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CLINICAL ARTICLE

Visual deterioration after endonasal endoscopic skull base surgery: causes, treatments, and outcomes

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OBJECTIVE Visual deterioration after endoscopic endonasal transsphenoidal surgery (EETS) for sellar and parasellar masses is a rare but serious complication caused by either compressive or ischemic mechanisms. Timely diagnosis and intervention may restore vision if instituted appropriately. The associated risk factors and their relation to the success of intervention are not well understood.

METHODS The authors examined a series of 1200 consecutive EETS cases performed by the senior author at Weill Cornell/NewYork-Presbyterian Hospital from 2010 to 2020. Cases with postoperative visual deterioration were identified. Pre- and postoperative clinical data, mechanism of visual decline, latency to intervention, and long-term visual outcome were retrospectively collected and analyzed with appropriate statistical methods.

RESULTS Twenty-one patients (1.75%) complained of early postoperative visual deterioration. The most common pathology associated with postoperative visual loss was craniopharyngioma (7.69%), followed by meningioma (5.43%) and then pituitary adenoma (1.94%). Timely intervention restored vision in 81% of patients for a 0.33% rate of permanent visual deterioration. Average time to visual deterioration was 28.8 hours, and over 70% of patients experienced vision loss within the first 13 hours. Compressive etiology (n = 11), consisting of either hematoma (n = 8) or graft displacement (n = 3), occurred 7.3 hours and 70.3 hours after surgery, respectively, and was more common in adenomas. Acute postoperative visual deterioration was more common in firm closures (4.78%) compared with soft closures (1.03%; p = 0.0006). Ischemic etiology (n = 10) occurred 10.3 hours after surgery and was more common with craniopharyngiomas and meningiomas (p = 0.08). Sixteen patients (76.2%) underwent early reoperation to explore and decompress the optic apparatus. Vision was restored to baseline after reoperation in all 11 compressive cases, whereas 6/10 ischemic cases improved with supplemental oxygen and hypervolemic hypertensive therapy (p = 0.02). Fluid expansion from 8 to 16 hours (p = 0.034) and systolic blood pressure elevation from 32 to 48 hours (p = 0.05) after surgery were significantly higher in those ischemic patients who recovered some vision compared with those with persistent visual deficits.

CONCLUSIONS Visual deterioration after EETS is a rare event but can be effectively treated if acted upon appropriately and in a timely fashion. Compressive etiology is reversible with early reoperation. Ischemic etiology can be successfully treated in roughly half of cases with supplemental oxygen and hypertensive hypervolemic therapy but may result in permanent visual deterioration if not instituted appropriately or if delayed with unnecessary exploratory surgery.

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KEYWORDS skull base; endonasal; endoscopic; transsphenoidal; pituitary surgery; vision loss; visual field; complication

Endoscopic endonasal transsphenoidal surgery (EETS) is a minimally invasive procedure that allows surgeons to treat anterior skull base tumors via direct transsphenoidal access to the sellar and parasellar regions.[1–9] While EETS offers advantages over the transcranial approach, patients can still experience postoperative complications related to damage to adjacent structures, including the optic apparatus and the optic nerves and their vascular supply. A rare but clinically important complication among patients undergoing EETS is postoperative visual deterioration (PVD).[1–7,10–20] Rates of postoperative visual loss can vary from as low as 1% in large case series with multiple pathologies[11] to as high as 30% in smaller series of meningiomas.[4,5]

Hematoma, surgical graft volume or displacement, and direct surgical trauma are well-defined mechanisms that

ABBREVIATIONS DI = diabetes insipidus; EEA = endoscopic endonasal approach; EETS = endonasal transsphenoidal surgery; GTR = gross-total resection; MAP = mean arterial pressure; PVD = postoperative visual deterioration; SOHHT = supplemental oxygen and hypervolemic hypertensive therapy; STR = subtotal resection.

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can cause injury to the optic chiasm, resulting in visual deficits postoperatively.[1–5,11,14–16,20] In these cases, reoperation to evacuate the hematoma, reposition the graft, or remove any excess packing is generally successful and these patients do not typically experience permanent visual defects, depending on the delay to intervention. There have also been reported cases of vision loss with ischemic optic neuropathy caused by vascular compression, injury, or sacrifice during surgery.[17–19] However, the timing, treatment, and outcomes of patients with different forms of postoperative vision loss have not been directly compared and evaluated to determine the best treatment measures. In this study we aimed to determine possible causes of vision loss in this population, potential management strategies, and long-term outcomes in our single-institution series.

Methods

After receiving approval from the institutional review board at Weill Cornell Medical College, we queried a prospective database of 1200 consecutive EETS cases for which surgery was performed by the senior author at Weill Cornell/NewYork-Presbyterian Hospital between January 2010 and February 2020. A detailed retrospective chart review of surgical documents, medical records, and radiology reports was performed and patients with PVD were identified from this cohort and selected for further review (n = 21). For the purposes of this study, we defined PVD as a subjective deterioration in vision immediately following surgery, with bedside visual field finger confrontation testing for confirmation. This deterioration included worsening of a previously existing visual deficit as well as development of a new deficit in a patient with normal preoperative vision. Objective proof of deterioration with formal visual field testing was not required, because formal testing of visual fields cannot be performed in the inpatient setting at our institution and delays to obtain such studies would be deleterious. Formal visual field testing was used to establish preoperative and long-term visual deficits when available. Documentation of complete formal visual field testing, including preoperative and long-term visual testing, was obtained in 42.9% of patients, while 90.5% of patients had at least one documented perioperative formal visual field test. All patients were also directly contacted to obtain a subjective assessment of their long-term visual outcomes.

