Successful repair of intraoperative cerebrospinal fluid leaks improves outcomes in endoscopic skull base surgery

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Background: **The impact of failed cerebrospinal fluid leak (CSF) leak repair in endoscopic skull base surgery has not been adequately studied.**

Methods: **In this investigation we reviewed patients who had undergone endoscopic skull base surgery between 2002 and 2014 at 7 international centers. Demographic variables, comorbidities, tumor characteristics, and repair techniques were evaluated to determine association with successful repair of CSF leak. Postoperative complications and length of stay were compared among groups.**

Results: **Data were collected on 2097 patients who were divided into 3 groups: (1) those with no intraoperative leak (n = 1533); (2) those with successful repair of their intraoperative leak (n = 452); and (3) those with failed repair (n = 112). Compared with successful repair, failed repair was associated with an increased risk of intracranial infection (odds ratio [OR], 5.6; 95% confidence interval [CI], 5.3-13.15), pneumocephalus (OR, 16; 95% CI, 5.8-44.4), 30-day readmission (OR, 8.4; 95% CI, 5.3-13.5), reoperation (OR, 115.4; 95% CI, 56.3-236.8), and prolonged hospital stay (14.9 vs 7.0 days, $p < 0.01$). Outcomes in patients who had successful repairs of intraoperative leaks were similar to those who never had leakage. Intraoperative use of pedicled nasoseptal flaps was associated with successful repair (OR, 0.60; 95% CI, 0.34-0.92).**

Conclusion: **Intraoperative CSF leaks are a frequent and expected occurrence during endoscopic skull base surgery. Failed CSF leak repair has a significant impact on patient outcomes, with increased rates of postoperative pneumocephalus, intracranial infections, reoperation, deep vein thrombosis, readmission, and prolonged hospital stay. Recognition and repair of intraoperative CSF leaks reduces postoperative complications. Use of pedicled nasoseptal flaps improves outcomes in reconstructing defects at higher risk for postoperative leak.**

Key Words:
complication; intraoperative leak; postoperative leak; skull base reconstruction; skull base tumor

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Endoscopic skull base surgery has become increasingly common in the management of a wide variety of skull base lesions.[1–6] Complications of endoscopic skull base surgery include postoperative cerebrospinal fluid (CSF) leak, pneumocephalus, intracranial infection, orbital injury, vascular injury, and cranial nerve injury. Reported risk factors include site and extension of tumor- and patient-specific factors such as increased body mass index (BMI) and revision status.[7,8] Postoperative CSF leaks are the most uniformly reported complications in skull base surgery; rates have generally been <6% in recent studies.[7,9] More complex pathologies, such as clival chordomas and craniopharyngiomas, are associated with increased rates of postoperative leaks, which range from 8% to 58%.[10–12] Over the past 15 years, there has been a gradual decrease in reported rates of CSF leaks, due in part to the advent of various pedicled flaps as well as institutional quality improvement strategies.[13] Variations in postoperative leak rates may be a function of tumor type, location, or repair strategy. However, these variables have not been examined in the context of a multi-institutional study.

Despite being one of the most commonly reported complications, the sequelae of postoperative CSF leaks on patient morbidity are largely unstudied. In previous studies, postoperative CSF leaks were associated with pneumocephalus, meningitis, and prolonged hospitalization.[14,15] However, most studies have been underpowered to determine the effect of postoperative CSF leak on patient outcomes. Our primary aim was to analyze a multi-institutional cohort of patients who underwent endoscopic resection of skull base lesions in order to better understand the impact of failed CSF leak repair on specific postoperative outcomes. Secondary aims included determination of whether certain tumor characteristics or intraoperative repair strategies are associated with higher failure rates for CSF leak repair.

Patients and methods

Study population

A retrospective analysis was performed on all patients undergoing endoscopic resection of skull base tumors or other pathologies, such as encephaloceles or cholesterol granulomas, between 2002 and 2014, at the following 7 international centers: Medical University of South Carolina (MUSC); the University of Adelaide (South Australia); Mount Sinai Medical Center; the University of Toronto (St. Michael's Hospital); Emory University; the Cleveland Clinic; and the University of Alabama at Birmingham (UAB). Included patients were those whose pathologies involved the bone of the skull base or resection of which require removal of skull base bone. The study was approved by the institutional review board (IRB) of the Medical University of South Carolina (HR #11037) and the IRB of each participating institution. Demographic data (age, race, and gender) were collected. Comorbidity, patient history, and perioperative data were also obtained. The Charlson Comorbidity Index was calculated and the American Society of Anesthesiology physical status classification was recorded to summarize comorbidities using validated systems.[16] Tumors were classified by diagnosis and location at the anterior cranial fossa (ACF), middle cranial fossa (MCF)/parasellar region, or posterior cranial fossa (PCF).

