma requiring evacuation was necessary in 2 patients (3.6%). The mean follow-up duration was 47.5 ± 25.8 months. Lesion progression or recurrence requiring redo surgery occurred in 5 patients (8.9%). Regarding the learning curve, the postoperative cerebrospinal fluid leak, meningitis, new hormonal deficits, and diabetes insipidus decreased in the second half of the patients.**

■ CONCLUSIONS: **EES provides an effective and safe surgical option with low morbidity and mortality for the treatment of sellar, suprasellar, and anterior skull base lesions in a community hospital setting.**

INTRODUCTION

Endoscopic endonasal surgery (EES) has been gaining popularity over the past 2 decades as an atraumatic and a reliable approach for the management of sellar, suprasellar, and anterior cranial fossa lesions. Visual field defects, headaches, ophthalmoplegia, hypopituitarism, and hormone hypersecretion are common presentations of a pituitary adenoma, one of the most common sellar lesions.[1-3] Microsurgical transsphenoidal approaches had been the gold standard for sellar and suprasellar procedures for decades before the introduction of EES into the neurosurgical field in the mid to late 1990s.[2] The sellar and suprasellar EES technique was a translation from the field of otolaryngology, where it was initially used to replace the previous "open" method of sinus surgery.[3] Microscopic transsphenoidal pituitary surgery had not evolved significantly since its introduction by Harvey Cushing in 1909, until the pioneering work of Hae-Dong Jho in 1997 at the University of Pittsburgh school of medicine.[4] Jho et al[5] demonstrated that endoscopic transsphenoidal approaches were possible for

Key words
- Clinical outcomes
- Community hospital
- Endoscopic endonasal surgery
- Olfactory groove
- Sellar
- Suprasellar
- Tuberculum sellae

Abbreviations and Acronyms
CSF: Cerebrospinal fluid
EES: Endoscopic endonasal surgery
GTR: Gross total resection

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pituitary surgery and could facilitate faster postoperative recovery compared with the gold standard microsurgical approach. EES has continued to gain favorability over conventional microsurgical transsphenoidal approaches for sellar-suprasellar lesions whatever the size and type of the tumor due to the panoramic view of the surgical field, easier mobility of surgical instruments, and better views of anatomic corners with angled lenses.[6-13]

Endoscopic surgical approaches are associated with a learning curve, and for this reason many neurosurgeons have steered clear of attempting this newer technique.[11] However, current EES research has not focused on the specifics of this learning curve, the clinical and practical implications for a surgeon just beginning to practice EES, or the amount of experience required to become proficient. As well, neurosurgeons in favor of the traditional microscopic approach prefer maintaining stereoscopic vision and direct instrument visualization throughout the procedure. Initially, there were concerns regarding instrument maneuverability in EES; however, technologic advances such as the binarial endoscopic approach have resolved early concerns.[14]

Li et al[15] demonstrated that countries such as the United States, with high gross domestic products, tend to contribute more to the field of EES. With this in mind, it is understandable how only large, well-funded academic centers have been able to introduce EES successfully into their neurosurgery programs.[15]

There is currently no research showing the adoption and success of EES in small, nonacademic community hospitals, yet a portion of patients with sellar and suprasellar lesions are seen by community neurosurgeons. In Ontario, wait times in 2018 exceeded 26 weeks for neurosurgical patients to access surgery at a university-affiliated health science center.[16,17] Knowledge regarding the feasibility of EES in smaller community hospitals may help increase access to evidence-based neurosurgical practices for patients with sellar and suprasellar lesions, especially after recent recommendations during the COVID-19 pandemic of fair allocation of medical resources among different types of hospitals.[18] The purpose of this study was to demonstrate that EES can be used successfully for the treatment of sellar, suprasellar, and anterior skull base lesions in a community hospital setting, as well as to demonstrate and quantify the steep learning curve associated with EES.

MATERIAL AND METHODS

STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines were used to ensure the appropriate reporting of this observational study.[19]

Data Acquisition

We retrospectively reviewed the charts of 56 patients with sellar, suprasellar, and anterior skull base lesions who underwent EES between 2010 and 2018 at Windsor Regional Hospital. Demographic and surgical characteristics were reviewed including patient age, sex, clinical picture, lesion size, extent of resection (according to postoperative MRI, it was divided into gross total resection [GTR, absence of any tumor residual]; subtotal resection [<10% residual of the initial tumor size]; and biopsy), pathology, surgical complications, and clinical outcomes.

Surgical Technique

All surgeries were performed by 1 of the 4 neurosurgeons and 1 of the 2 otolaryngologists. They achieved binostril access using a 4-handed technique. A perioperative lumbar drain was not used generally except in 2 patients who developed postoperative cerebrospinal fluid (CSF) leak. All patients received intravenous cefazolin 30 minutes before surgery and another single dose 8 hours after surgery, which is similar to previously reported regimens.[20,21] After the patient was generally anesthetized and endotracheally intubated, the area of the nose was prepped and draped in the usual sterile fashion. Next, the otolaryngologist lateralized the middle turbinates bilaterally, followed by harvesting a vascularized unilateral nasoseptal flap. In recurrent cases, the vascularized nasoseptal flap of the contralateral side of the previous approach was harvested. Depending on the location and extent of the tumor, the bony access was expanded from the sphenoid to include transclival and/or transplanum exposure (extended endonasal) as needed. In the olfactory groove meningioma patient, the tumor was accessed through a transethmoid approach. The dura over the tumor was coagulated and opened in a cruciate fashion. The tumor excision/biopsy was carried out according to the pathology of the tumor. After excision/biopsy of the tumor, adequate hemostasis was achieved, followed by reconstruction of the skull base using a simple layer of Surgicel (Ethicon, Somerville, New Jersey, USA), a layer of Tisseel (Baxter Healthcare, Deerfield, Illinois, USA); a small layer of fat graft in the sinus, followed by of Tisseel (Baxter Healthcare, Deerfield, Illinois, USA); and finally a vascularized nasoseptal flap (added only in the second half of patients). In cases of intraoperative high-flow CSF leak and extended approaches, an additional layer of inlay and onlay fascia lata graft were used. Valsalva maneuver was done to confirm no CSF leakage. Medialization of the middle turbinates were done as the final stage of the procedure.

Learning Curve

For each surgeon, the patients were divided evenly into the first and second halves. The results of the first and second halves of each surgeon and the total number of patients were compared in terms of postoperative CSF leak, meningitis, new hormonal deficit, permanent diabetes insipidus, and visual improvement. We divided the outcomes according to surgeons to show the initial outcomes of neurosurgeons who received formal training on the endoscopic transsphenoid skull base surgeries and compare them with the other general neurosurgeons.