Other variables of interest included age, sex, tumor histology, extent of resection (gross-total resection [GTR] versus subtotal resection [STR; < 95%]), procedure length, perioperative visual outcomes, presumed cause of vision loss, and long-term visual acuity at most recent follow-up. Tumor histology was determined by pathology specimens reviewed by independent neuropathologists, while data regarding tumor size and extent of resection were derived from imaging studies reviewed by two independent reviewers.

The presumptive etiology of vision loss was determined by examining imaging reports, surgical data, and chart notes from the immediate postoperative period. In cases for which a second operation was performed to attempt to restore vision, data from the surgical procedure and subsequent hospital stay were included in this analysis. The etiology of the visual loss was divided into either compressive or ischemic. Compressive etiology was determined based on reoperation, where compression was identified and addressed, and vision improved. Ischemic etiology was presumed if imaging revealed no compression of the optic apparatus, or if intraoperative exploration revealed no compressive etiology. Direct trauma was included in this category since it could not be differentiated from ischemia. The hemodynamics, fluid balance, and laboratory values of all patients were also followed and analyzed throughout the postoperative course. Variables collected included estimated blood loss, blood pressure, hourly fluid totals, episodes of emesis, complete metabolic profile, and urine specific gravity. Diabetes insipidus (DI) was defined as urine output greater than 250 ml for 2 consecutive hours or urine output greater than 500 ml for 1 hour combined with either specific gravity less than 1.005, blood sodium level greater than 145 mEq/L, or any case in which the patient was treated with desmopressin.

Statistical Analysis

Etiology of acute PVD was divided based on presumed etiology into compressive (n = 11) and noncompressive (n = 10) (see the *Results* section for details of the two groups). A two-tailed Student t-test was used to compare all continuous variables between the groups, and ANOVA was used to calculate p values when there were more than two analysis groups. Fisher's exact method was used for categorical variables due to the small group sizes within our analysis groups. The two-proportion hypothesis test was used to compare proportions of categorical variables within this analysis, such as the proportion of patients with vision loss in the immediate postoperative setting at specific time intervals. For all analyses, a p value < 0.05 was considered statistically significant.

Results

In total, 1200 consecutive EETS cases were performed between March 2010 and February 2020. Distribution of pathology is presented in Fig. 1. From this large series, 21 patients were identified who complained of early PVD, for an incidence of 1.75%. Of these, 13 patients (62%) were female and 8 (38%) were male. At the time of surgery, the mean age was 52.05 ± 18.6 years, with patient age ranging from 9 to 79 years (Table 1). The mean length of follow-up was 31.8 months, with all but 4 patients having been seen within the last year to assess long-term outcome. In the majority (81.0%) of these cases, visual deterioration was transient. Long-term permanent visual field deterioration was confirmed in only 4 patients, for an incidence of 0.33%. Figure 2 provides a schematic breakdown of our study population, disease etiology, interventions, and outcomes.

Of the patients with PVD, the most common preoperative presenting symptom and indication for surgery was preoperative visual deterioration, occasionally accompanied by headache or endocrinopathies. Two patients had endocrinopathy alone without any preoperative visual loss.

The most common tumor identified histologically in

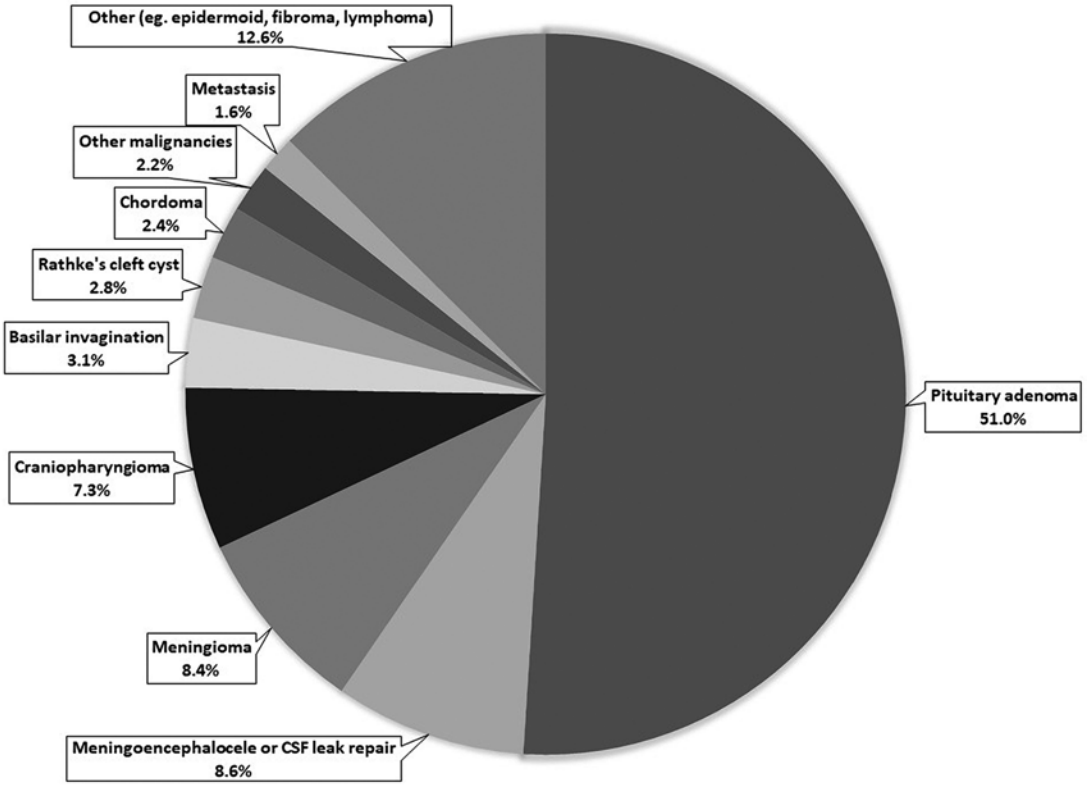

FIG. 1. Distribution of pathology for 1200 consecutive EEA cases performed between March 2010 and February 2020.

