Title

Endonasal Free Flap Reconstruction Combined With Draf Frontal Sinusotomy for Complex Cerebrospinal Fluid Leak: A Technical Report & Case Series.

Journal

Operative Neurosurgery, 21(6)

Authors

Lee, Jake
Chicoine, Michael
Dowling, Joshua
et al.

Publication Date

2021-11-15

DOI

10.1093/ons/opab309

Peer reviewed

Endonasal Free Flap Reconstruction Combined With Draf Frontal Sinusotomy for Complex Cerebrospinal Fluid Leak: A Technical Report & Case Series

Jake J. Lee, MD, MSCI [*]
Elizabeth H. Wick, MD [‡]
Michael R. Chicoine, MD [§]
Joshua L. Dowling, MD [§]
Eric C. Leuthardt, MD [§]
Paul Santiago, MD [§]
Patrik Pipkorn, MD, MSCI [*]

[*]Department of Otolaryngology-Head and Neck Surgery, Washington University in St. Louis, Saint Louis, Missouri, USA; [‡]Department of Otolaryngology-Head & Neck Surgery, University of Miami – Miller School of Medicine, Miami, Florida, USA; [§]Department of Neurosurgery, Washington University in St. Louis, Saint Louis, Missouri, USA

Correspondence:
Patrik Pipkorn, MD, MSCI,
Department of Otolaryngology-Head and Neck Surgery,
Washington University School of Medicine,
660 South Euclid Ave,
Campus Box 8057,
St. Louis, MO 63110, USA.
Email: ppipkorn@wustl.edu
Twitter: @JakeJLeeMD1

Received, April 1, 2021.
Accepted, July 8, 2021.
Published Online, August 23, 2021.

BACKGROUND: Frontal sinus cranialization with closure via bifrontal pericranial flaps is the gold standard for separating the nasofrontal recess from the intracranial cavity for posterior table defects. Despite the high success rate, cerebrospinal fluid (CSF) leak may persist and is particularly challenging when vascularized reconstructive options from the bicoronal incision are exhausted.

OBJECTIVE: To assess a novel endonasal technique using an adipofascial radial forearm free flap delivered to the frontal recess through a Draf sinusotomy to repair complex CSF leaks from the frontal sinus.

METHODS: A retrospective review of 3 patients (all male; ages 42, 43, and 69 yr) with persistent CSF leak despite frontal sinus cranialization and repair with bifrontal pericranium was performed. Etiology of injury was traumatic in 2 patients and iatrogenic in 1 patient after anaplastic meningioma treatment. To create space for the flap and repair the nasofrontal ducts, endoscopic Draf III (Case 1, 3) or Draf IIb left frontal sinusotomy (Case 2) was performed. The forearm flap was harvested, passed through a Caldwell-Luc exposure, and placed within the Draf frontal sinustomy. The flap vessels were tunneled to the left neck and anastomosed to the facial vessels by the mandibular notch.

RESULTS: Intraoperatively, the flaps were well-seated and provided a watertight seal. Postoperative hospital courses were uncomplicated. There were no new CSF leaks or flap necrosis at 12, 14, and 16 mo.

CONCLUSION: Endoscopic endonasal free flap reconstruction through a Draf procedure is a novel viable option for persistent CSF leak after failed frontal sinus cranialization.

KEY WORDS: Endoscopic, Endonasal, Skull base, Free flap, Reconstruction, Cerebrospinal fluid leak

Operative Neurosurgery 21:478–484, 2021 https://doi.org/10.1093/ons/opab309

The treatment for frontal sinus fractures has evolved with advancements in endoscopic endonasal techniques.[1] Whereas the main objectives of repair of the anterior table remain largely cosmetic, the preserved function of the nasofrontal duct is important to decrease the long-term risk of mucocele. Although minimally displaced posterior table defects can be safely observed,[2-4] comminuted defects have a significant risk of mucocele development from trapped mucosal elements, resulting in significant morbidity.[5-7] In addition, comminuted posterior table defects have a significant risk of cerebrospinal fluid (CSF) leak.