Literature Review

We compared our results with the recently published data discussing in detail the clinical outcomes of EES in pituitary adenoma resection (most of our patients were pituitary adenomas, and there is a paucity of studies describing the outcomes of sellar-suprasellar lesions in general) at academic centers in the past 5 years. Non-English language studies and studies describing the clinical outcome in a certain age group were excluded.

Statistical Analysis

Continuous variables were described as a mean ± standard deviation, whereas discrete variables were described as frequency (% of total). Continuous and discrete variables were analyzed via the Exact Fischer test and chi-square test. P value <0.05 was considered statistically significant. Data were analyzed using SPSS version 16.0 (IBM Inc).

RESULTS

Preoperative Characteristics

In our retrospective observational study, there were 56 patients, with male predominance (53.6%) and a mean age of 54.9 ± 13.7 (range, 27–82) years. The mean follow-up duration was 47.5 ± 25.8 months. All patients were undergoing a first-time resection of their lesion except there were 5 patients (8.9%) who had recurrent tumors treated with prior surgery (4 with previous microscopic transnasal transsphenoidal and 1 with a previous transcranial resection). Lesions included 45 pituitary adenomas (36 nonfunctioning, 3 prolactinomas, 3 gonadotrophin releasing hormone secreting, 2 adrenocorticotropic hormone secreting, and 1 growth hormone secreting), 5 meningiomas (4 tuberculum sellae and 1 olfactory groove), 3 metastatic lesions, 1 craniopharyngioma, 1 Rathke cyst, and 1 mucocele (Table 1). The mean size of the lesions was 2.76 ± 1.06 cm in the craniocaudal dimension, 2.15 ± 0.82 cm in the anteroposterior dimension, and 2.2 ± 0.81 cm in the transverse dimension (Figures 1 and 2). The patients with Knosp grades 3 and 4 were 35.5% of the pituitary adenoma patients. The tumor location, extension, and neurovascular relations of each case are reported in Table S1.

Table 1. Preoperative Characteristics

Parameter	Value
Age (years)	
Mean	54.9
Range	27–82
Standard deviation	13.7
Sex	
Male	30 (53.6)
Female	26 (46.4)
Recurrent tumor	5 (8.9)
Lesion type	
Pituitary adenomas	45 (80.4)
Nonfunctioning	36 (64.3)
Prolactinoma	3 (5.4)
Growth hormone secreting	1 (1.8)
GnRH secreting	3 (5.4)
ACTH secreting	2 (3.8)
Meningioma	5 (8.9)
Tuberculum sellae	4 (7.1)
Olfactory groove	1 (1.8)
Metastasis	3 (5.4)
Craniopharyngioma	1 (1.8)
Mucocele	1 (1.8)

All values are number of patients (%) unless stated otherwise.
GnRH, gonadotropin releasing hormone; ACTH, adrenocorticotropic hormone.

Clinical Presentation

The clinical presentation of patients in our study was heterogeneous. Patients presented with, in order of prevalence, headache, hormonal deficit, visual deficit, cranial nerve deficit, diplopia, and pituitary apoplexy. The majority of patients (42/56, 75%) presented with headache. A large proportion also presented with some form of hormonal deficit (31/56, 57.1%). These included panhypopituitarism, hypothyroidism, hypogonadism, hypoadrenalism, and hyperprolactinemia. Some patients experienced more than 1 hormonal deficit. The GnRH-secreting pituitary adenomas presented with mass effect rather than endocrine symptoms. Most (31 of 56) patients (55.4%) presented with a visual deficit. The most common visual deficit was bitemporal hemianopia (14/31, 45% of patients with visual field defects). Ten patients had cranial nerve deficits (17.9%), most commonly a third nerve palsy. Nine (16.1%) of 56 patients experienced diplopia. Eight (14.3%) of 56 patients had pituitary apoplexy. The majority of patients had a normal mental status; however, 12.5% presented with a disturbed level of consciousness (Table 2).

Perioperative Outcomes

Standard EES surgery was done in 49 (87.5%) patients, and extended EES was done in 7 (12.5%) patients. GTR was achieved in 32 (57.1%) patients, subtotal excision in 21 (37.5%) patients, and decompression and biopsy in three (5.4%) patients. The reasons for not achieving GTR were cavernous sinus invasion in 13 (23.2%) patients, surgeon's inexperience in 5 (8.9%) patients, and optic apparatus invasion/adherence in 2 (3.6%) patients. Finally, the initial aim of surgery was not GTR in four (7.1%) patients. None of the patients received adjuvant radiotherapy except the 3 metastatic lesions. There was no reported intraoperative complication. Postoperative vision normalized or improved in 27 (86.1%) patients or remained stable in 4 (13.9%) patients. There was no worsening of visual symptoms. Recovery of a preexisting hormonal deficit occurred in 13 (23.2%) patients, and a new hormonal deficit requiring hormonal replacement occurred in 9 (16.1%) patients. The mean hospital stay was 6.1 ± 4.9 days. Postoperative complications included postoperative CSF leak in 8 (14.3%) patients (3 [5.4%] of them were operated on by extended EES). Four (7.1%) patients had meningitis, diabetes insipidus was present in 19 (33.9%) patients (6 permanent and 13 transient), and postoperative intracranial hematomas required evacuation in 2 (3.6%) patients. Of the 8 patients who suffered a CSF leak, 3 resolved nonoperatively. One resolved by bed rest only, and 2 resolved with a lumbar drain. Five patients with postoperative CSF leak required surgical repair with Surgicel (Ethicon, Somerville, New Jersey, USA), Tisseel (Baxter Healthcare, Deerfield, Illinois, USA), fat graft, and fascia lata graft. Two of these patients required only 1 repair attempt, 1 required 2 attempts, and 2