patients with PVD was pituitary adenoma (8 cases), followed by craniopharyngioma (7 cases), meningioma (5 cases), and Rathke cleft cyst (1 case). However, as a percentage of each histology, visual deterioration occurred most commonly with craniopharyngiomas (7.69%, total n = 91), followed by meningiomas (5.43%, total n = 92) and then pituitary adenomas (1.94%, total n = 412). Permanent PVD occurred with 2.17% (2/91) of craniopharyngiomas, 2.17% (2/92) of meningiomas, and 0% of pituitary adenomas. Types of operative closure were also analyzed for the associated incidence of visual loss. Closures were divided into soft (Gelfoam, fat, fascia lata, Allomax ± nasoseptal flap) versus firm (rigid buttress involving reconstruction of floor or gasket seal, i.e., Medpore or vomer ± nasoseptal flap). Among patients undergoing surgery with an endoscopic endonasal approach (EEA), 230 had firm closures and 970 received soft closures. Acute PVD was more commonly associated with firm closures (4.78%) than soft closures (1.03%; p = 0.0006). Likewise, permanent vision loss occurred in 1.30% versus 0.10% of all patients with firm and soft closures, respectively (p = 0.024). Among the 21 patients with PVD, soft closures were performed in 47.6% of cases and firm closures in 52.4%. While 25.0% of permanent visual deterioration cases had soft closures, 75.0% had firm closures. Preoperative imaging, from which tumor size was estimated, was available for all 21 patients (Table 2). The mean preoperative tumor volume was 5.53 ± 2.9 cm^3, and suprasellar extension was present in 90.4% of patients. GTR, as confirmed by postoperative MRI, was achieved in 17 of the 21 cases (81.0%).

Postoperative Course

All patients in this case series were hemodynamically stable upon extubation and subsequently transferred to the postanesthesia care unit (PACU), but their recovery was complicated by acute PVD sometime thereafter. The aver-

TABLE 1. Clinical characteristics

Variable	Etiology		p Value*
	Compressive	Ischemic	
Sex (no. of pts)			NS
Female	7	6	
Male	4	4	
Age (yrs)			
Min	21	9	
Median	57	52	
Mean ± SD	51.09 ± 18.8	53.10 ± 19.3	NS
Max	73	79	
Mean op length (hrs:mins)	3:02	3:39	NS
Mean total anesthesia time (hrs:mins)	5:00	5:40	NS
Mean blood loss (ml)	154.5	252.0	NS
Mean follow-up length (mos)	44	18.3	0.05

Max = maximum; Min = minimum; NS = not significant.
* Numerical values are given for significant p values.

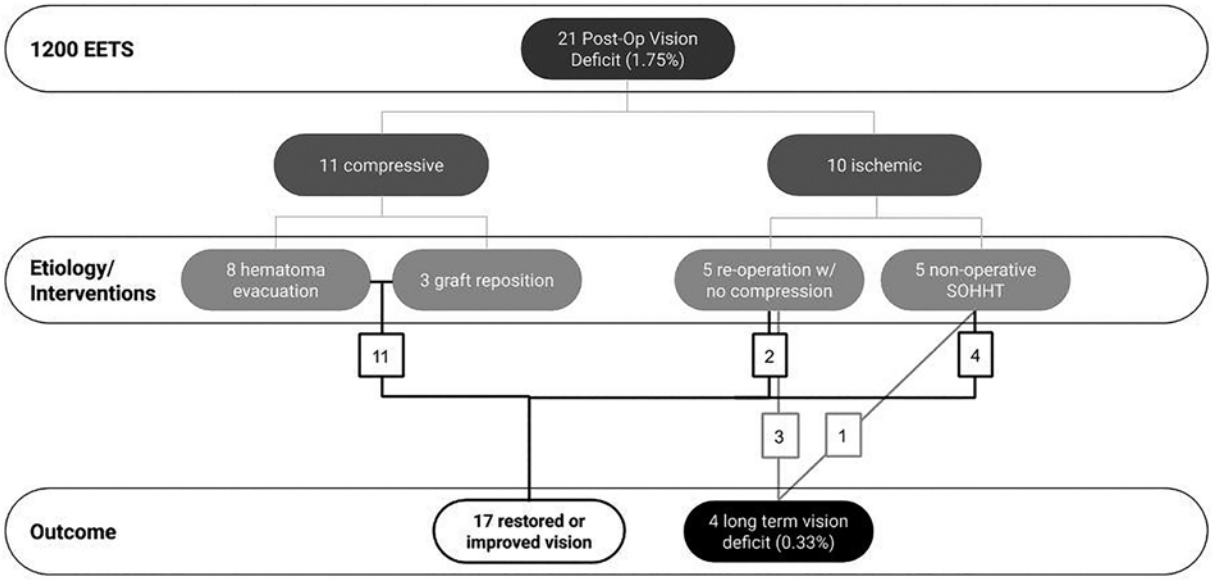

FIG. 2. Schematic of 21 of 1200 consecutive EEA cases with etiology of vision loss, specific intervention, and outcome on follow-up.

age time to PVD (Table 3) was 28.8 hours, and over 70% of patients experienced a deterioration in vision within the first 13 hours after surgery. Immediate imaging was performed in 90.5% of patients (CT 33.3%, MRI 76.2%) to determine the etiology of the visual loss, whereas 9.5% of patients were brought immediately back to the operating room for reexploration without imaging.