ABBREVIATION: RFFF, radial forearm free flap

The gold standard for repairing CSF leaks from the frontal sinus after trauma or surgery for tumors or other pathologies is obliterate the frontal sinus through a cranialization procedure.[7] The details and efficacy of this procedure have been well documented.[8] During cranialization, the posterior wall of the frontal sinus is removed, and the nasofrontal recess is occluded with vascularized or non-vascularized tissue. The most commonly used tissue is a bifrontal pericranial flap given its close proximity to the surgical site, lack of a separate donor site, and reliable blood supply from the supratrochlear and supraorbital vessels.[9] However, trauma or other surgical procedures that disrupt the frontal sinus may also disrupt the integrity of the pericranial flap, thereby making it unusable for repair. Although nonvascularized options have

successfully been used, vascularized options are particularly advantageous when locoregional options are unusable due to collateral damage and donor site morbidity.

Despite the high success rate of frontal sinus cranialization, persistent CSF leak may still occur.[10] Traditionally in these cases, the craniotomy is revised via bicoronal incision in order to attempt a new repair. Few additional vascularized local options, if any, may be available in this setting. Instead, repair from the nasal side with endoscopic techniques may be an option. However, the most commonly used flap for endonasal repair, the nasoseptal flap, has limited reach towards the frontal recess. In addition, the most distal end of the flap farthest away from its pedicle is most prone to necrosis yet is the most critical for the repair. In this setting, free tissue transfer with endoscopic technique may be a viable option and has been described for repair of other complex skull base defects and CSF leaks.[11]

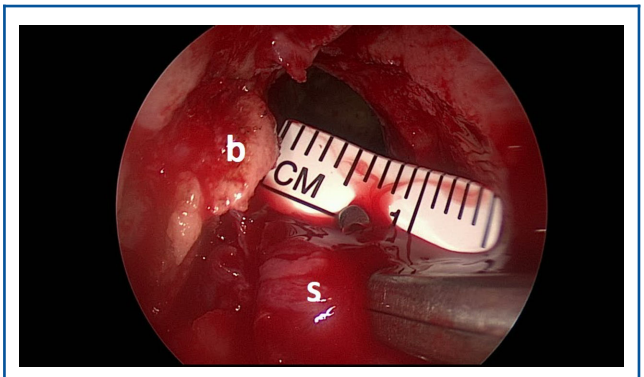

FIGURE 1. *Precise intraoperative measurement of the Draf frontal sinusotomy is performed with a ruler under endoscopic visualization.*

METHODS

A retrospective chart review was performed of consecutive patients treated between January 1, 2015, and July 1, 2020, who underwent repair of the nasofrontal recess after failed cranialization using forearm free tissue transfer via endoscopic endonasal Draf procedure combined with a transbuccal Caldwell-Luc approach. This reconstructive technique was chosen after multidisciplinary discussions between multiple neurosurgeons and otolaryngology reconstructive surgeons. Prior to commencement, Institutional Review Board approval was obtained. Due to the retrospective nature of the study, patient consent was not required. All patients provided consent for intraoperative photography and publication of their images.

Surgical Technique

In order to gain access to the ablated frontal sinus and enable delivery of vascularized tissue, a Draf procedure was performed. The surgical details for Draf procedures have previously been described in detail.[12-15] The essential components of the Draf procedure include removal of the agger nasi cells, frontal beak, middle turbinate, and/or anterosuperior portion of the nasal septum. The Draf procedure was performed on the side where the previous frontal sinus cranialization had been performed; if both sides were previously removed, a Draf III was performed removing all the tissue and bony partitions from orbit to orbit including the anterosuperior nasal septum and frontal inter-sinus septum. Given the lack of posterior table from the prior frontal sinus cranialization, endonasal dissection was performed with caution, as the lack of this landmark can be somewhat disorienting even for the experienced endoscopic surgeon. Intraoperative computed tomography (CT) navigation was utilized.

Once the Draf procedure was performed, the dimensions of the narrowest part of the defect were measured. The true size may be overestimated due to the use of endoscopic instrumentation and magnification. Thus, a ruler or some objective measure was used (Figure 1). Correct measurements from the beginning significantly enhanced instrumentation and fitting of the flap endonasally.