Categorization of patients

Patients were placed into 1 of 3 categories: (1) *no CSF leak*, defined as no recorded intraoperative or postoperative CSF leak; (2) *successful repair*, defined as a recorded intraoperative CSF leak without a postoperative CSF leak; and (3) *failed repair*, defined as a postoperative CSF leak. We then examined variations in patient demographics/comorbidities, tumor-specific factors, as well as associated complications and reconstructive techniques. All patients were included, with pairwise exclusion from specific analyses (in an available-case analysis fashion) to maximize the usable data. For simplicity, solitary encephalocele/primary CSF leak patients are referred to as encephalocele patients throughout the text. Intracranial pathologies were defined as meningiomas, chordomas, craniopharyngiomas, chondrosarcomas, cholesterol granulomas, encephaloceles, and other benign or malignant skull base pathologies. Pituitary neoplasms were considered separately. Intracranial infections included meningitis, intracranial abscess, or ventriculitis, and were based on clinical diagnosis criteria. Expected postoperative aseptic meningitis was not included. Imaging was not routinely used to determine the rate of pneumocephalus postoperatively. Imaging was ordered as part of the work-up for an unexpected postoperative course, such as mental status changes or neural deficits. The diagnosis of pneumocephalus was given when the amount of intracranial air was thought to be higher than the expected postoperative amount.

Statistical analysis

All analyses were performed with SPSS Statistics version 23.0 (IBM Corporation, Armonk, NY). Categorical variables are presented as frequency and percent, and continuous variables are presented as mean ± standard deviation, range, or median with interquartile range (IQR) in text and tables. All continuous variables were assessed for normality using the Kolmogorov-Smirnov test. If these variables

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were not normally distributed, descriptive measurements, such as median and IQR, were calculated. Comparisons of patients' characteristics were performed using a chi-square test or Fisher's exact test for categorical variables and an independent *t* test or Mann-Whitney rank sum test for continuous variables. A correlation model was used to determine the relationships among all outcome variables. Logistic regression was performed in reference to denoted categories to determine predictors of failed repair by diagnosis. The adjusted odds ratios (ORs), their 95% confidence intervals (CIs), and *p* values were obtained from the final model as a measure of the association between the independent predictors and the dependent responses. Alpha was set at <0.05 for all statistical tests.

Results

Demographics

A total of 2097 patients were identified, with a mean age of 51 (range, 1–92) years. The most common entities were pituitary tumors (n = 1111), encephaloceles (n = 412), benign sinonasal tumors (n = 143), meningiomas (n = 54), craniopharyngiomas (n = 53), and squamous cell carcinomas (n = 52). Although the overall rate of postoperative CSF leak repair failures was 5.3%, if an intraoperative leak was recorded, the rate of failed repair increased to 19.9%. Patient-specific data are presented in Table 1. On post-hoc analysis, younger age was associated with an increased risk of failed CSF leak repair (47 ± 14 years), as compared with successful repair (53 ± 16 years) or no leakage (51 ± 17 years) ($p < 0.001$ and 0.007, respectively). There were also minor, but significant differences in racial distribution across the 3 groups. Although there were similar rates of failed repair among racial groups, Caucasian patients were slightly more likely to never have had leakage compared with African American patients. We did not find any significant differences in BMI or associated comorbidities among the groups.

Morbidity of failed CSF leak repair

Failed CSF leak repair is associated with increased morbidity. Rates of readmission, reoperation, pneumocephalus, intracranial infection, and deep vein thrombosis (DVT) were significantly increased in patients with failed CSF leak repair compared with successful CSF leak repair (Table 2). When compared with patients who had successful CSF leak repair, those with failed CSF leak repair had higher rates of DVT (8.0% vs 2.0%), 30-day readmission (52.3% vs 11.5%), reoperation (75% vs 2.7%), pneumocephalus (15.2% vs 1.1%), and intracranial infection (21.4% vs 4.6%). Length of hospitalization and invasive ventilation were significantly increased in patients with failed CSF leak repair. There were no differences among groups with regard to mortality, pneumonia, cardiac compromise, cerebrovascular accidents, and carotid or cranial nerve injury.