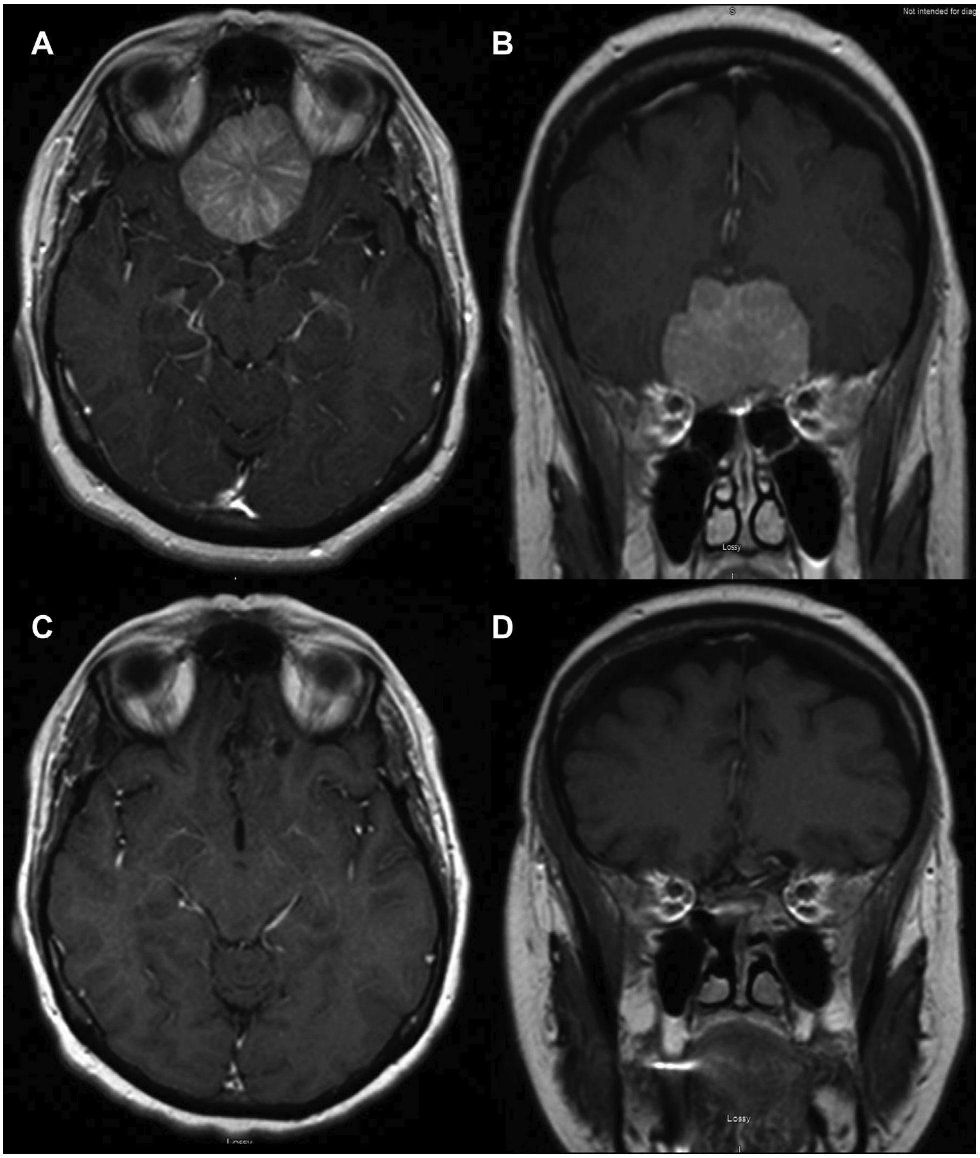

Figure 1. T1-weighted magnetic resonance imaging of the head with contrast of a 62-year-old female patient who presented with loss of smell sensation. (**A**) Preoperative axial view. (**B**) Preoperative coronal view. (**C**) Postoperative axial view. (**D**) Postoperative coronal view.

required 3 attempts to treat the CSF leak. There is no reported mortality during the first 30 days post surgery. Lesion progression or recurrence requiring redo surgery occurred in 5 (8.9%) patients; all of them were nonfunctioning pituitary adenomas (Table 3). We compared our results with the recently published data discussing in detail the clinical outcomes of EES in pituitary adenoma resection at academic centers in the past 5 years (Table 4).

Learning Curve

There was a higher rate of complications in earlier cases. When comparing the first half of operations to the latter half, the combined 4 neurosurgeons found a statistically significant ($P < 0.05$) decrease in postoperative CSF leak from 7/28 (25%) to 1/28 (3.6%) cases (Figure 3A). Combined rates of postoperative meningitis decreased from 3/28 (10.7%) to 1/28 (3.6%) cases ($P = 0.3$) (see Figure 3B). Combined rates of new hormonal deficits decreased from 6/28 (21.4%) to 3/28 (10.7%) ($P = 0.28$) (see Figure 3C). Combined rates of permanent postoperative diabetes insipidus decreased from 5/28 (17.9%) to 1/28 (3.6%) cases ($P = 0.08$) (see Figure 3D). As well, combined rates of visual improvement increased from 13/17 (76.5%) to 17/18 (94.4%) cases ($P = 0.13$) when comparing the early half of cases