Sixteen patients (76.2%) ultimately underwent a second operation to determine if there was a compressive etiology and reverse the compression, and in 10 of these patients (all with compressive etiology) vision improved immediately (see below for details). The 6 patients in whom no compression was identified intraoperatively were treated with steroids and supplemental oxygen and hypervolemic hypertensive therapy (SOHHT) for presumed ischemic etiology. The remaining 5 patients who did not go immediately to the operating room for reoperation, since imaging revealed no evidence of possible optic apparatus compression, were treated with SOHHT for presumed ischemia (see below). At last follow-up, 11 patients (52.4%) subjectively endorsed improved vision from their preoperative baseline, whereas 6 patients (28.6%) endorsed stable vision (although improved from the postoperative decline). Four patients (19.0%) experienced permanent worsening in vision compared with their preoperative baseline (Table 3).

Causes of Visual Deterioration

PVD was divided into two categories: compressive (n = 11) and ischemic (n = 10). Moreover, in the compressive group the causes of PVD could be further divided into hematoma or graft displacement. Postoperative vision loss occurred most acutely with graft displacement (mean 7.3 ± 5.0, range 2.8–12.7 hours) and then ischemia (mean 10.3 ± 15.5, range 0.5–51.5 hours). Patients with postoperative hematomas experienced visual decline with the longest delay, an average of 70.3 ± 87.4 hours (range 0.5–241.2 hours; p = 0.078). There was a trend to more compressive etiology in adenomas and Rathke cleft cysts and more ischemic etiology in craniopharyngiomas and meningiomas (p = 0.08; Table 2). Among the 17 patients in our cohort whose vision improved to at least the preoperative baseline, the mean time to improvement following surgery or treatment with SOHHT was 7.2 hours in the compressive etiology group as compared to 62.2 hours in the ischemia group (p = 0.01).

Compressive Etiology

There were 11 PVD patients with compressive etiology. Of these, 8 were found to have a postoperative hematoma on imaging. The pathologies in this group were adenoma (6 patients), craniopharyngioma (1 patient), and Rathke cleft cyst (1 patient). Soft closures were performed in the majority of these cases (62.5%) with fat graft and nasoseptal flap. Once identified, these patients were brought immediately back to the operating room for hematoma evacuation, and in all cases vision eventually returned to baseline. Seven patients (87.5%) showed immediate improvement and 1 patient (12.5%) improved at last follow-up. Three patients were found to have direct compression of the optic apparatus on MRI by the graft used to seal off the cranial cavity. Pathologies represented in this group included meningioma (n = 2) and craniopharyngioma (n = 1). Firm closure was used in 2 cases and soft closure in 1 case. All 3 of these patients underwent a second operation to reposition their grafts and showed immediate visual improvement back to their preoperative baseline. In summary, in all cases of compressive visual loss the patients' vision eventually improved after immediate reoperation to decompress the optic apparatus.

Ischemic Etiology

The remaining 10 patients (47.6%) in this cohort did not demonstrate a compressive etiology on imaging that contributed to PVD. Within this group, visual deterioration

TABLE 2. Tumor characteristics

Variable	Etiology		p Value
	Compressive	Ischemic	
Histology			0.08*
Craniopharyngioma & meningioma	2 (18.2%) 2 (18.2%)	5 (50%) 3 (30%)	
Pituitary adenoma & Rathke cleft cyst	6 (54.5%) 1 (9.1%)	2 (20%)	
Mean preop tumor vol, ml	6.30	4.75	NS
Suprasellar extension	10 (90.9%)	9 (90%)	NS
Extent of resection			NS
GTR	9 (81.8%)	8 (80%)	
STR	2 (18.2%)	2 (20%)	

Values are presented as number (%) of patients unless otherwise indicated.
* There was a trend to more ischemic etiology in craniopharyngiomas and meningiomas and more compressive etiology in adenomas and Rathke cleft cysts.

TABLE 3. Visual outcomes

Variable	Etiology		p Value*
	Compressive	Ischemic	
Mean time to vision loss, hrs	49.30	10.27	NS
Reop performed, n (%)			0.012
Yes	11 (100%)	5 (50%)	
No	0	5 (50%)	
Vision at last follow-up, n (%)			0.035
Improved + stable	7 (63.6%) 4 (36.4%)	4 (40%) 2 (20%)	
Worse	0	4 (40%)	
Mean time to vision improvement, hrs	7.2 (n = 11)	62.2 (n = 6)	0.010

* Numerical values are given for significant p values.

occurred most commonly with craniopharyngiomas (n = 5), followed by meningiomas (n = 3) and then pituitary adenomas (n = 2). Firm closure with Medpore implants, gasket seal, and nasoseptal flap was used in 60% of cases, while 40% of cases were completed with soft closure. Five of these patients underwent an exploratory second operation to look for residual tumor, hematoma, graft displacement, or another compressive mechanism. Aside from the removal of minor blood products, no compressive pathology was identified in any of these cases, and patients continued to report visual deficits even after their exploratory reoperation. The most likely etiology in these noncompressive cases is either cytotoxic or vasogenic edema, or ischemia attributable to blood flow compromise from vessel sacrifice or vasospasm, all of which are, in part or in whole, caused by limited perfusion to the optic apparatus. These 10 patients (5 treated after unsuccessful reoperation for possible compression and 5 treated immediately for presumed ischemia) were treated with SOHHT, as well as hyperbaric oxygen in 1 case. Of the 5 patients who underwent reoperation for exploration, 1 patient (20%) demonstrated improved vision, 1 patient (20%) returned to preoperative baseline, and the remaining 3 patients (60%) endorsed permanent visual deficits. Of the 5 patients who were treated immediately with SOHHT, 80% improved. Although this is not a statistically significant finding given the small numbers, when coupled with the data showing that early increases in volume expansion and blood pressure were more likely to lead to improvement, this result provides support for the tentative conclusion that delaying therapy in patients with ischemic etiology by performing reoperation to explore for compression may be deleterious.

