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Risk-stratified endoscopic multilayer reconstruction for non-iatrogenic cerebrospinal fluid rhinorrhea: a single-center retrospective study

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Abstract

Purpose

To describe the feasibility and short-term clinical outcomes of endoscopic multilayer reconstruction guided by risk stratification in patients with non-iatrogenic cerebrospinal fluid (CSF) rhinorrhea.

Methods

We retrospectively reviewed consecutive patients with traumatic or spontaneous non-iatrogenic CSF rhinorrhea who underwent endoscopic multilayer reconstruction at a single center between 2018 and 2025. Patients with postoperative or transsphenoidal leaks, incomplete records, or follow-up of less than 6 months were excluded. Defects were classified as high-risk when at least one of the following was present: dural defect ≥ 1.5 cm, rapid/pulsatile intraoperative CSF egress, recurrent leak after prior repair, or preoperative intracranial infection. Low-risk defects underwent reconstruction with free autologous grafts, whereas high-risk defects were managed with nasoseptal flap-based reconstruction with or without additional autologous tissue.

Results

Twenty-two patients were included, comprising 12 low-risk and 10 high-risk cases. The overall 6-month closure rate was 95.5% (21/22), including 100% (12/12) in the low-risk group and 90.0% (9/10) in the high-risk group. High-risk cases required longer operative time and had greater intraoperative blood loss. Postoperative nasal discomfort resolved more slowly in the high-risk group, while other between-group differences were not statistically significant.

Conclusion

In this small single-center retrospective series, endoscopic multilayer reconstruction guided by risk stratification achieved a high short-term closure rate in non-iatrogenic CSF rhinorrhea. This pragmatic strategy may help tailor reconstructive intensity to defect complexity while avoiding unnecessary flap harvest in selected low-risk cases.

Introduction

Cerebrospinal fluid (CSF) rhinorrhea represents a pathological communication between the subarachnoid space and the sinonasal tract and carries a substantial risk of meningitis, pneumocephalus, and persistent intracranial hypotension if left untreated[10, 21]. Over the past two decades, endoscopic endonasal repair has largely replaced transcranial approaches for most anterior skull base leaks because it provides direct access to the defect with lower morbidity, less brain

manipulation, and high rates of successful closure[2, 7, 17]. Systematic reviews have shown that contemporary endoscopic repair can achieve primary closure rates exceeding 90%, confirming its role as the current standard of care for most cases of CSF rhinorrhea[17, 19]. These observations are also reflected in more recent evidence syntheses and institutional series, which support endoscopic reconstruction as the preferred first-line strategy for appropriately selected skull base leaks.

Despite these advances, CSF rhinorrhea remains a heterogeneous clinical entity. Traumatic and spontaneous leaks differ not only in their pathogenesis, but also in defect geometry, local tissue quality, intracranial pressure environment, and risk of recurrence[8, 24]. In particular, spontaneous CSF rhinorrhea is increasingly recognized as part of the spectrum of idiopathic intracranial hypertension, which may predispose patients to persistent or recurrent leakage even after technically successful closure[1, 6]. At the same time, large dural defects, rapid or high-flow leakage, prior repair failure, and intracranial infection may substantially increase reconstructive complexity and postoperative risk[3, 15, 25]. Accordingly, a uniform reconstructive strategy may not be equally appropriate across all non-iatrogenic leaks. The association between spontaneous skull base leaks and idiopathic intracranial hypertension, as well as the need to adapt reconstruction to leak flow and anatomic risk, has been emphasized in recent reviews and larger reconstructive studies.

Multilayer reconstruction has become the dominant operative principle in endoscopic skull base surgery because it combines mechanical sealing, dead-space obliteration, and biological coverage within a single reconstructive construct[8, 9, 23]. Nevertheless, the practical question is no longer whether multilayer repair should be used, but rather how reconstructive intensity should be matched to defect-specific risk. Vascularized nasoseptal flap reconstruction is widely regarded as indispensable for extensive or high-flow defects[9, 25], whereas smaller low-flow defects may be successfully repaired with free autologous grafts alone, thereby avoiding unnecessary septal morbidity[13, 20]. Moreover, recent analyses of skull base reconstruction have suggested that intraoperative CSF flow grade and anatomic site strongly influence postoperative leak risk, supporting a more selective and risk-based reconstructive strategy rather than routine escalation in every case[4, 15]. However, most published studies have either focused on postoperative skull base defects, mixed iatrogenic and non-iatrogenic etiologies, or emphasized overall closure success without explicitly linking preoperative/intraoperative risk features to graft selection within a reproducible decision framework. Tailoring reconstruction to intraoperative CSF flow and anatomic risk has been identified as a key unresolved issue in contemporary skull base repair.