Tumor pathologies and associations with failed CSF leak repair

Pituitary tumors were the most common pathology and were associated with a lower failure rate of CSF leak repair (OR, 0.58; 95% CI, 0.380-0.877; Table 3). Results from univariate and multivariate analyses are presented. Multivariate analysis was performed with respect to age, race, prior radiation, ventricular extension, and septal flap usage to minimize the contribution of various confounding factors. Meningiomas and chordomas did not seem to significantly affect rates of failed repair on univariate analysis. Craniopharyngiomas were associated with failed repair (OR, 2.35; 95% CI, 1.92-5.07), as were encephaloceles (OR, 1.72; 95% CI, 1.004-2.977), according to univariate analysis; however, multivariate analysis indicated a loss of this statistically significant outcome for craniopharyngiomas. Intracranial tumors were overall more likely to have failed CSF leak repair (OR, 2.18; 95% CI, 1.42-3.34). Multivariate analyses did not change outcomes of larger subgroups, such as pituitary and intracranial tumors.

Tumor/patient characteristics

Extension of tumors to the ventricular system increased the odds of failed repair (OR, 2.40; 95% CI, 1.08-5.36), as did prior radiotherapy (OR, 2.57; 95% CI, 1.01-7.06; Table 4). Tumor location (anterior, middle, or posterior cranial fossae), prior chemotherapy, and prior skull base surgery did not significantly affect outcomes.

Repair technique

On assessment of repair strategies, the use of pedicled nasoseptal flaps was associated with successful repair (OR, 0.60; 95% CI, 0.35-0.92; Table 5). Free graft, rigid reconstruction, and lumbar drain use did not protect against failed CSF leak repair. The use of external ventricular drains was excluded from the analysis given the small number of patients having undergone this intervention.

Discussion

Endoscopic resection of skull base tumors has gained tremendous popularity and acceptance in recent years. The rate of CSF leaks is markedly reduced with the use of the pedicled nasoseptal flap and with increasing surgical experience.[5,8,13,17] The impact of CSF leaks on postoperative complications has not been studied extensively, but several published case series showed increased complication rates in this group of patients.[14,18] The present multiinstitutional international series assessing 2097 consecutive patients who underwent endoscopic skull base surgery was undertaken to determine the impact of failed CSF leak repair on postoperative outcomes. Analysis of this large database allowed for more reliable examination of relationships and outcomes as compared with smaller series. Overall, we found that endoscopic skull base surgeries are safe and well tolerated (CSF leak rate 5.3%,

TABLE 1. Demographics

	No CSF leak (N = 1533)		Successful repair (N = 452)		Failed repair (N = 112)		
	N	%	N	%	N	%	*p* value
Age in years (mean ± SD)[a]	51 ± 17		53 ± 16		47 ± 14		**0.001**
Body mass index in kg/m^2 (mean ± SD)[b]	30 ± 8		31 ± 8		33 ± 11		0.203
Race							**0.010**
Caucasian (n = 1138)	872	76.6%	205	18.0%	61	5.4%	
African American (n = 614)	427	69.5%	149	24.3%	38	6.2%	
Other[a] (n = 170)	118	69.4%	43	25.3%	9	5.3%	
Gender							0.109
Female	819	53.4%	256	56.6%	70	62.5%	
Male	714	46.6%	196	43.4%	42	37.5%	
Myocardial infarction	37	2.4%	17	3.8%	1	0.9%	0.145
Congestive heart failure	37	2.4%	5	1.1%	1	0.9%	0.153
Peripheral vascular disease	22	1.4%	8	1.8%	2	1.8%	0.855
Coronary vessel disease	44	2.9%	13	2.9%	3	2.7%	0.993
Dementia	9	0.6%	6	1.3%	0	0%	0.170
Chronic pulmonary disease	75	4.9%	13	2.9%	5	4.5%	0.187
Connective tissue disease	32	2.1%	12	2.7%	1	0.9%	0.492
Peptic ulcer disease	29	1.9%	6	1.3%	5	4.5%	0.090
Mild liver disease	11	0.7%	7	1.5%	0	0%	0.146
Diabetes mellitus	280	18.3%	91	20.1%	23	20.5%	0.600
Diabetes with chronic complications	23	1.5%	11	2.4%	2	1.8%	0.405
Hemiplegia	9	0.6%	2	0.4%	0	0%	0.683
Renal disease	28	1.8%	9	2.0%	0	0%	0.336
Any tumor	164	10.7%	35	7.7%	13	11.6%	0.162
Leukemia	4	0.3%	0	0%	1	0.9%	0.209
Lymphoma	7	0.5%	2	0.4%	0	0%	0.774
Moderate or severe liver disease	4	0.3%	0	0.0%	0	0%	0.478