To explore the possible etiology for the ischemia as well as the best treatment algorithm, we evaluated several factors that may have contributed to optic nerve ischemia in the postoperative period, such as estimated blood loss, sodium, urine output, blood pressure, and presence of DI. Mean estimated blood loss in the operating room, urine specific gravity, and serum sodium were not statistically different between groups. The ischemia group had a trend toward higher mean sodium level at the time of vision loss. Between 8 and 16 hours after surgery, patients with ischemia lost significantly more total fluid than patients with compressive vision loss (ischemia 1708.0 ml and compression 588.3 ml fluid loss, p = 0.005). However, as will be shown below, some of these patients were already being given excess fluids to treat their vision loss so the increased urine output may have been iatrogenic and compensatory. DI complicated the postoperative course of 11 patients (52.4%) in the study cohort, more commonly in the ischemic group (60.0%) than the compressive group (36.4%), but this difference was not statistically significant (p = 0.39). By the end of the first 16 hours, 90% of patients in the ischemia group had experienced acute vision loss, compared to 45.5% in the compressive group (p = 0.031, Table 4). Compared with the compressive group, the ischemia group had a significantly greater average fluid intake at 16–24, 32–40, and 56–64 hours postoperatively, following aggressive fluid repletion for ischemic vision loss (p = 0.038, 0.007, and 0.047, respectively).

Mean systolic blood pressure was not significantly different between groups within the first 72 hours of surgery (Table 4). However, the mean arterial pressure (MAP) and mean maximum systolic blood pressure were both significantly greater in the ischemia group than the compressive group during different time intervals on postoperative day 2 (Table 4). This trend corresponds to the onset of treatment with induced SOHHT in the ischemia group, as 90% of patients (n = 9) in this group had already experienced vision loss by this time.

Treatment of Ischemia

We then examined factors that contributed to visual recovery in the ischemic group (Table 5). When comparing patients in the ischemic group who recovered vision with those who did not, we found that the recovery group had much more successful volume expansion and hypertensive therapy than those whose vision did not improve. Fluid expansion was statistically significantly higher 8–16 hours after surgery. From 8 to 32 hours after surgery, patients who recovered vision received 7103 ml of fluid compared with 3974 ml for those who did not. Overall, for patients

TABLE 4. Hemodynamic stability and visual outcomes within the first 72 hours postoperatively

	Etiology		
	Compressive	Ischemic	p Value*
Mean postop total fluid intake, ml			
0–8 hrs	1216.9	1309.7	NS
8–16 hrs	1296.4	2139.0	NS
16–24 hrs	1124.1	1890.2	0.04
24–32 hrs	1317.1	1823.7	NS
32–40 hrs	674.0	1358.3	0.007
40–48 hrs	906.4	1357.3	NS
48–56 hrs	793.7	1064.2	NS
56–64 hrs	603.6	1107.1	0.047
64–72 hrs	928.2	1166.4	NS
Mean postop fluid loss, ml			
0–8 hrs	1518.2	1796.0	NS
8–16 hrs	588.3	1708.0	0.005
16–24 hrs	1433.7	1733.7	NS
24–32 hrs	1305.5	1781.2	NS
32–40 hrs	1061.5	981.1	NS
40–48 hrs	1173.9	991.5	NS
48–56 hrs	1488.4	1361.9	NS
56–64 hrs	1409.5	1270.0	NS
64–72 hrs	1344.3	996.5	NS
Mean systolic blood pressure, mm Hg			
0–8 hrs	137.7	141.3	NS
8–16 hrs	125.9	133.3	NS
16–24 hrs	121.4	132.4	NS
24–32 hrs	122.5	138.9	NS
32–40 hrs	121.2	139.2	NS (0.06)
40–48 hrs	125.9	138.4	NS
48–56 hrs	131.7	141.5	NS
56–64 hrs	129.8	139.5	NS
64–72 hrs	132.3	133.1	NS
MAP, mm Hg			
0–8 hrs	92.1	95.0	NS
8–16 hrs	83.0	89.5	NS
16–24 hrs	82.1	92.6	NS (0.057)
24–32 hrs	81.6	94.8	0.04
32–40 hrs	83.6	95.3	NS (0.07)
40–48 hrs	86.5	100.0	NS
48–56 hrs	89.5	96.6	NS
56–64 hrs	89.9	94.9	NS
64–72 hrs	91.1	91.2	NS
Max systolic blood pressure, mm Hg			
0–8 hrs	158.0	156.4	NS
8–16 hrs	142.1	149.9	NS
16–24 hrs	133.1	146.8	NS

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TABLE 4. Hemodynamic stability and visual outcomes within the first 72 hours postoperatively

	Etiology		
	Compressive	Ischemic	p Value*
Max systolic blood pressure, mm Hg (*continued*)			
24–32 hrs	131.5	151.9	NS (0.051)
32–40 hrs	131.6	155.4	0.03
40–48 hrs	133.6	152.1	NS
48–56 hrs	144.5	153.8	NS
56–64 hrs	142.8	151.6	NS
64–72 hrs	142.5	146	NS
Proportion of pts w/ vision loss, n (%)			
0–8 hrs	3 (27.3%)	5 (50.0%)	NS
8–16 hrs	5 (45.5%)	9 (90.0%)	0.03
16–24 hrs	5 (45.5%)	9 (90.0%)	0.03
>25 hrs	—	—	—

* Numerical values are given for significant values and NS values approaching significance.

whose vision recovered, net fluid balance was positive 1104 ml compared with negative 166 ml for those whose vision deteriorated (Table 5). Likewise, mean, maximum, and minimum systolic blood pressures were significantly higher at several time intervals in the first 3 days after surgery in patients whose vision improved compared with those whose vision did not recover (Table 5).