In this context, non-iatrogenic CSF rhinorrhea constitutes a clinically meaningful subgroup in which reconstructive decisions may be especially sensitive to leak flow, defect size, recurrence status, and local tissue conditions. Postoperative and transsphenoidal leaks were not included in the present study because their mechanisms, operative environments, and prior tissue manipulation differ substantially from those of traumatic and spontaneous leaks, which would have introduced additional heterogeneity into a small retrospective cohort. We therefore performed a single-center retrospective study of patients with traumatic or spontaneous non-iatrogenic CSF rhinorrhea who underwent endoscopic multilayer

reconstruction guided by risk stratification. Rather than testing superiority between techniques, we aimed to describe the feasibility and short-term clinical outcomes of a pragmatic reconstructive algorithm in which graft selection was tailored according to predefined high-risk features. We hypothesized that such a strategy might provide durable closure while avoiding unnecessary reconstructive escalation in selected low-risk defects.

Methods

Study design and patient selection

This single-center retrospective study was conducted at Fujian Medical University Union Hospital and included consecutive patients with non-iatrogenic cerebrospinal fluid (CSF) rhinorrhea who underwent endoscopic multilayer reconstruction between January 2018 and December 2025. Eligible patients had either traumatic or spontaneous CSF rhinorrhea confirmed by clinical presentation, imaging findings, and intraoperative identification of a skull base defect. Patients with postoperative iatrogenic leaks after skull base or transsphenoidal surgery, follow-up shorter than 6 months, or incomplete clinical records were excluded.

Postoperative and transsphenoidal CSF leaks were intentionally excluded because their defect mechanisms, local tissue conditions, prior surgical manipulation, and reconstructive context differ substantially from those of traumatic and spontaneous non-iatrogenic leaks. Inclusion of these etiologically distinct entities in a small retrospective cohort was considered likely to introduce substantial heterogeneity and confound interpretation of a risk-stratified reconstructive strategy. The study was therefore designed to focus specifically on non-iatrogenic CSF rhinorrhea.

Preoperative evaluation

All patients underwent standardized preoperative assessment including detailed symptom review, nasal endoscopy, and radiographic localization of the skull base defect. High-resolution computed tomography (CT) was used to delineate bony anatomy and identify osseous defects, whereas magnetic resonance imaging (MRI), with or without cisternographic sequences when required, was used to assess dural violation, meningoencephalocele, and the relationship between the subarachnoid space and sinonasal tract. Imaging findings were reviewed in conjunction with operative records to determine defect site, estimated defect size, and associated high-risk features.

Because this was a retrospective study spanning several years, a formal validated intraoperative CSF leak grading scale was not consistently documented in all operative records. Accordingly, flow characteristics were classified pragmatically on the basis of operative descriptions and video review when available.

Risk stratification and reconstructive allocation

Patients were stratified into low-risk and high-risk groups according to predefined anatomical and clinical features. A defect was classified as high-risk if at least one of the following criteria was present: (1) dural defect diameter ≥ 1.5 cm; (2) fast-flow leak confirmed intraoperatively; (3) recurrent CSF rhinorrhea after prior repair; or (4) preoperative intracranial infection. All other defects were categorized as low-risk.

In this study, a fast-flow leak was defined as continuous or pulsatile egress of CSF from the dural defect after adequate exposure, rather than intermittent low-volume seepage or oozing. This definition was selected as a practical operative marker of reconstructive complexity in the absence of uniform formal leak grading across the full study period.

Risk stratification directly guided reconstructive allocation within a predefined institutional algorithm. Low-risk defects were reconstructed using free autologous tissue only, typically a combination of fat and fascia or a small muscle graft when required by local contour. High-risk defects with a single high-risk feature underwent nasoseptal flap (NSF)-based reconstruction, whereas high-risk defects with two or more high-risk features underwent combined reconstruction using an NSF together with additional autologous tissue. This algorithm was designed to match reconstructive intensity to defect complexity while avoiding unnecessary flap harvest in straightforward cases.

Surgical technique

All procedures were performed under general anesthesia by the same multidisciplinary skull base team using a binostril endoscopic endonasal approach. Surgical corridor selection was determined by defect location and included transethmoidal, transsphenoidal, or extended exposure as needed to achieve direct visualization of the skull base defect. After identification of the leak site, all surrounding devitalized tissue, scar, and overlying mucosa were removed, and the bony margin was circumferentially freshened. When anatomically feasible, bony exposure was extended approximately 5 mm beyond the dural defect to create a stable recipient bed for graft apposition.

A standardized multilayer reconstruction sequence was used throughout the study period. In defects reconstructed with free tissue, autologous fat was fashioned into a plug-like graft to fill the defect tract and obliterate dead space. A fascial graft was then placed as an overlay buttress, with a small muscle graft added in selected cases to improve contour matching or local support. In high-risk cases requiring vascularized reconstruction, an NSF was harvested and rotated to provide broad mucosal coverage over the reconstructed skull base. For patients with a single high-risk feature, the NSF served as the principal vascularized layer. For patients with multiple high-risk features, the NSF was combined with autologous fat and/or fascia to reinforce the central seal. Fibrin sealant, absorbable gelatin sponge, antibiotic-impregnated gauze, and balloon support were then applied as external stabilization layers.