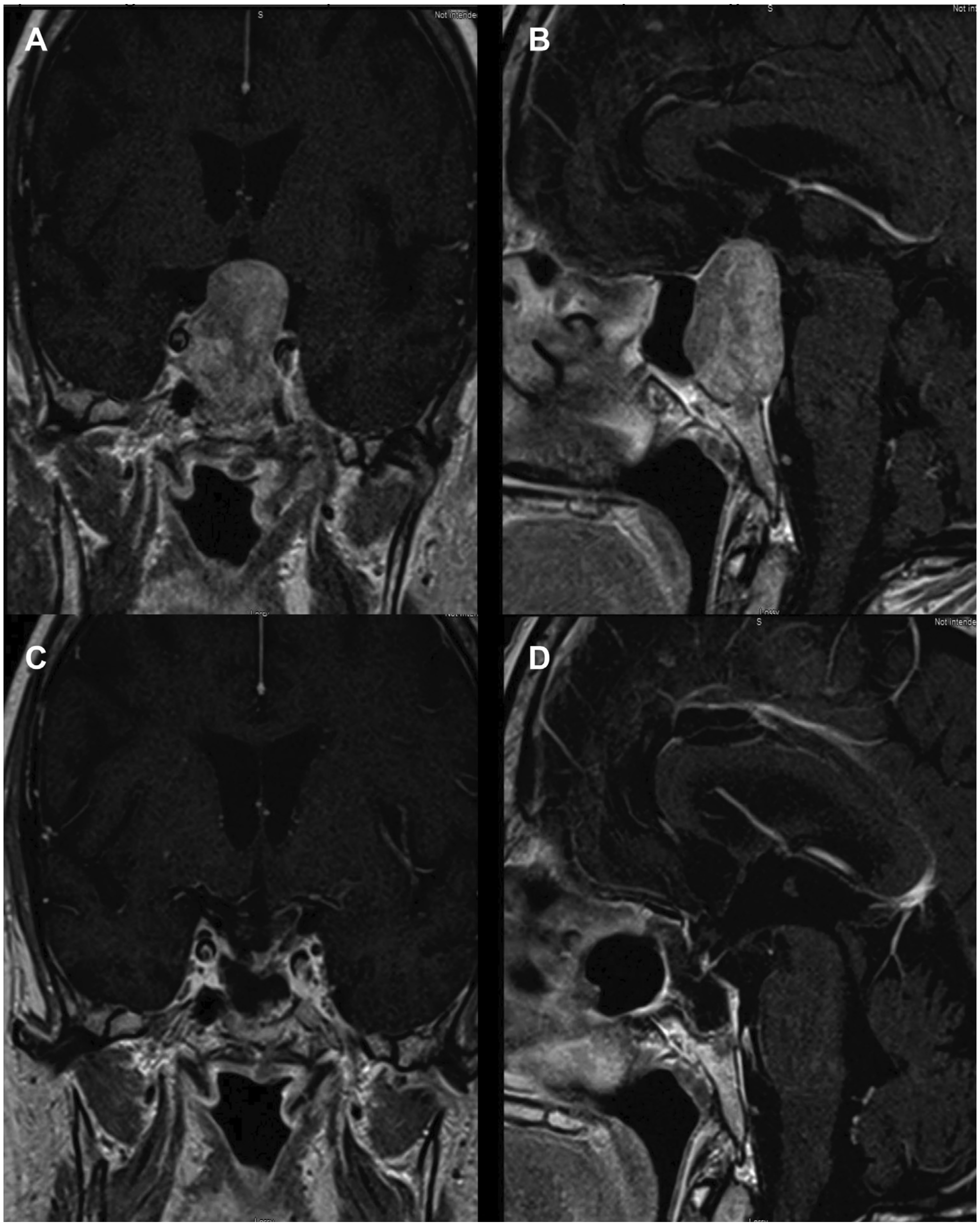

Figure 2. T1-weighted magnetic resonance imaging of the sella with contrast of a 68-year-old female patient who presented with bitemporal hemianopia. (**A**) Preoperative coronal view. (**B**) Preoperative sagittal view. (**C**) Postoperative coronal view. (**D**) Postoperative sagittal view.

to the latter half (see **Figure 3E**). The least rate of complications was among the only neurosurgeon who did a formal endoscopic skull base fellowship (**Table 5**).

DISCUSSION

There is a growing trend toward fully endoscopic endonasal transsphenoidal surgery. Many studies show a similar if not greater efficacy of EES compared with the gold standard microsurgical techniques.[26,42,44] This is the first study to look for the outcomes of patients undergoing endoscopic transnasal sellar, suprasellar, and anterior cranial fossa lesion excisions in a community hospital setting. It has also been demonstrated that the transition to EES is hindered by its learning curve, although the details of this learning curve and its clinical implications have not been studied in detail.[45] Given the prevalence of sellar and suprasellar lesions, as well as the growing evidence for the efficacy of endoscopic endonasal transsphenoidal surgery,

Table 2. Clinical Presentation

Parameter	Value
Headache	42/56 (75%)
Hormonal deficit	32 (57.1%)
Hypothyroidism	12/32 (37.5%)
Hypogonadism	11/32 (34.4%)
Panhypopituitarism	6/32 (18.8%)
Hyperprolactinemia	5/32 (15.6%)
Hypoadrenalism	4/32 (12.5%)
Cushing disease	3/32 (9.4%)
Visual field deficit	31/56 (55.4%)
Bitemporal hemianopia	14/31 (45.2%)
Other deficits	17/31 (54.8%)
Cranial nerve deficit	10/56 (17.9%)
Third nerve palsy	3/10 (33.3%)
Diplopia	9/56 (16.1%)
Pituitary apoplexy	8/56 (14.3%)
Disturbed level of consciousness	7/56 (12.5%)

All values are number of patients (%) unless stated otherwise.

understanding the dynamics of the learning curve, especially in the setting of a community hospital, may help increase adoption, surgical proficiency, and improve outcomes in the management of patients with these lesions in the future in all hospital settings (academic centers, community hospitals, and developing country hospitals). Other supportive specialties, such as neurointervention to back up any intraoperative vascular complications and neuroendocrine for managing any endocrine manifestations perioperatively should be present.

Extent of Resection

It is difficult to evaluate or compare the extent of resection when discussing the many different types of sellar and suprasellar lesions that may be approached and resected through endoscopic endonasal surgery. Certain lesions require an attempt for GTR, while others, such as metastatic lesions, have high levels of success when combined with adjuvant therapy. Definitions of GTR, subtotal resection, decompression, and/or biopsy are unique and can vary for each study. In a review of 16 studies of giant adenomas, Komotar et al[46] noted the microscopic transsphenoidal cohort had a lower rate of total resection and worse visual outcome than the endoscopic group. Pituitary adenomas are the most frequently studied and managed endoscopically. A 2018 metanalysis of 50 studies by Almutairi et al[47] demonstrated a GTR rate for pituitary adenomas of 74%. For tumors invading the cavernous sinus, many authors noted a higher resection rate with an endoscope than a microscope, indicating the advantage of the panoramic and angled views of the medial wall of the cavernous sinus provided by endoscopes. In addition, endoscopic endonasal surgery has been reported to be a valid option for resection in recurrent adenomas.[48] Graffeo et al[49] demonstrated in their metanalysis that current GTR rates are 89.7% for olfactory groove meningiomas, 79.9% for tubercula sella meningiomas, 59% for craniopharyngiomas, and 58.8% for clival chordomas. Our series showed that GTR was achieved in 62.2% of pituitary adenomas, 50% of tuberculum sellae meningiomas, olfactory groove meningioma and mucocele patient, subtotal resection of the tumor in the craniopharyngioma patient, and decompression and biopsy of the tumors in all metastasis patients. The main reason for not achieving GTR in our series was the cavernous sinus invasion (23.1%). Due to the paucity of cases of olfactory groove meningiomas, metastasis, craniopharyngioma, mucocele, and Rathke cyst, we could not compare our results with the literature for such pathologies.

Perioperative Outcomes

Visual and postoperative outcomes in our study were consistent with the results shown in other studies.[24,33,40,42,43,50] Of patients experiencing visual issues at the time of diagnosis, 86.1% of patients had vision improvement and only 13.9% had no change in vision. No patients had a worsening vision. Other studies have reported rates of vision improvement from as low as 23% to as high as 100%.[22-26,28-34,37-43,50] In our study, no patients had

Table 3. Perioperative Outcomes

Parameter	Value
Excision	
Gross total excision	31 (55.4)
Subtotal excision	22 (39.3)
Decompression and biopsy	3 (5.4)
Vision	
Normal to improved	27 (86.1)
Remained stable	4 (13.9)
Worsened	0
Complications	
New hormone deficiency	9 (16.1)
Postoperative CSF leak	8 (14.3)
Meningitis	4 (7.1)
Diabetes insipidus	
Transient	13 (23.2)
Permanent	6 (10.7)
Hematoma and evacuation	2 (3.6)
Vascular injury	0
Nasal complications	0
Other complications	0
Lesion progression or recurrence	5 (8.9)

All values are number of patients (%) unless stated otherwise.
CSF, cerebrospinal fluid.