Bold values are statistically significant.
[a]Mean ± standard deviation is shown for continuous variables.
[b]Percentages do not add to 100% due to missing data with regard to race.
CSF = cerebrospinal fluid.

mortality 0.57%). Interestingly, it appears that patients with failed repair were slightly younger. We believe that this may be due in part to the more aggressive total resection usually undertaken for younger patients, aimed at reducing recurrences and long-term morbidity associated with residual disease. Although there were no differences in race among patients with failed repair, we found that Caucasian patients were slightly more likely to never experience leakage. On the other hand, non-Caucasian patients were more likely to have successful repair, which is a reflection of the higher percentage of these patients having intraoperative leakage. These findings may at least in part be secondary to differences in access to healthcare and time to presentation. Patients with failed CSF leak repair had an increased number of postoperative complications. Those with successful repair of CSF leaks had very similar outcomes to patients without a recorded intraoperative leak. Generally, the rate of postoperative leaks in this study was comparable to published series, reflecting a lower overall failure rate for pituitary pathologies and higher rates for high-risk tumors, such as those with ventricular extension.[5]

TABLE 2. Complications rates by CSF leak group

	No leak (N = 1533)		Successful repair (N = 452)		Failed repair (N = 112)			95% CI for OR	
	N	%	N	%	N	%	OR[a]	Lower	Upper
Readmission within 30 days	132	8.6%	52	11.5%	58	52.3%	8.4	5.3	13.5
Reoperation	53	3.5%	12	2.7%	85	75.9%	115.4	56.3	236.8
Pneumocephalus	2	0.1%	5	1.1%	17	15.2%	16.0	5.8	44.4
Intracranial infection	10	0.7%	21	4.6%	24	21.4%	5.6	3.0	10.5
Internal carotid artery injury	9	0.6%	0	0.0%	0	0.0%			
Cranial nerve injury	17	1.1%	8	1.8%	0	0.0%			
Postoperative bleed	48	3.1%	9	2.0%	5	4.5%			
Deep vein thrombosis	9	0.6%	9	2.0%	9	8.0%	4.3	1.7	11.1
Pneumonia	22	1.4%	15	3.3%	6	5.4%			
Cerebrovascular accident	7	0.5%	7	1.5%	5	4.5%			
Cardiac compromise	17	1.1%	6	1.3%	2	1.8%			
Death	9	0.6%	2	0.4%	1	0.9%			
Days on ventilation (mean ± SD)[b]	0.1 ± 1.0		0.3 ± 2.0		1.8 ± 8.7		$\beta = 1.5$[c]	$p = 0.001$	
Hospital days (mean ± SD)[b]	4.3 ± 4.1		7.0 ± 6.9		14.9 ± 16.9		$\beta = 8.0$[c]	$p < 0.001$	

[a]OR compares failed CSF leak repair to successful CSF leak repair (only significant ORs are shown).
[b]Mean ± standard deviation data are shown for continuous variables.
[c]For continuous outcomes, β is the slope of the linear regression comparing successful and failed categories.
CI = confidence interval; CSF = cerebrospinal fluid; OR = odds ratio.

TABLE 3. Association of skull base diagnosis with failed CSF leak repair.

		Univariate			Multivariate		
	Failure rate	OR[a]	95% CI	*p* value	OR[a]	95% CI	*p* value
Pituitary (n = 352)[a]	**16.50%**	**0.58**	**0.38–0.88**	**0.010**	**0.556**	**0.36–0.87**	**0.011**
Meningioma (n = 27)	29.60%	1.75	0.75–4.12	0.197			
Chordoma (n = 13)	38.50%	2.59	0.83–8.09	0.100			
Craniopharyngioma (n = 31)	**35.50%**	**2.35**	**1.09–5.07**	**0.029**	2.071	0.83–5.16	0.118
Encephalocele (n = 78)	**28.20%**	**1.73**	**1.004–2.978**	**0.048**	**1.868**	**1.04–3.35**	**0.036**
All intracranial (n = 167)[b]	**29.30%**	**2.20**	**1.44–3.38**	**<0.001**	**2.352**	**1.48–3.75**	**<0.001**