Postoperative management and follow-up

Postoperative management was individualized according to leak severity, reconstructive complexity, and intraoperative findings. Lumbar drainage was used selectively, primarily in cases with fast-flow leakage, extensive defects, or concern regarding elevated postoperative CSF pressure. Drainage was discontinued once CSF output remained stable and there was no clinical evidence of persistent rhinorrhea.

Nasal packing constituted the outermost support layer and was generally removed on postoperative day 3 in low-risk autologous reconstructions and later in NSF-based repairs depending on flap stability and local healing. Patients were followed at 1, 3, and 6 months after surgery and thereafter as clinically indicated. Follow-up assessment included symptom review, endoscopic examination, and documentation of postoperative discomfort, recurrence, and need for reintervention. When in-person review was not feasible, structured telephone follow-up was performed to collect recovery-related data.

Outcome measures

The primary outcome was successful closure at 6 months, defined as absence of recurrent CSF rhinorrhea on clinical and endoscopic assessment. Secondary outcomes included operative time, intraoperative blood loss, use and duration of lumbar drainage, timing of nasal packing removal, length of postoperative hospitalization, recurrence, patient-reported nasal discomfort duration, residual nasal discomfort at last follow-up, and patient satisfaction score.

Because high-risk reconstruction was further determined by whether one or multiple high-risk features were present, the distribution of these features within the high-risk subgroup was additionally recorded. These data were analyzed descriptively to clarify the internal composition of the high-risk cohort and the allocation of NSF-only versus combined reconstruction.

Statistical analysis

Given the limited sample size, all statistical analyses were considered exploratory and primarily descriptive. Continuous variables were summarized as mean ± standard deviation (SD) for approximately normally distributed data or median with interquartile range (IQR) for skewed data. Categorical variables were summarized as counts and percentages. Comparisons between low-risk and high-risk groups were performed using the Mann-Whitney U test for continuous variables and Fisher's exact test for categorical variables, as appropriate. The 95% confidence interval (CI) for the 6-month closure rate was calculated using the Wilson method. Two-sided p values < 0.05 were considered statistically significant. All analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA).

Ethical approval

This study was approved by the Institutional Review Board of Fujian Medical University Union Hospital. Owing to the retrospective design and use of de-identified clinical data, the requirement for informed consent was waived.

Results

Cohort characteristics

A total of 22 consecutive patients with non-iatrogenic cerebrospinal fluid (CSF) rhinorrhea met the inclusion criteria. The mean age was 40.3 ± 10.9 years (range, 23–59 years), and the mean body mass index was 25.7 ± 4.5 kg/m². Twelve patients (54.5%) were classified as low-risk and 10 (45.5%) as high-risk according to the predefined risk stratification criteria. The underlying etiology was traumatic in 9 patients (40.9%) and spontaneous in 13 (59.1%). Clear rhinorrhea was the most common presenting symptom (22/22, 100%), followed by headache in 5 patients (22.7%) and meningitis in 2 (9.1%). The median duration of symptoms before surgery was 2.0 months (IQR, 0.5–6.0 months), and the median follow-up duration was 28.2 months (IQR, 18.3–40.2 months) .

Defect characteristics and risk distribution

The ethmoid sinus was the most frequent leak site (14/22, 63.6%), followed by the sphenoid sella (5/22, 22.7%) and the sphenoid lateral recess (3/22, 13.6%). Multiple-site defects were identified in 4 patients (18.2%). The mean defect length was 10.8 ± 8.6 mm, and the mean defect area was 155.2 ± 225.6 mm², with a median area of 62.0 mm² (IQR, 24.0–180.0 mm²). Encephaloceles were present in 3 patients (13.6%) .

Ten patients (45.5%) fulfilled at least one high-risk criterion. Among the high-risk features, large dural defects > 1.5 cm were present in 8 patients (36.4%), fast-flow leaks in 7 (31.8%), recurrent CSF rhinorrhea after prior repair in 3 (13.6%), and preoperative intracranial infection in 2 (9.1%) . Within the high-risk subgroup, 5 patients underwent NSF-only reconstruction and 5 underwent combined NSF plus autologous tissue reconstruction, consistent with the predefined allocation of single-feature versus multiple-feature high-risk defects . Representative radiographic and intraoperative findings illustrating low- and high-risk lesions are shown in Figure 1 .

Reconstructive allocation

All 12 low-risk patients underwent reconstruction using free autologous tissue only. Among the 10 high-risk patients, 5 underwent NSF-based reconstruction alone and 5 underwent combined reconstruction with an NSF and additional autologous graft material. Thus, the reconstructive strategy followed the predefined risk-based algorithm across the entire cohort, with no low-risk patient requiring vascularized flap reconstruction and no high-risk patient treated with free grafting alone .

Primary closure outcomes

The overall 6-month closure rate was 95.5% (21/22; 95% CI, 78.2–99.8). Closure was achieved in all low-risk patients (12/12, 100%) and in 9 of 10 high-risk patients (90.0%) . One recurrence (4.5%) occurred in the high-risk group . At re-exploration, the original reconstruction was found to remain intact, and the

recurrent rhinorrhea was attributed to a new traumatic defect at a separate site rather than failure of the initial repair. No major perioperative complications were observed.