Table 4. Comparison of Demographics, Postoperative Results, and Complications of Endoscopic Endonasal Studies in the Past 5 Years

Study	Age (Years)	Sex (% male)	Macroadenoma (%)	GTR	Vision Normalized or Improved (%)	Vision Worsened (%)	New Hormonal Deficit (%)	Postoperative CSF Leak (%)	Postoperative Hematoma (%)	Meningitis (%)	Permanent DI (%)	30-day Mortality (%)	Recurrence
Chabot et al., 2015[22]	56.3	64.1	100	85	79	0	12.8	10.3	—	—	7.7	0	0
Marenco et al., 2015[23]	72.4	44	100	65.4	70.8	0	16	4	—	4	—	4	21.4
Wang et al., 2015[24]	40.3	44.3	79	91.7	92	0.43	1.3	0.6	0.69	1.03	0.69	—	—
Akin et al., 2016[25]	35.5	46.5	86.6	-	100	0	18.2	2.1	-	2.8	0	—	3.5
Guo-Dong et al., 2016[26]	43.4	59	-	73.1	75	0	3	1	3	0	1	0	—
Jang et al., 2016[27]	48.4	43.8	70.4	69.2	—	—	1.2	1.8	0.6	0.6	0.9	0.3	—
Jones et al., 2016[28]	62.3	96	—	80	100	0	0	4	0	0	0	—	—
Magro et al., 2016[29]	57	57	100	59	86.6	2.4	13.7	2.7	2	3.3	6.2	0.7	—
Qureshi et al., 2016[30]	52.6	55.1	96.1	93.6	96.5	0	10.8	1.3	—	—	2.6	—	—
Yildirim et al., 2016[31]	48.5	55	100	90	39.1	0	7.5	1.8	—	—	1.3	0.6	—
Zhan et al., 2016[32]	36.5	57.8	62.2	86.7	92.7	0	11.1	4.4	—	0	0	0	—
Beltrame et al., 2017[33]	48.5	44	78.6	60	73.8	3.2	12.1	2.1	1.4	1.4	3.2	0.7	2.9
Gondim et al., 2017[34]	54.9	69.2	100	79.5	74.1	—	—	0	—	0	**5.1**	**0**	—
Linsler et al., 2017[35]	55.5	41.4	81.4	88	—	0	11	0	0	0	1.4	0	6
Thawani et al., 2017[36]	55.7	51.2	100	29.6	—	1.48	—	10.3	—	1	4.4	1	—
Zhang et al., 2017[37]	—	53.3	100	67.2	37.2	0.7	3.5	1.5	—	2.9	0	—	16.7
Zoli et al., 2017[38]	52.4	62.7	100	80	85.5	0	20	1.3	-	0	5.3	-	4

Hajdari et al., 2018[39]	57.4	57.1	85.3	73.4	58.6	1.17	11.8	8.2	0.6	2.3	—	—	—
López-García et al., 2018[40]	54	47	89	77	91	2.2	9	0	1.2	1.2	3	—	—
Taghvaei et al., 2018[41]	39.4	47.1	76.5	89.7	100	0	4.4	2.9	—	0	5.9	0	—
Castano-Leon et al., 2019[42]	52	40	82.5	63.9	71.4	1.03	18.6	2.1	2.1	4.1	3.1	0.7	6.2
Pablo et al., 2019[43]	—	—	78.6	60	23	1.03	12	2.1	1.4	2.1	2.1	0.7	7
Our study	54.9	53.6	94.6	55.4	87.1	0	16.1	8.9	3.6	7.1	10.7	0	8.9

DI, diabetes insipidus.

worsened vision after surgery. This is consistent with results found by other researchers who generally saw a very low rate of worsened visual deficits after surgery, on the order of 0%–3.2%.[22-26,28-33,35-43,50]

The rate of recovery from hormonal deficits in our study is greater than that found by other researchers. Most of our patients (83.9%) showed stable or improved hormonal deficits. Pablo et al[43] and Castano-Leon[42] found that hormonal deficits were stable or improved in 76.9% and 75.3% of patients, respectively. However, our rate of new deficits postoperatively seems to be in line with that of other researchers, at 16.1%. Rates of new deficits in other studies have ranged from 0% to 20%.[22-33,35,37-43,50-54]

Perioperative complications that we analyzed include the rates of hematoma requiring evacuation, diabetes insipidus, CSF leak, and meningitis. Our patients experienced a similar rate of postoperative hematoma when compared with previous studies described in the literature. In our literature review, the rate of this complication ranged from 0% to 3%.[24,26-29,33,35,39,40,42,43] Two (3.6%) of our patients experienced this complication and required surgical evacuation of the hematoma. We did have a high rate of permanent diabetes insipidus postoperatively. Six (10.7%) of our patients experienced this complication, whereas the existing literature estimates this complication occurring in 0%–7.7% of cases.[22,24-38,40-43,50]

In terms of the other postoperative complications, our study showed increased rates of postoperative CSF leak and meningitis. Among our patients, 14.3% experienced postoperative CSF leak. In previous studies, the prevalence of postoperative CSF leak ranged from 0%-10.3%.[22-43,50,55] Of these 8 patients, 3 resolved nonoperatively (1 with bed rest only and 2 with a lumbar drain). Five required surgical repair using Surgicel (Ethicon, Somerville, New Jersey, USA), Tisseel (Baxter Healthcare, Deerfield, Illinois, USA), fat graft, fascia lata graft, and vascularized nasoseptal flap. Two patients required only 1 repair, 1 patient required 2 repair attempts, and 2 patients required 3 attempts to successfully treat the CSF leak. Out of the 7 patients who were operated on by extended EES, 3 (42.9%) of them developed postoperative CSF leak. This constitutes 37.5% of the patients who developed postoperative CSF leak. However, the CSF leak rate has significantly dropped from 25% to 3.6% ($P < 0.05$) after using vascularized nasoseptal flaps and proper skull base reconstruction, especially in extended EES cases, and the results were comparable with similar studies.[23,25,28,29,33,41-43,56,57] Of our patients, 7.1% experienced meningitis, whereas the prevalence of this in other studies generally ranged from 0%–4.1%. The 30-day mortality rate was 0%, and in the other studies it ranged from 0%–4%.[22,23,26,27,29,31-36,41-43]