Bold values are statistically significant.
[a]OR comparing failed CSF leak repair to successful CSF leak repair.
[b]Denotes number of patients in whom an intraoperative CSF leak was encountered. Pathologies with <10 patients in failed and successful repair groups were excluded. Three tumors were labeled as pituitary adenoma and craniopharyngioma cases and were classified as craniopharyngioma given prior reports of higher failure rate.[22]
[c]Includes all intracranial pathologies, excluding pituitary tumors.
CI = confidence interval; CSF = cerebrospinal fluid; OR = odds ratio.

Failed CSF leak repair was associated with a number of adverse outcomes. Overall, it resulted in prolonged invasive ventilation, from 0.3 to 1.8 days, and a doubling of hospital stay, from 7.0 to 14.9 days. It is not clear whether invasive ventilation was used as a measure to treat pneumocephalus or altered mental status. Failed CSF leak repair patients had significantly higher rates of intracranial complications, such as intracranial infections and pneumocephalus. These increased rates are likely secondary to persistent communication of the intracranial space with the contaminated nasal cavity. It should be noted that these data are prone to bias as postoperative imaging was not used routinely in all patients and expected postoperative pneumocephalus can be misdiagnosed as pathologic. Compared with successfully repaired patients, those with failed repair had a significantly increased rate of DVT (OR, 4.3; 95% CI, 1.7-11.1), which is likely secondary to prolonged immobility and the contraindication to use of prophylactic anticoagulation.

TABLE 4. Association of tumor variables and adjuvant therapies with failed CSF leak repair

	OR[a]	95% CI	*p* value
Prior skull base operation (n = 434)	1.25	0.75–2.08	0.393
Prior radiation therapy (n = 70)	**2.67**	**1.01–7.06**	**0.047**
Prior chemotherapy (n = 38)	1.01	0.11–9.12	0.994
ACF (n = 745)	0.90	0.58–1.41	0.650
MCF/perisellar (n = 1316)	1.16	0.74–1.84	0.517
PCF (n = 17)	3.08	0.68–13.94	0.145
Ventricular extension (n = 64)	**2.40**	**1.08–5.36**	**0.033**

Bold values are statistically significant.
[a]OR = odds ratio of failed repair compared with successful repair.
ACF = anterior cranial fossa; CI = confidence interval; CSF = cerebrospinal fluid; MCF = middle cranial fossa, OR = odds ratio; PCF = posterior cranial fossa.

TABLE 5. Association of various repair techniques with failed CSF leak repair

	OR[a]	95% CI	*p* value
Rigid reconstruction	0.8756	0.44–1.74	0.705
Septal flap	**0.6048**	**0.34–0.92**	**0.018**
Free graft	1.0133	0.67–1.55	0.951
Lumbar drain	0.9553	0.63–1.45	0.829

Bold values are statistically significant.
[a]OR = odds ratio of failed repair compared with successful repair.
CSF = cerebrospinal fluid; OR = odds ratio.

Failed CSF leak repair often resulted in the need for reoperation (OR, 115.4; 95% CI, 56.3-236.8) or 30-day readmission (OR, 8.4; 95% CI, 5.3-13.5). The increased readmission rate likely reflects a cohort of patients whose leaks were not detected during the initial hospitalization, as well as those with delayed failures. Overall, it appears that patients in the failed CSF repair cohort had a markedly poorer postoperative course. These findings reinforce the need for definitive measures to achieve a successful primary repair of CSF leaks to reduce morbidity and related costs.