Operative burden and postoperative recovery

Operative and postoperative outcomes are summarized in Table 3. Mean operative time was significantly longer in the high-risk group than in the low-risk group (178.6 ± 57.8 min vs 128.3 ± 35.5 min, p = 0.048), and median intraoperative blood loss was also greater in high-risk cases (65 mL [IQR, 35–100] vs 20 mL [IQR, 20–22.5], p = 0.001) .

Lumbar drainage was used in 14 of 22 patients (63.6%), including 7 of 12 low-risk patients (58.3%) and 7 of 10 high-risk patients (70.0%), without a statistically significant between-group difference (p = 0.675) . Drainage duration was numerically longer in the high-risk group (11.7 ± 3.3 days vs 7.8 ± 4.0 days), but this difference did not reach statistical significance (p = 0.113) . Likewise, postoperative hospitalization was numerically longer in high-risk patients (median, 15 days [IQR, 10.5–18.5] vs 10 days [IQR, 6.5–14.5]), although no significant between-group difference was observed (p = 0.155) . In contrast, nasal packing was removed significantly later in the high-risk group (median, 13 days [IQR, 3–17] vs 3 days [IQR, 3–3], p = 0.044) .

Patient-reported satisfaction remained high in both groups, with mean scores of 9.4 ± 0.6 in the low-risk group and 8.7 ± 0.9 in the high-risk group; however, this between-group difference was not statistically significant (p = 0.052) . Postoperative nasal discomfort resolved significantly sooner in the low-risk group (2.33 ± 1.30 months vs 4.55 ± 1.21 months, p = 0.001), and residual nasal discomfort at last follow-up was observed only in high-risk patients (4/10 vs 0/12, p = 0.031) .

Discussion

In this single-center retrospective study of non-iatrogenic cerebrospinal fluid (CSF) rhinorrhea, endoscopic multilayer reconstruction guided by risk stratification was associated with a high 6-month closure rate and acceptable perioperative morbidity across both traumatic and spontaneous leaks. The overall closure rate was 95.5%, including successful closure in all low-risk cases and in 90.0% of high-risk cases. These findings are broadly consistent with previously reported outcomes of endoscopic skull base repair, for which pooled primary closure rates generally exceed 90%[12, 17, 19]. However, the present study was not designed to establish superiority of one reconstructive technique over another. Rather, our data suggest that, within the context of a pragmatic institutional algorithm, reconstructive intensity can be matched to defect complexity without obvious compromise of short-term closure. This distinction is important, because the present cohort was small, retrospective, and clinically heterogeneous, and therefore should be interpreted primarily as descriptive evidence of feasibility rather than comparative proof of efficacy.

The central premise of our approach is that the success of skull base repair depends less on the absolute number of reconstructive layers than on appropriate matching between defect risk and the

biological and mechanical properties of the chosen graft construct. Multilayer reconstruction has become the dominant paradigm in endoscopic skull base surgery because it simultaneously addresses several critical requirements: obliteration of dead space, establishment of a watertight seal, resistance to CSF pulsation, and promotion of graft incorporation[9, 23, 25]. Yet not all defects require the same degree of reconstructive escalation. Small, low-flow leaks with limited bony disruption can often be managed effectively with free autologous tissue, whereas large dural defects, rapid CSF egress, recurrent leaks, or infected fields may require vascularized coverage to improve healing reliability[13, 15, 20]. This is consistent with previous reports describing satisfactory outcomes with layered free graft techniques in selected CSF rhinorrhea cases[18]. Our findings support this principle indirectly: low-risk patients treated with free autologous grafts alone achieved complete short-term closure, whereas high-risk patients underwent more intensive reconstruction at the cost of longer operations, greater blood loss, delayed packing removal, and slower recovery of nasal comfort. Taken together, these observations support the practical value of stratifying reconstructive burden rather than applying routine flap harvest in every case.

One clinically relevant implication of this study is the selective use of the nasoseptal flap (NSF). Since its modern standardization by Hadad and Bassagasteguy, the NSF has become a cornerstone of endoscopic skull base reconstruction, particularly for extensive or high-flow defects[9, 25]. Its vascularized nature improves mucosalization and provides robust biological coverage, especially in settings of wide dural violation or persistent CSF stress[15, 25]. At the same time, flap harvest is not biologically neutral and may be accompanied by crusting, dryness, donor-site morbidity, and delayed sinonasal recovery[11, 20]. In our cohort, all low-risk defects were repaired without flap harvest, and these patients experienced significantly faster resolution of postoperative nasal discomfort. Although this observation should not be interpreted as definitive comparative evidence, it is consistent with the view that routine NSF use in straightforward low-risk lesions may represent overtreatment. Conversely, the high-risk subgroup—particularly those with multiple adverse features requiring combined reconstruction—illustrates the continued importance of vascularized support in more complex leaks. Thus, our results favor a selective rather than universal flap strategy, aligned with defect-specific risk.