Next, the corridor from the frontal sinus to the facial vessels for delivery of the free flap pedicle was created. This corridor included an endoscopic medial maxillectomy to gain endonasal access to the maxillary sinus, a gingivolabial incision to expose the maxilla, an anterior maxillary antrostomy through a Caldwell-Luc procedure, and a soft tissue tunnel through the buccal space to the facial vessels as they cross the mandibular notch (Figure 2). Throughout all of these procedures, care was taken to ensure that the corridor is wide enough and void of sharp edges in order to minimize compression and potential for vascular injury.

Vessels were exposed using a curvilinear cervical incision by the facial notch. Small subplatysmal flaps were raised. The vessels can be exposed superior or inferior to the marginal mandibular nerve depending on pedicle length. In general, the forearm flap had significant pedicle length enabling anastomosis below the notch at the level of the submandibular gland while being used for frontal sinus repair.

Next, the radial forearm free flap (RFFF) was harvested as a purely adipofascial free flap after placement of a tourniquet (Figure 3). A skin paddle over the distal radius was not needed. A curvilinear incision was carried proximally from the distal radius to the antecubital fossa through the skin and subcutaneous tissue. The volume of the flap was increased as needed by adding fascia underlying the skin over the distal forearm. The cephalic vein was identified and preserved on the radial aspect of the distal forearm. An incision was then made through the fascia of the brachioradialis and flexor carpi radialis muscles. The subfascial flap was elevated off the brachioradialis tendon, and the radial nerve was identified and preserved. The radial artery was then clamped and ligated. The flap pedicle was then elevated from distal to proximal, and the branches of the radial artery were clipped. Frequently there is some fat around the pedicle distally in the lateral intramuscular fascia. More proximally the pedicle was narrowed but still taken with a small rim of fat to bolster and prevent any kinking within the previously created tunnel. Next, the antecubital fossa and the vascular pedicle were exposed. The radial recurrent artery was identified and skeletonized for preservation. The venous plexus was skeletonized, and the venae were kept in communication with the cephalic vein. Once the flap was raised and ready to be harvested, the final dimensions were again meticulously measured to confirm appropriate flap volume for placement into the dumbbell-shaped defect. The tourniquet was next taken down to allow for re-perfusion through the flap. Distal hemostasis was meticulously achieved in order to prevent any bleeding from the flap from getting trapped intracranially once re-vascularized. After achieving hemostasis and waiting 15 min for re-perfusion, the veins and artery were clamped and ligated. Since no skin was harvested, the donor site was closed primarily over a suction drain without a skin graft, thereby obviating

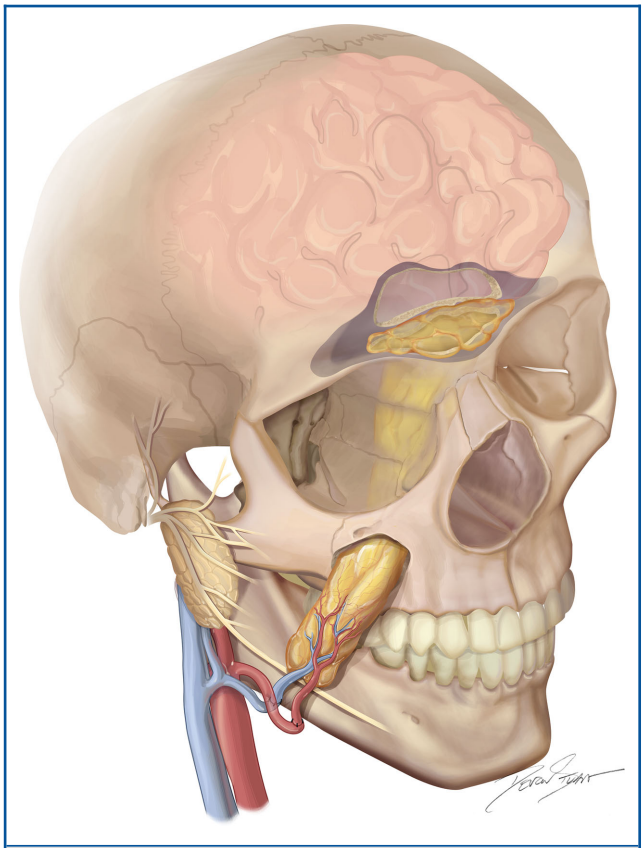

FIGURE 2. *Illustration demonstrating adipofascial RFFF transfer through a right gingivobuccal incision, extended Caldwell-Luc antrostomy, medial maxillectomy, and nasal cavity for inset into a Draf III frontal sinusotomy cavity. The free flap vessels were anastomosed to the right facial artery and vein.*