We also examined the association of various patient and tumor parameters with failed CSF leak repair. This was done in 3 ways: by location of tumor (anterior, middle, or posterior cranial fossa); by intracranial extension to the ventricles; and by tumor type. One of the strongest predictors of failed CSF leak repair was extension of the tumor to the ventricular system. This subset of patients was significantly more likely to experience a failure in their repair (OR, 2.4; 95% CI, 1.08-5.36). Despite trends toward increased failure in tumors from the posterior cranial fossa, there were no significant changes in outcomes associated with any of the 3 unique tumor locations. We performed univariate and multivariate testing with respect to age, race, prior radiation therapy, ventricular extension, and septal flap use, to determine the likelihood of having failure in various pathologies. Multivariate analysis was performed to minimize the contribution of the confounding factors identified on univariate analysis to impact outcomes. Pituitary tumors were the most commonly encountered pathology and, fortunately, CSF leaks in these patients were associated with reduced rates of failed repairs (OR, 0.58; 95% CI, 0.38-0.88). These findings did not change markedly, according to the multivariate analysis. However, patients with encephaloceles (OR, 1.72; 95% CI, 1.004-2.977) and craniopharyngiomas (OR, 2.35; 95% CI, 1.92-5.07) were more likely to have postoperative failures. On univariate analysis, our data for meningioma and chordoma did not reach statistical significance, despite trends suggesting increased failure in these patients. It is likely that subtotal resection in a subset of these patients contributed to slightly more favorable short-term outcomes. On multivariate analysis, craniopharyngiomas were not associated with poorer outcomes. Generally, it appears that, with the exception of pituitary tumors, all intracranial pathologies were associated with higher rates of failed repair, but statistical significance was not reached in most cases due to the small numbers of patients. Therefore, we assessed the likelihood of failed repair in a pooled population of intracranial pathologies compared with a pooled population of intranasal and pituitary lesions. We detected very significant and increased rates of failed repair in patients with intracranial pathologies (OR, 2.18; 95% CI, 1.42-3.34). In fact, if patients who were never found to have a leak are excluded, the rate of postoperative failure would be 29.2% in this group, as compared with 13.3% and 16.5% failure rates in patients with intranasal and pituitary pathologies, respectively. This observed difference in intranasal and intracranial pathologies likely stems from the need for creation of bigger dural defects in patients with intracranial tumors. Prior surgery or chemotherapy did not significantly affect the rate of postoperative leaks. However prior treatment with radiation therapy appeared to increase the rate of failed repair (OR, 2.57; 95% CI, 1.01-7.06), presumably secondary to the frequently observed poor wound healing in these patients.

Various techniques and graded approaches to skull base repairs have been proposed to prevent CSF leaks after tumor resection.[19] Similar to other published reports, we found that pedicled nasoseptal flap was associated with reduced postoperative leak rates.[8,17,20] Among the various repair strategies tested, the pedicled nasoseptal flap approach was the only one protective against failed repair. Factors that did not seem to impact postoperative CSF leaks included rigid plating, free grafts, and lumbar drain, yet these techniques have not been widely utilized. Unfortunately, we are unable to draw any conclusions with regard to use of lumbar drains, as the timing of lumbar drain usage was not recorded. The data for extraventricular drain were excluded due to the small number of patients who underwent this procedure. Given the clear benefit in reduction of postoperative leaks in this heterogeneous group of patients and institutions, we recommend the use of pedicled nasoseptal flaps for all high-risk tumor types, including those with

ventricular extension. These data are in agreement with other reports suggesting reduced rates of postoperative CSF leaks with the advent of vascularized mucosal flaps.[20,21]

The major strength of this study is that it relied on the largest multi-institutional international series of patients having undergone endoscopic skull base surgery for a myriad of indications. The large number of patients in the database, along with the diversity of pathologies and surgical techniques, make this report representative of typical cases seen at tertiary medical centers. Our findings can be used to help identify patients at higher risk for postoperative CSF leaks, who would benefit from definitive attempts at intraoperative leak repair. One significant shortcoming of our study is that the data were collected in a retrospective fashion. In addition, we relied on operative reports to identify whether an intraoperative leak had occurred. Using the strict criterion of a recorded intraoperative leak, our failure rate was 19.9%. This is certainly an overestimation, as there were some tumor types, such as meningiomas and craniopharyngiomas, that typically have a 100% intraoperative leak rate, yet none was recorded. This is likely secondary to missing data from the operative report or failure to recognize small leaks intraoperatively. As a result, the no-leak cohort probably included some patients with intraoperative leaks that were successfully repaired, and thus our true failure rate would be <19.9%. Furthermore, pituitary neoplasms and encephaloceles comprised >60% of the overall pathologies in our cohort, which may not be representative of surgical patients elsewhere.

Conclusion

Failed repair of CSF leaks in endoscopic skull base surgery results in significant additional comorbidity for patients, yet successful repair of intraoperative leaks can minimize the comorbidity rate. Certain demographic and tumor characteristics allow skull base surgeons to predict those patients at higher risk for postoperative CSF leaks, and the use of repair strategies, such as the pedicled nasoseptal flap procedure, appear to improve outcomes.

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