The role of free autologous tissue in contemporary skull base reconstruction also deserves emphasis. Despite increasing interest in vascularized flaps and synthetic adjuncts, autologous fat and fascia remain widely used because they are readily available, biocompatible, moldable, and familiar to most skull base teams[13, 23]. In our series, low-risk defects were reconstructed with fat-fascia or fat-muscle constructs, often using a plug-like central component to fill the fistulous tract and support the overlay layer. This principle resembles the “bath-plug” technique described by Wormald, which was designed to secure the graft within the defect and resist displacement by CSF pulsation[23]. Such a configuration may be particularly useful in narrow, deep, or irregular channels, including lesions involving the lateral recess of the sphenoid sinus[16]. The present results do not demonstrate that autologous grafting is equivalent to vascularized reconstruction in all settings; rather, they indicate that within a risk-selected subgroup, free tissue repair can provide satisfactory short-term closure while minimizing additional

septal manipulation. For a small retrospective cohort, that is a more defensible conclusion than any claim of technique superiority.

Another important aspect of the present study is the emphasis on graft-bed preparation. Reconstruction is not determined solely by the graft itself, but by the quality of the interface between the graft and the recipient skull base. Prior skull base literature has highlighted the importance of circumferential mucosal denudation, bony edge exposure, and adequate contouring to maximize graft apposition and reduce the risk of flap migration, mucocele formation, or late sealing failure[14, 15]. Our institutional practice similarly relied on removal of overlying mucosa and freshening of the bony margin, with extension beyond the visible dural defect when feasible. In anatomical regions such as the cribriform plate, planum-sellar transition, or lateral recess of the sphenoid sinus, such preparation is particularly important because the shape of the recipient bed may strongly influence the stability of both free and vascularized grafts[16, 22]. Although the present study does not isolate graft-bed preparation as an independent variable, the consistently high short-term closure rate observed across anatomically diverse lesions suggests that careful preparation likely contributed materially to reconstructive success. For this reason, our findings support viewing graft-bed optimization not as a minor technical detail, but as a core component of the reconstructive strategy itself.

The heterogeneous biology of non-iatrogenic CSF rhinorrhea further underscores the rationale for a risk-based framework. Traumatic leaks often arise in the setting of discrete mechanical disruption and may close spontaneously or respond well to relatively simple reconstruction, whereas spontaneous leaks frequently reflect chronic skull base attenuation, altered CSF dynamics, and, in many patients, underlying idiopathic intracranial hypertension[1, 6, 10, 24]. In spontaneous CSF rhinorrhea, especially in patients with suspected abnormal CSF dynamics, reconstruction alone may not fully address the underlying pathophysiology[5]. These distinctions may influence both initial defect behavior and the likelihood of future leakage at the same or a different site. Indeed, the single recurrence observed in our study was ultimately attributable to a new traumatic defect rather than breakdown of the original reconstruction, highlighting the fact that postoperative rhinorrhea does not necessarily equate to failure of the original repair construct. This point is clinically relevant when interpreting recurrence in mixed-etiology cohorts. It also reinforces why non-iatrogenic leaks should not automatically be treated as a homogeneous group, and why risk features beyond etiology alone may be more useful in guiding reconstructive decisions.

Our findings should also be interpreted in light of the growing literature on CSF leak flow grading and reconstructive tailoring. Several skull base studies have shown that higher intraoperative flow states are associated with greater postoperative leak risk and often justify more aggressive reconstruction[4, 15]. The present study was limited by the absence of a uniformly recorded formal leak grading system across the entire study period, and therefore relied on a pragmatic retrospective definition of fast-flow leakage. This is a methodological weakness, but it also reflects the reality of many retrospective institutional series spanning multiple years of practice evolution. By explicitly acknowledging this limitation and treating our analysis as exploratory, we aimed to avoid overstating the precision of the proposed algorithm. Future studies should ideally incorporate standardized intraoperative leak grading

and prospectively defined reconstruction pathways, which would allow more rigorous evaluation of which combinations of defect size, flow, recurrence, and infection most strongly predict the need for vascularized or combined repair.

Several limitations merit emphasis. First, it was a single-center retrospective study with a small sample size, which limited statistical power and precluded reliable assessment of rare complications. Second, despite restricting the cohort to non-iatrogenic leaks, the population remained clinically heterogeneous with respect to etiology, defect location, and risk profile. Third, a formal validated intraoperative CSF leak grading system was not consistently documented across the study period. Finally, follow-up was sufficient for short-term closure assessment but not designed to fully evaluate long-term recurrence or sinonasal functional outcomes.

Despite these limitations, the study has several strengths. It focuses on a clinically meaningful but methodologically underdefined subgroup—non-iatrogenic CSF rhinorrhea—and applies a consistent institutional algorithm across all cases. It also integrates defect morphology, leak behavior, recurrence status, and infection into a pragmatic decision framework that can be readily understood and replicated in routine skull base practice. In an area where many published reports emphasize technical success but provide less explicit guidance regarding reconstructive selection, our findings may help shift attention toward a more structured and individualized approach to defect management. Larger multicenter studies with standardized leak grading, longer follow-up, and formal patient-reported outcome measures are needed to validate this strategy and clarify which patients truly benefit from vascularized or combined reconstruction.