In summary, while 100% (11/11) of the patients in the compressive group experienced restored vision following reoperation, only 60% (6/10) in the ischemic group were able to regain vision following SOHHT ($p = 0.035$). In this latter group, early and effective medical therapy is more likely to lead to improvement than delayed or less effective therapy.

Discussion

EETS is a safe and effective minimally invasive procedure for the removal of anterior skull base tumors, with rates of GTR equivalent or superior to those for transcranial operations.[1,2,21,22] Although rare, PVD can be a serious and occasionally permanent complication. In this single-institution analysis, we demonstrated the incidence of this rare complication and its etiology and treatment outcomes. The key finding is that compressive etiology is reversible with early surgery and decompression. Similarly, ischemic etiology can be effectively, although not as successfully, treated with SOHHT. However, in the absence of high suspicion for compressive etiology, return to the operating room for exploration can waste valuable time, and delay in SOHHT can be deleterious to the ultimate outcome. Tips to avoid PVD include minimizing manipulation or damage to the small vessels feeding the chiasm, avoiding direct trauma to the nerves, and careful determination of noncompressive positioning of closure materials.

TABLE 5. Ischemia patients with vision recovery versus those with deterioration

	Vision		
	Recovery	Deterioration	p Value*
No. of pts	6	4	
Mean preop tumor vol (ml)	4.70	4.82	NS
Mean total anesthesia time (hrs:mins)	5:34	5:51	NS
Mean op duration (hrs:mins)	3:22	4:04	NS
Mean EBL (ml)	261.7	237.5	NS
Mean time to vision loss (hrs)	5.76	17.0	NS
Mean time to therapy initiation (hrs)†	10.2	9.81	NS
Mean total postop fluid intake (ml)			
0–8 hrs	1256.3	1389.6	NS
8–16 hrs	2708.9	1284.1	0.034
16–24 hrs	2132.9	1526.3	NS
24–32 hrs	2263.0	1164.8	NS
32–40 hrs	1580.9	1024.4	NS
40–48 hrs	1386.5	1313.5	NS
48–56 hrs	1190.7	874.4	NS
56–64 hrs	1210.9	951.5	NS
64–72 hrs	1349.1	892.4	NS
Total	15,079	10,421	
Mean postop fluid loss (ml)			
0–8 hrs	1935.0	1587.5	NS
8–16 hrs	1735.8	1666.3	NS
16–24 hrs	2189.2	1050.5	NS
24–32 hrs	2104.2	1296.8	NS
32–40 hrs	1072.5	844	NS
40–48 hrs	898.3	1131.3	NS
48–56 hrs	1537.5	1098.5	NS
56–64 hrs	1428.3	1032.5	NS
64–72 hrs	1074.2	880	NS
Total	13,975	10,587	
Overall fluid balance	+1104	−166	
Mean systolic blood pressure (mm Hg)			
0–8 hrs	146.4	133.7	NS
8–16 hrs	143.7	117.6	NS
16–24 hrs	138.1	123.8	NS
24–32 hrs	146.4	127.7	NS
32–40 hrs	149.6	123.7	0.044
40–48 hrs	149.5	121.8	0.035
48–56 hrs	149.0	130.1	NS
56–64 hrs	143.9	133.0	NS
64–72 hrs	138.4	125.2	NS
MAP (mm Hg)			
0–8 hrs	94.9	95.3	NS
8–16 hrs	92.2	85.5	NS
16–24 hrs	93.9	90.8	NS

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TABLE 5. Ischemia patients with vision recovery versus those with deterioration

	Vision		
	Recovery	Deterioration	p Value*
MAP (mm Hg) (*continued*)			
24–32 hrs	97.3	91.0	NS
32–40 hrs	100.0	88.1	NS
40–48 hrs	107.5	88.8	NS
48–56 hrs	99.4	92.3	NS
56–64 hrs	94.4	95.7	NS
64–72 hrs	92.1	89.8	NS
Maximum systolic blood pressure (mm Hg)			
0–8 hrs	161.0	149.5	NS
8–16 hrs	164.5	128.0	NS (0.06)
16–24 hrs	152.7	138.0	NS
24–32 hrs	162.0	136.8	NS
32–40 hrs	167.0	138.0	0.05
40–48 hrs	166.3	130.8	0.05
48–56 hrs	160.3	144.0	NS
56–64 hrs	153.7	148.5	NS
64–72 hrs	151.2	138.3	NS
Minimum systolic blood pressure (mm Hg)			
0–8 hrs	127.2	113.3	NS
8–16 hrs	118.7	107.0	NS
16–24 hrs	116.3	107.5	NS
24–32 hrs	126.2	106.3	NS
32–40 hrs	136.2	109.8	0.026
40–48 hrs	132.5	113.3	0.05
48–56 hrs	134.2	118.0	NS
56–64 hrs	134.0	119.5	NS
64–72 hrs	120.7	113.5	NS

EBL = estimated blood loss.
* Numerical values are given for significant values and NS values approaching significance.
† Time to initiation of vasopressors following PVD.