Fewer studies have assessed the length of stay after EES; however, our patients' length of stay appears to be on the high end of a range from 3–6 days.[33,42,55] Our patients remained in the hospital for 6.1 ± 4.9 days. This may have been due to the relative unfamiliarity of our center with the procedure; the staff therefore may have wanted to observe patients for a longer duration of time. Finally, our recurrence rate was 8.9%, which is within the reported range from 2%–21.4%.[22,23,25,33,35,37,38,42,43]

Overall, our outcome results and complication rates were relatively higher than those of researchers in academic

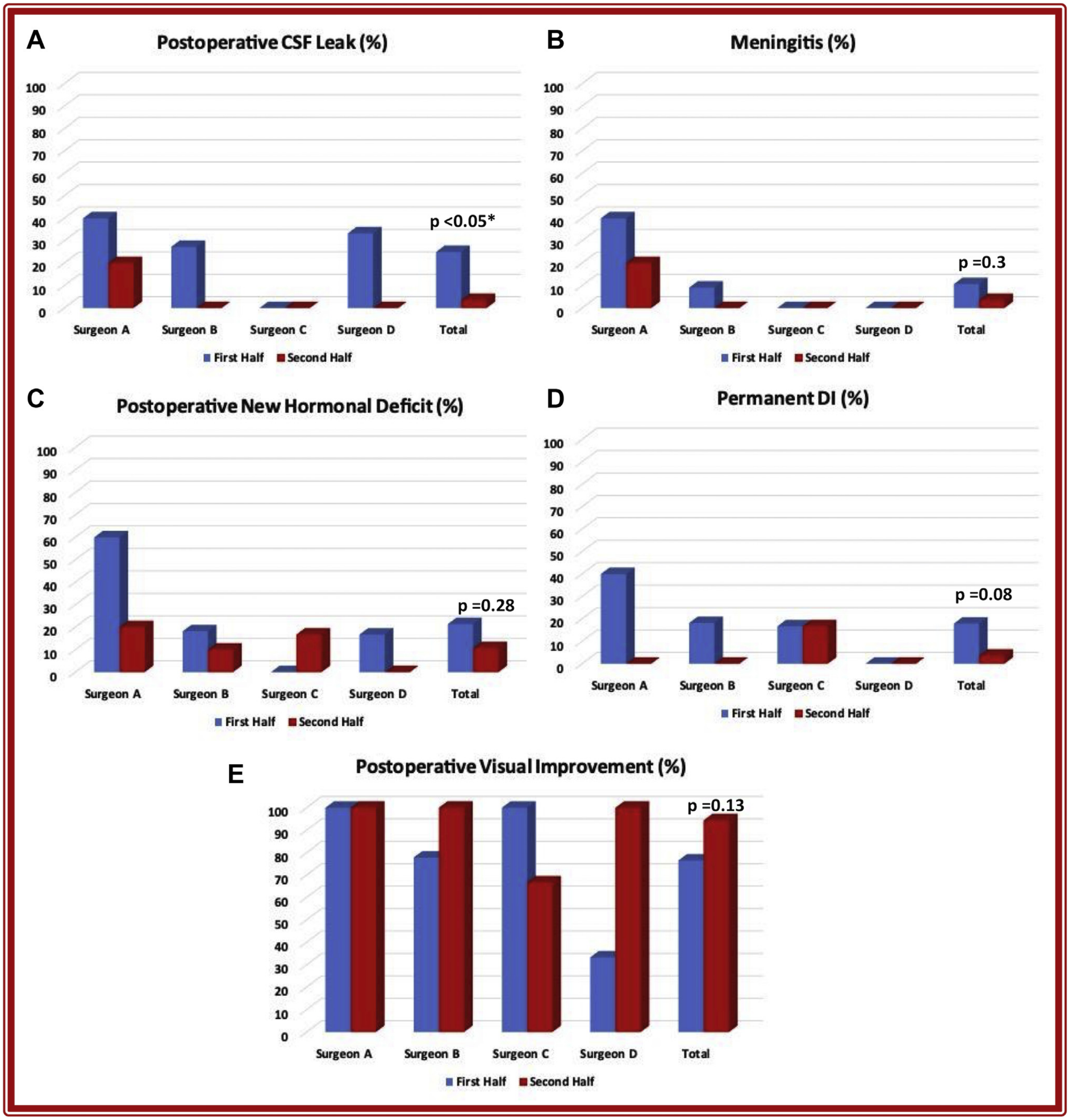

Figure 3. Postoperative clinical outcomes for each half of sample population, by surgeon showing the learning curve. (**A**) Percentage of postoperative cerebrospinal fluid leak. (**B**) Percentage of meningitis. (**C**) Percentage of postoperative new hormonal deficit. (**D**) Percentage of permanent diabetes insipidus. (**E**) Percentage of postoperative visual improvement.

centers. However, this postoperative complication rate showed a decrease from the first to second half of cases. Therefore this number is likely influenced by the fact that such a large proportion of our cases represented our community neurosurgeons beginning to perform these types of surgeries.

Table 5. Statistical Significance of Postoperative Clinical Outcomes for Each Half of Sample Population, by Surgeon

Parameter	First Half	Second Half	*P* Value
Postoperative CSF leak:			
Surgeon A	2/5 (40)	1/5 (20)	0.49
Surgeon B	3/11 (27.3)	0/10 (0)	0.07
Surgeon C	0/6 (0)	0/6 (0)	1
Surgeon D	2/6 (33.3)	0/7 (0)	0.1
Total	7/28 (25)	1/28 (3.6)	**<0.05**
Meningitis			
Surgeon A	2/5 (40)	1/5 (20)	0.49
Surgeon B	1/11 (9.1)	0/10 (0)	0.33
Surgeon C	0/6 (0)	0/6 (0)	1
Surgeon D	0/6 (0)	0/7 (0)	1
Total	3/28 (10.7)	1/28 (3.6)	0.3
New hormonal deficits			
Surgeon A	3/5 (60)	1/5 (20)	0.2
Surgeon B	2/11 (18.2)	1/10 (10)	0.59
Surgeon C	0/6 (0)	1/6 (16.7)	0.3
Surgeon D	1/6 (16.7)	0/7 (0)	0.26
Total	6/28 (21.4)	3/28 (10.7)	0.28
Permanent diabetes insipidus			
Surgeon A	2/5 (40)	0/5 (0)	0.11
Surgeon B	2/11 (18.2)	0/10 (0)	0.16
Surgeon C	1/6 (16.7)	1/6 (16.7)	1
Surgeon D	0/6 (0)	0/7 (0)	1
Total	5/28 (17.9)	1/28 (3.6)	0.08
Vision improvement			
Surgeon A	1/1 (100)	4/4 (100)	1
Surgeon B	7/9 (77.8)	7/7 (100)	0.18
Surgeon C	4/4 (100)	2/3 (66.7)	0.21
Surgeon D	1/3 (33.3)	4/4 (100)	0.05
Total	13/17 (76.5)	17/18 (94.4)	0.13

P value indicates statistically significant.
CSF, cerebrospinal fluid.