Conclusions

In this small single-center retrospective study, endoscopic multilayer reconstruction guided by risk stratification was associated with a high short-term closure rate in patients with non-iatrogenic cerebrospinal fluid rhinorrhea. The findings suggest that free autologous reconstruction may be sufficient for selected low-risk defects, whereas vascularized flap-based or combined reconstruction may provide additional support in more complex high-risk lesions. Rather than supporting a uniform reconstructive strategy for all cases, these results favor a pragmatic, defect-specific approach that integrates leak characteristics, recurrence status, and local tissue conditions into surgical decision-making.

Declarations

Author Contribution

H.C., R.Z., and Z.X. contributed equally to this work and share first authorship. H.C. and J.C. conceived and designed the study. H.C. collected the data and drafted the manuscript. R.Z. performed imaging analysis and verified the surgical data. Z.X. performed the statistical analysis and prepared Figs. 1–2.

B.Z. acquired the clinical data and conducted patient follow-up. J.P.C. supervised the methodology and validated the surgical technique. R.L. critically revised the manuscript and contributed to interpretation of the results. J.C. supervised the study, oversaw the surgical procedures, and approved the final manuscript. All authors read and approved the final manuscript.

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Tables

Table 1. Patient demographics and baseline clinical characteristics.

Factor	**Patients (n = 22)**	
Female, %	12	(54.5%)
Age, mean (SD, range), years	40.3	(10.9, 23–59)
BMI, mean (SD, range), kg/m²	25.7	(4.5, 19.8–36.3)
Past medical history, n (%)		
Chronic rhinosinusitis	6	(27.3%)
Hypertension	4	(18.2%)
Diabetes	1	(4.5%)
Seizure disorder	1	(4.5%)
Prior repair	5	(22.7%)
Use of acetazolamide	6	(22.7%)
Tobacco use	4	(18.2%)
Time symptomatic, median (IQR), months	2.0	(0.5-6.0)
Presenting symptoms, n (%)		
Clear rhinorrhea	22	(100%)
Headache	5	(22.7%)
Meningitis	2	(9.1%)
Pneumonitis	3	(13.6%)
Seizure	1	(4.5%)
Follow-up duration, median (IQR), months	28.2	(18.3 – 40.2)

Abbreviations: BMI, body mass index; CSF, cerebrospinal fluid; MRI, magnetic resonance imaging; SD, standard deviation.

Table 2. Defect characteristics and risk stratification features

Factor	Patients (n = 22)	
Defect location, n (%)		
Ethmoid sinus	14	(63.6%)
Sphenoid sella	5	(22.7%)
Sphenoid lateral recess	3	(13.6%)
Sphenoid planum	2	(9.1%)
Frontal sinus	1	(4.5%)
Multiple-site defects	4	(18.2%)
Presumed etiology, n (%)		
Traumatic	9	(40.9%)
Spontaneous	13	(59.1%)
Defect length, mean (SD, range), mm	10.8	(8.6, 2.0–30.0)
Defect area, mean (SD, range), mm^2	155.2	(225.6, 4.0–750.0)
median (IQR), mm^2	62.0	(24.0–180.0)
Encephalocele, n (%)	**3**	**(13.6 %)**
High-risk classification, n (%)	10	(45.5%)
Large dural defect >1.5 cm	8	(36.4%)
Fast-flow leak	7	(31.8%)
Recurrent CSF leak	3	(13.6%)
Preoperative intracranial infection	2	(9.1%)

Abbreviations: CSF, cerebrospinal fluid; MRI, magnetic resonance imaging.

Table 3. Operative and postoperative outcomes.

Variable	Total (n=22)	Low-risk (n=12)	High-risk (n=10)	p-value
Surgical duration, min, mean (SD)	151.18 (57.32)	128.33 (35.50)	178.60 (57.78)	0.048
Intraoperative bleeding, ml, median (IQR)	30.0 (20.0–50.0)	20.0 (20.0–22.5)	65.0 (35.0–100.0)	0.001
Repair strategy, n (%):				
Fat/muscle graft only	12 (54.5%)	12 (100%)	0 (0%)	–
NSF only	5 (22.7%)	0 (0%)	5 (50.0%)	–
Fat + NSF	5 (22.7%)	0 (0%)	5 (50.0%)	–
Lumbar drainage used, n (%)	14 (63.6%)	7 (58.3%)	7 (70.0%)	0.675
Lumbar drainage duration, days, median (IQR)	10.08 (3.96)	7.80 (4.02)	11.71 (3.25)	0.113
Nasal packing removal day, median (IQR)	3.0 (3.0–10.5)	3.0 (3.0–3.0)	13.0 (3.0–17.0)	0.044
Postoperative hospitalization, days, median (IQR)	12.0 (7.25–17.0)	10.0 (6.5–14.5)	15.0 (10.5–18.5)	0.155
Postoperative CSF leak recurrence, n (%)	1 (4.5%)	0 (0%)	1 (10.0%)	0.29
6-month closure success, n (%)	21 (95.5%)	12 (100%)	9 (90.0%)	–
Patient satisfaction (0–10), mean (SD)	9.1 ± 0.8	9.4 ± 0.6	8.7 ± 0.9	0.052
Nasal discomfort duration, months, mean (SD)	3.34 (1.67)	2.33 (1.30)	4.55 (1.21)	0.001
Residual nasal discomfort, n (%)	4 (18.2%)	0 (0%)	4 (40.0%)	0.031