These results emphasize the importance of determining the etiology of the visual loss prior to instituting therapy. In some circumstances, the surgeon may have an instinct as to the cause of the visual loss. Perhaps an excessive amount of packing was used, or a rigid graft was placed close to the optic apparatus. In these circumstances, return to the operating room can be done immediately without imaging, although immediate imaging is recommended to differentiate compressive from noncompressive etiology. Patients who underwent surgical exploration in which no compression was found were less responsive to SOHHT. It is not clear if this outcome was due to a delay in instituting therapy, hypotension during the operative procedure, or the possibility that visual loss was caused by an irreversible trauma refractory to SOHHT. Nevertheless, the main

TABLE 6. Literature review of vision loss for sellar and parasellar resections

Authors & Year	Approach	Sample Size	Acute Postop Visual Deficit Rate	Long-Term Visual Complication Rate
Ciric et al., 1997[14]	TSS	638; survey estimate	0.5%; 0.5%–2.4%	—
Sudhakar et al., 2004[27]	TSS	126	1.5%	—
Kitano et al., 2007[30]	TSS, TC	16 (TSS), 12 (TC)	38% (TSS), 42% (TC)	—
Fahlbusch & Schott, 2002[23]	TC	47	20%	—
Pamir et al., 2005[24]	TC	42	14%	—
Schick & Hassler, 2005[25]	TC	53	13.2%	—
Cappabianca et al., 2002[11]	EEA	146	0.7%	0
de Divitiis et al., 2007[9]	EEA	20	0	0
de Divitiis et al., 2008[8]	EEA, TC	7 (EEA), 44 (TC)	0 (EEA), 13.6% (TC)	0
Gardner et al., 2008[3]	EEA	16	6.3%	0
Fatemi et al., 2008[6]	EEA	812	<1%	<0.4%
Kassam et al., 2011[26]	EEA	800	0.9%	0.5%
Elliott et al., 2011[29]	EEA, TC	352 (EEA), 2029 (TC)	2.3% (EEA), 13% (TC)	—
Komotar et al., 2012[21] (Olf groove meningioma; tuberculum sellae meningioma)	EEA, TC	19; 93 (EEA), 474; 840 (TC)	0; 12.7% (EEA), 4.3%; 14.2% (TC)	—
Paluzzi et al., 2014[4]	EEA	555	1.1%	0.4%
Wang et al., 2015[31]	EEA	1166	0.69%	0.43%
Moussazadeh et al., 2016[1]	EEA, TC	21 (EEA), 5 (TC)	10% (EEA), 0 (TC)	—
Magro et al., 2016[15]	EEA	300	3%	2.2%
Bander et al., 2018[2]	EEA, TC	17 (EEA), 15 (TC)	0 (EEA), 26.7% (TC)	—
Sakata et al., 2019[5]	EEA	6	0	16.7%
Younus et al., 2020[28]	EEA	583	1.5%	0.2%
Tafreshi et al., 2020[16]	EEA	47	0	0
Present study	EEA	1200	1.75%	0.33%

Olf = olfactory; TC = transcranial; TSS = transsphenoidal.

message is that compressive etiology resolves with removal of the compression while ischemic etiology improves roughly half the time with timely institution of SOHHT. However, if therapy is not adequate and volume status is not net positive or blood pressure not adequately elevated, the outcome may be suboptimal. These findings are encouraging and resulted in an overall effective permanent visual deterioration rate of 0.33% in this larger series.

Visual deterioration following EETS and transcranial surgery has been reported with varying incidence, occurring commonly as a delayed event. Among patients undergoing transcranial surgery, PVD has been reported at rates between 0 and 20.8% and for EETS between 0 and 16.7%.[1–6,8,9,11,15,16,23–27] In the majority of these cases, PVD is transient (Table 6). Most patients in our study initially presented with adenomas, craniopharyngiomas, or meningiomas. There are several large series assessing complications following EETS, including acute and long-term visual outcomes, with respect to each of these pathologies. Visual deterioration in the context of EEA for adenomas has been particularly well described. In a study by Magro et al. describing complications and long-term outcomes in 300 consecutive patients undergoing EEA for nonfunctioning macroadenomas, a total of 7 patients (2.4%) experienced permanent visual deficits, related to hematoma in 2 patients and unknown etiology in 5 patients.[15] Magro et al. argued that despite prompt reoperation to remove compressive lesions, tumor remnants may bleed into the potential space following removal of a large tumor, thereby providing a means for a hematoma to grow large enough to compress the optic apparatus.[15] Younus et al. also demonstrated that size was a predictor of postoperative hemorrhage, with macroadenomas larger than 30 mm particularly at increased risk.[28] These observations align with the trends we observed within our cohort, as 75% of the patients who developed compressive visual decline due to hematomas initially presented with larger adenomas.

Elliott et al. examined the rate of PVD in pediatric patients undergoing EETS for craniopharyngioma and observed incidence rates varying from 0 to 16.7%.[29] These authors did not primarily discuss the etiology of PVD in their analysis, but argue that visual deficits may arise transiently due to manipulation of the optic apparatus intraoperatively rather than due to delayed compressive or ischemic mechanisms.[29] However, if this were the case in our patients, then SOHHT would not be as effective. In another cohort of patients undergoing EEA for tuberculum sellae meningiomas, Kitano et al. reported a 22% incidence of PVD. These authors were unable to assess why visual acuity improved in certain patients, although they hypothesized that microvascular trauma or suboptimal decompression of the optic chiasm may play an impor-

tant role in the development of this phenomenon.[30] In our series, patients with ischemic vision loss tended to have either craniopharyngioma or meningioma, suggesting microvascular ischemia may be a more important pattern of injury formation with these tumors compared to adenoma. Though additional studies are needed to better understand these relationships, in patients with craniopharyngioma or meningioma prompt assessment and initiation of treatment for ischemia may be warranted if the patients present with acute PVD, in order to maximize visual preservation.