Learning Curve

Our study showed that rates of postoperative CSF leak, meningitis, new hormonal deficits, and permanent diabetes insipidus decreased from the first group of surgeries to the second group when all surgeons were analyzed together. However, only the incidence of postoperative CSF leak decreased significantly (7/28 in the first patient group, 1/28 in the second patient group, $P < 0.05$). This significant decrease is attributed to the use of vascularized nasoseptal flap in the second half of patients. Our small sample size may be the reason that the other complications did not reach statistical significance. However, this is consistent with other studies that have also not shown statistical significance for a decrease in complications.[30,58,59] One study has even shown an increase in the complication rate, which was hypothesized to be due to increased surgeon confidence and aggressiveness in attempting GTR as surgeons gained experience with the procedure.[51] Despite this, the decrease in complication rate is certainly clinically significant and reduces the burden on surgeons and patients when reintervention is necessary.

In terms of improvement in outcome, the visual improvement did better from the first half of the case series (13 of 17 patients) to the second (17 of 18 patients); however, this was not statistically significant ($P = 0.13$). When we divided the outcomes according to surgeons, we found that the initial outcomes of the neurosurgeon who received formal training on the endoscopic transsphenoid skull base surgeries were better than the other general neurosurgeons.

The rapid decrease in complications from the first to second series of cases, while not statistically significant, shows that the learning curve for EES is steep. This means that once our surgeons gained experience with the procedure, the complication rates decreased dramatically.

Challenges and Limitations

This study has several limitations. Firstly, this is a retrospective study with an extremely heterogeneous patient population in regard to pathologic diagnosis encompassing a variety of pituitary adenomas, tuberculum sellae and olfactory groove meningiomas, metastasis, craniopharyngioma, Rathke cyst, and a mucocele. The patient population was small with 56 cases, with each of surgeons A, B, C, and D completing 10, 21, 12, and 13 operations, respectively. All of these challenges were overcome. We think that there is a better outcome in terms of patient care when there is interspecialty teamwork among neurosurgeons, otolaryngologists, endocrinologists, ophthalmologist/optometrist, and neuro-interventionist. One challenge in regards to initiating the EES, especially in a community hospital setting where EES is relatively new, is that neurosurgeons do not have an abundance of previous experience with endoscopic nasal anatomy. Therefore if there were any intraoperative complications regarding nasal anatomy, an otolaryngologist would be called into the operating room without any prior notice. This was going to lead to increased levels of frustration, especially between neurosurgeons and otolaryngologists. The obvious solution was to increase teamwork and collaboration between the specialties. In this regard, 2 neurosurgeons and 2 otolaryngologists attended several cadaveric courses to learn this new technique together. Only 2 of the local otolaryngologists agreed to participate in the EES operations. This presented another challenge. If any of the postoperative patients presented to the emergency department after discharge, none of the uninvolved otolaryngologists would consider seeing these patients. The otolaryngologists had to better intercommunicate so that they were all comfortable seeing patients post EES presenting with purely nasal problems such as epistaxis. The neuronavigation billing code for remuneration also needed to be alternated between the neurosurgeons and otolaryngologists to better develop the working relationship between the specialties. Other challenges that arose included administrative issues, such as a lack of funding for and a shortage of nasal instrument sets; the logistics of arranging an otolaryngologist and neurosurgeon to be available at the same time; and education of the neurosurgical operating room nursing staff in regards to otolaryngologic procedures. We overcame all these challenges.

The future direction is to train more neurosurgeons in EES techniques. Then it will be more feasible to perform these cases in a community hospital setting. In our case series, only 1 surgeon (D) had a previous fellowship training in endoscopic transsphenoidal surgery with better outcomes than other neurosurgeons. We hope that new trainees will be trained and confident in performing these surgeries in community hospitals.

CONCLUSION

Despite the fact that our overall complications are higher than those in the reported literature, the outcomes of the second half of patients after the surgeons gained experience were similar to those in academic centers. However, complex cases (e.g., anterior cranial fossa lesions and craniopharyngiomas) should be referred to an experienced surgeon, such as a well-trained endoscopic skull base surgeon in the same center or in an academic center. The learning curve for EES is steep and improves greatly and quickly with adequate practice. So, endoscopic endonasal resection of sellar, suprasellar, and anterior skull base lesions is safe, minimally invasive, and efficient in a community hospital setting, provided the presence of a multidisciplinary team such as neurointervention and neuroendocrinology. Extent of resection, visual, and postoperative outcomes after gaining experience are similar to those reported in larger academic centers. In the future, as time will allow for the progression of endoscopy instruments and increased surgeon experience, this approach should become first line for the treatment of sellar and suprasellar lesions in hospitals of all settings (academic centers, community hospitals, and developing country hospitals).

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Mohamed A.R. Soliman: Writing - original draft, Writing - review & editing, Conceptualization, Methodology, Data curation, Validation, Formal analysis. **Sydney Eaton:** Writing - original draft, Writing - review & editing. **Elise Quint:** Writing - original draft, Writing - review & editing. **Abdullah F. Alkhamees:** Writing - review & editing, Data curation, Validation. **Saba Shahab:** Writing - review & editing. **Avalon O'Connor:** Writing - review & editing. **Erika Haberfellner:** Writing - review & editing. **Jacob Im:** Writing - review & editing. **Abdurrahim A. Elashaal:** Supervision. **Francis Ling:** Writing - review & editing, Supervision. **Mustafa Elbreki:** Writing - review & editing, Supervision. **Tommy Dang:** Writing - review & editing, Supervision. **Dante J. Morassutti:** Writing - review & editing, Supervision. **Abdalla Shamisa:** Conceptualization, Validation, Writing - review & editing, Supervision.