Abbreviations: NSF, nasoseptal flap; CSF, cerebrospinal fluid

Figures

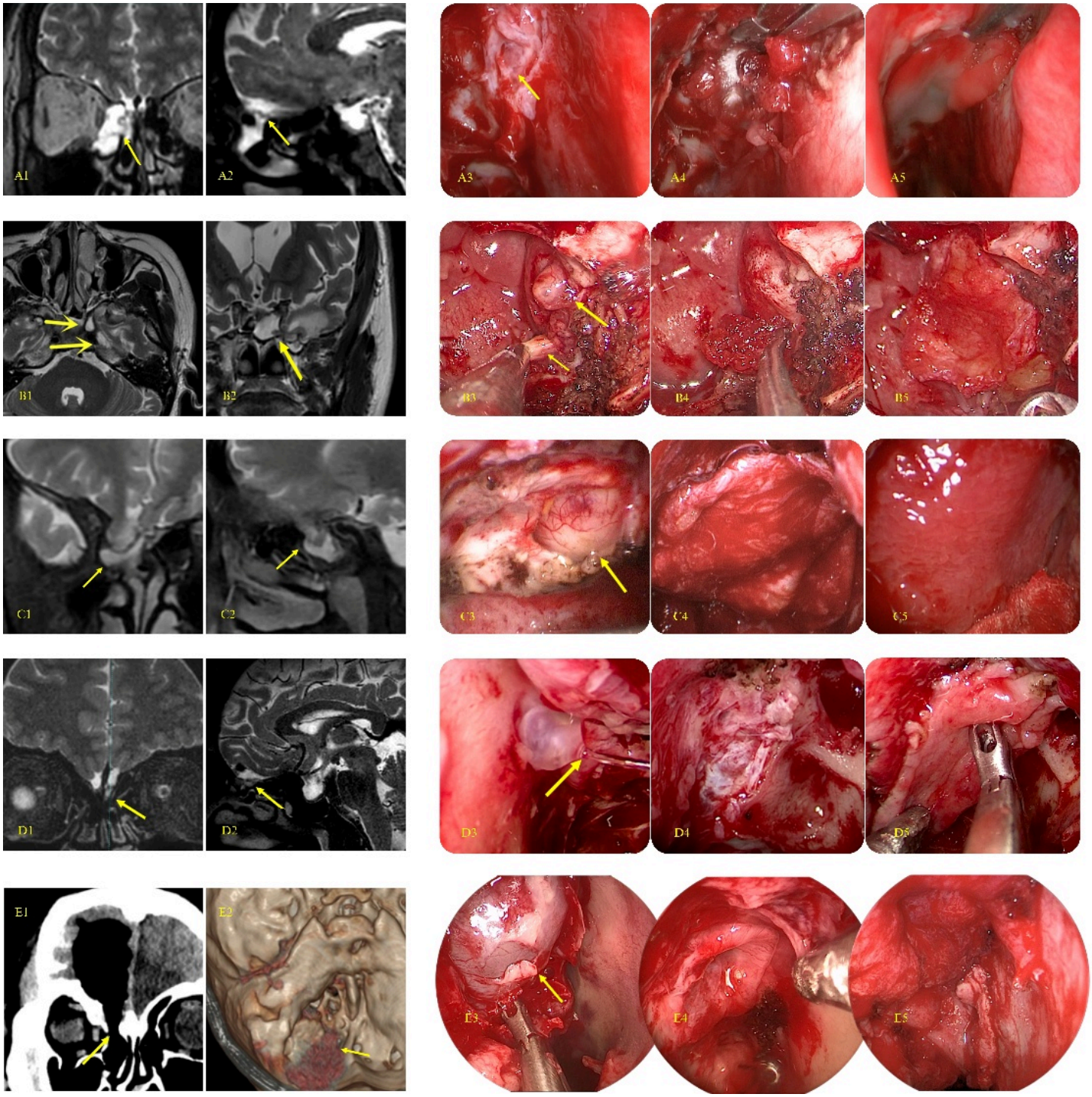


Figure 1

Representative imaging and intraoperative findings of low- and high-risk cerebrospinal fluid rhinorrhea and corresponding endoscopic multilayer reconstruction techniques.