When comparing surgical approaches to anterior skull base pathology, EEA surgery has been shown in large cohort studies to result in better long-term visual outcomes than transcranial procedures.[1,2,21] In their case-matched single-institution analysis, Moussazadeh et al. demonstrated significantly greater improvement in visual outcomes from preoperative baseline in patients undergoing EEA procedures than in patients undergoing traditional transcranial surgery.[1] Komotar et al. and Schwartz et al. performed systematic literature reviews and found that EEA results in significantly improved visual outcomes compared to open transcranial surgery.[21,22] Based on these findings, EEA offers significantly improved long-term visual outcomes compared to transcranial surgery, while the incidence rates of worsening postoperative vision appear to be approximately equivalent in both groups, with the majority of series reporting a value of 0%–20%.[1–3,8,23–25] Despite available data on the rates of acute PVD following EEA and transcranial surgery, data in the literature regarding potential risk factors in noncompressive etiologies are scarce, nor is there evidence on the success of subsequent management strategies.

To the best of our knowledge, this study is the first analysis to directly compare compressive and ischemic mechanisms of PVD following EETS. Compressive vision loss, both transient and long-term, has been well documented in the literature. In the context of EEA, the most commonly described etiologies of compressive vision loss include residual tumor, gross hematoma, and displacement of the surgical graft material used to seal the cranial cavity.[15,26,28] Regardless of the etiology, timely imaging and reoperation are believed to be the gold standard to restore PVD. However, visual deficits may persist following reoperation, and as Kitano et al. point out, it is unclear why certain patients recover and others do not in cases of presumed compressive vision loss.[30] In a large series by Wang et al., gross hematomas causing compressive vision loss were observed in 8 patients, but only 3 patients (37.5%) improved following reoperation and 5 patients (62.5%) experienced permanent visual deficits on long-term follow-up.[31] In our larger series we also observed 8 patients with compressive hematomas in addition to 3 patients with compressive vision loss due to graft displacement. However, in our series, all patients who underwent reoperation demonstrated improved vision to at least preoperative baseline, suggesting that reoperation is an appropriate treatment and does not necessarily predict poorer visual outcomes. Nonetheless, we believe careful analysis of each patient's etiology of vision loss is essential, as performing a second operation on an ischemic patient will likely not improve their vision and may instead exacerbate the microvascular ischemic damage.

There is a lack of data concerning postoperative ischemia following EETS, and the true incidence of this rare complication is unknown. Cerebral vasospasm and posterior reversible encephalopathy syndrome have been documented in a few isolated cases as rare causes of vision loss following EETS.[12,13,32,33] Eseonu et al. described 13 cases of cerebral vasospasm following EETS.[12] In their patient series, management strategies ranged from volume expansion to induced hypertension, calcium channel blockers, and balloon angioplasty. Four patients (30.8%) did not improve despite aggressive therapy and unfortunately died. Only 1 patient recovered to preoperative baseline, but the remainder survived. The authors suggested that early and aggressive volume expansion treatment may promote survival in patients who experience ischemia following vasospasm.[12]

The risk factors for ischemic vision loss are poorly understood. In several case reports describing PVD following EEA, subarachnoid hemorrhage was a common feature that preceded vasospasm in the majority of cases.[12,34–41] Another potential risk factor for ischemia is DI, which is a commonly reported complication following EETS.[1,2,4,5,11,14–16] Within our cohort, DI occurred more frequently on average among patients with ischemic vision loss, although this trend was not significant. Nonetheless, careful management of fluid balance in the acute postoperative setting can help mitigate the risk of volume depletion among these patients, which may ultimately prove to be an early risk factor for ischemic vision loss.

In the absence of a large multicenter trial, we are unable to recommend specific targets for volume repletion or hypertensive therapy. There is also a theoretical risk that hypertensive and hypervolemic therapies could cause a hematoma, although such an event did not appear to have occurred in our series. However, among ischemic patients who demonstrated visual improvement compared to ischemic patients who did not, we found a significantly greater total fluid intake at 16 hours postoperatively and significantly higher MAPs at 40 and 48 hours postoperatively. Additionally, the ischemic patients who experienced visual improvement had MAPs and total postoperative fluid intake values that were higher than the group of ischemic patients who showed no visual improvement at all time intervals assessed. These findings suggest that SOHHT can be effective for restoring visual deficits in patients with noncompressive, ischemic vision loss, though additional work is needed to better characterize this phenomenon and determine early warning signs.

Study Limitations

This study was retrospective in design and was limited by a small sample size. However, our database was prospectively acquired, and no patients were missed. A multicenter prospective registry would provide a higher level of data. Additional cases would have increased the overall power of our analysis, but this study is one of the larger series of its kind.[1–3,5]

Conclusions

We demonstrate that visual deterioration following EETS can be divided into compressive and ischemic etiol-

ogy. The former is effectively managed with reoperation, while the latter may respond, albeit less well, to supplemental oxygen, hypertension, hypervolemia, and steroids. Accurate diagnosis of the etiology of visual deterioration is critical to effectively employ the proper therapy in a timely fashion to minimize long-term permanent visual loss.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Schwartz, Carnevale, Babu, Fong. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Carnevale. Critically revising the article: Schwartz. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Schwartz. Statistical analysis: Carnevale, Babu. Administrative/technical/material support: Schwartz, Carnevale, Fong. Study supervision: Schwartz, Carnevale.

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