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SUPPLEMENTARY DATA

Table S1. Tumor Type, Location, Extension, Neurovascular Relation, Type of Surgery, and Extent of Resection of 56 Patients

Case Number	Tumor Type	Location	Extension	Optic Chiasm	Vascular Relation	Surgery	Extent of Resection
1	Pituitary adenoma (GnRH)	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Bilateral mass effect on carotid	Standard	GTR
2	Prolactinoma	Sellar	—	—	—	Standard	GTR
3	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous sinus	Invasion	Rt. encased Lt. mass effect	Standard	GTR
4	Nonfunctioning pituitary adenoma	Sellar, suprasellar, infrasellar	Bilateral cavernous sinus	Compressed	Rt. encased Lt. mass effect	Standard	GTR
5	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Right cavernous sinus	Compressed	Rt. encased	Standard	GTR
6	Nonfunctioning pituitary adenoma	Sellar	—	—	—	Standard	GTR
7	Olfactory groove meningioma	Olfactory groove	—	—	—	Extended	GTR
8	Tuberculum sellae meningioma	Suprasellar	—	—	—	Extended	GTR
9	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Bilaterally around the carotid	Standard	GTR
10	Nonfunctioning pituitary adenoma	Sellar-suprasellar	—	Compressed	—	Standard	GTR
11	Pituitary adenoma (GnRH)	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Bilaterally around the carotid	Standard	GTR
12	Pituitary adenoma (ACTH)	Sellar	—	—	—	Standard	GTR
13	Nonfunctioning pituitary adenoma	Sellar-Suprasellar	—	Compressed	—	Standard	GTR
14	Nonfunctioning pituitary adenoma	Sellar-Suprasellar	Bilateral cavernous sinus, supraclinoid	Compressed	Bilaterally around the carotid	Standard	GTR
15	Pituitary adenoma (ACTH)	Sellar-suprasellar	Bilateral cavernous sinus, left temporal lobe	—	Bilaterally around the carotid	Standard	GTR
16	Nonfunctioning pituitary adenoma	Sellar-Suprasellar	Bilateral cavernous Sinus	—	Bilateral mass effect on carotid	Standard	GTR
17	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Left cavernous sinus	Compressed	Lt. encased	Standard	GTR
18	Prolactinoma	Sellar	—	—	—	Standard	STR
19	Metastasis	Suprasellar	—	—	—	Standard	Decompression and biopsy
20	Tuberculum sellae meningioma	Sellar-suprasellar	—	Compressed	—	Standard	STR
21	Tuberculum sellae meningioma	Sellar-suprasellar	Frontal lobe	—	—	Extended	GTR

Continues

Table S1. Continued

Case Number	Tumor Type	Location	Extension	Optic Chiasm	Vascular Relation	Surgery	Extent of Resection
22	Mucocele	Sellar	—	—	—	Standard	GTR
23	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Rt. encased and left around the carotid but not totally encased	Standard	STR
24	Pituitary adenoma (GnRH)	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Bilaterally around the carotid	Standard	STR
25	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Left cavernous sinus	Compressed	Lt, around the carotid	Standard	STR
26	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Bilaterally around the carotid	Standard	STR
27	Rathke cyst	Sellar-suprasellar	—	Compressed	—	Standard	STR
28	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Rt. cavernous sinus	Compressed	Rt. around the carotid	Standard	STR
29	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Bilaterally around the carotid	Standard	STR
30	Nonfunctioning pituitary adenoma	Sellar-Suprasellar	—	Compressed	—	Standard	STR
31	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Rt. cavernous sinus	Compressed	Rt. encased	Standard	STR
32	Tuberculum sellae meningioma	Sellar-suprasellar	Hypothalamus, orbital apex, left supraclinoid, frontal lobe	Compressed	Lt. supraclinoid carotid artery encased	Extended	STR
33	Nonfunctioning pituitary adenoma	Sellar	—	—	—	Standard	GTR
34	Nonfunctioning pituitary adenoma	Sellar-suprasellar	—	Compressed	—	Standard	GTR
35	Nonfunctioning pituitary adenoma	Sellar	—	—	—	Standard	GTR
36	Nonfunctioning pituitary adenoma	Sellar-suprasellar	—	Compressed	—	Standard	GTR
37	Nonfunctioning pituitary adenoma	Sellar-suprasellar	—	Compressed	—	Standard	STR
38	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Bilaterally around the carotid	Standard	STR
39	Nonfunctioning pituitary adenoma	Sellar-suprasellar	—	Compressed	—	Standard	STR
40	Prolactinoma	Sellar-suprasellar	Bilateral cavernous sinus, frontal lobe	Compressed	Bilaterally around the carotid	Standard	STR
41	Nonfunctioning pituitary adenoma	Sellar-suprasellar	—	Compressed	—	Standard	STR
42	Pituitary adenoma (GH)	Sellar	—	—	—	Standard	GTR
43	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Bilateral encased	Standard	STR
44	Nonfunctioning pituitary adenoma	Sellar-suprasellar	—	Compressed	—	Standard	GTR

All values are number of affected patients/total number of patients (%).
GnRH, gonadotropin releasing hormone; GTR, gross total resection; ACTH, adrenocorticotropic hormone; STR, subtotal resection; GH, growth hormone.

Continues

Table S1. Continued

Case Number	Tumor Type	Location	Extension	Optic Chiasm	Vascular Relation	Surgery	Extent of Resection
45	Nonfunctioning pituitary adenoma	Sellar	—	—	—	Standard	GTR
46	Nonfunctioning pituitary adenoma	Sellar	—	—	—	Standard	GTR
47	Nonfunctioning pituitary adenoma	Sellar, suprasellar, infrasellar	Bilateral cavernous sinus, hypothalamus, bilateral temporal lobes	Compressed	Lt. encased Rt. mass effect	Extended	STR
48	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous Sinus	Compressed	Bilaterally around the carotid	Standard	GTR
49	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous sinus	Compressed	Bilaterally mass effect	Standard	GTR
50	Nonfunctioning pituitary adenoma	Sellar-Suprasellar	—	Compressed	—	Standard	GTR
51	Nonfunctioning pituitary adenoma	Sellar-suprasellar	Bilateral cavernous sinus, frontal lobe	Compressed	Bilaterally around the carotid	Standard	GTR
52	Nonfunctioning pituitary adenoma	Sellar	—	—	—	Standard	GTR
53	Nonfunctioning pituitary adenoma	Sellar, clival, infrasellar	Bilateral cavernous sinus, Rt. Meckel cave and prepontine cistern	Invasion	Encased bilateral	Extended	STR
54	Metastasis	Sellar, infrasellar	Bilateral cavernous sinus, Meckel cave	—	Bilaterally around the carotid	Standard	Decompression and biopsy
55	Metastasis	Sellar-suprasellar	Bilateral cavernous sinus, hypothalamus	Compressed	Bilaterally around the carotid	Standard	Decompression and biopsy
56	Craniopharyngioma	Sellar-suprasellar	Hypothalamus	Invasion	—	Extended	STR

All values are number of affected patients/total number of patients (%).
GnRH, gonadotropin releasing hormone; GTR, gross total resection; ACTH, adrenocorticotropic hormone; STR, subtotal resection; GH, growth hormone.