(a) Low-risk spontaneous ethmoidal leak with a small dural defect. (b) Low-risk leak involving the lateral recess of the sphenoid sinus with limited bony disruption and small encephaloceles. (c) High-risk sphenoid planum defect with a large meningoencephalocele and extensive skull base loss. (d) High-risk anterior ethmoidal defect with fast-flow cerebrospinal fluid egress. (e) Traumatic high-risk anterior skull

base defect involving the cribriform plate and posterior wall of the frontal sinus. Low-risk defects were reconstructed with free autologous grafts, whereas high-risk defects underwent nasoseptal flap-based reconstruction. Arrows indicate confirmed leak sites.

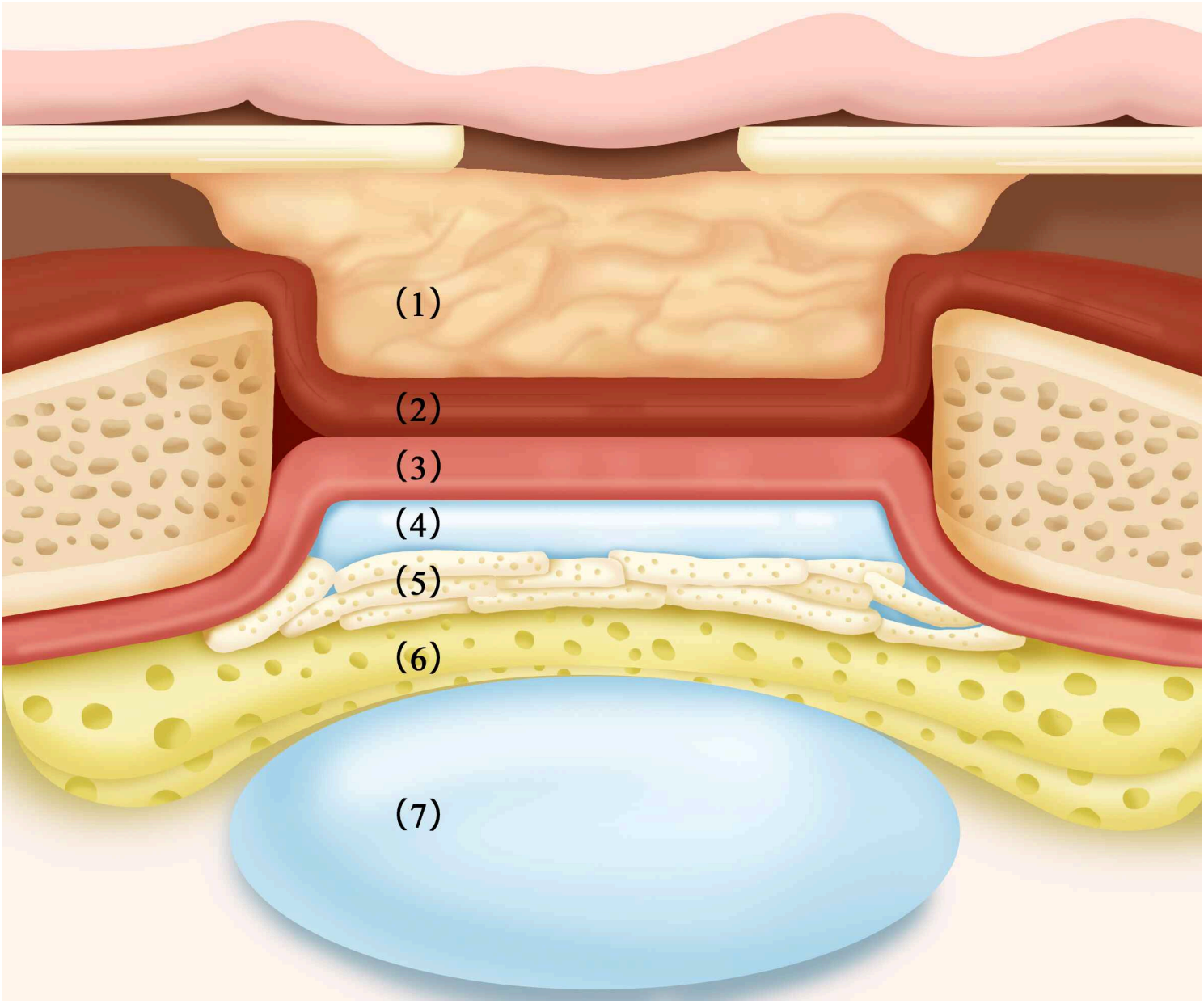


Figure 2

Schematic illustration of the standardized seven-layer endoscopic multilayer reconstruction sequence used for skull base defect repair.

The reconstructive construct consisted of (1) an autologous fat graft placed in a plug-like configuration, (2) fascial overlay, (3) nasoseptal flap when indicated by risk stratification, (4) fibrin sealant, (5) absorbable gelatin sponge, (6) antibiotic-impregnated gauze, and (7) balloon compression. The overall multilayer architecture was standardized, whereas the core reconstructive components were selected according to defect risk.