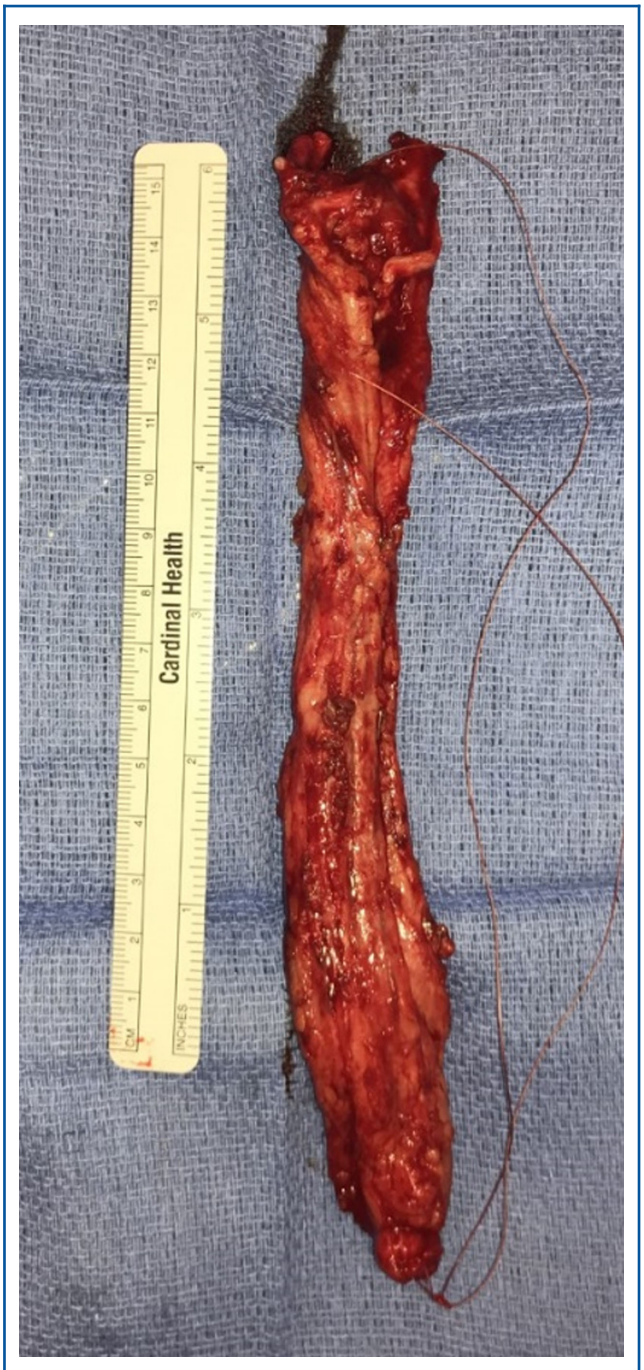

FIGURE 3. *Left adipofascial RFFF with suture attached distally at the time of harvest.*

the need for postoperative arm immobilization or significant limb use restrictions.

After flap harvest, positioning of the flap was performed. Although no suturing is needed, this maneuver is technically challenging. The most critical factor determining success of delivery was meticulously harvesting a flap with correct dimensions. For easier delivery, a suture was placed on the distal end of the flap (Figure 3). The suture was then positioned through the Caldwell-Luc into the maxillary sinus with forceps, and endonasally it was grasped under 30 degree endoscopic guidance (Figure 4). The distal end of the flap was pulled out extranasally for accommodation of the proximal flap and proper reorientation and then re-advanced into the nasal cavity (Figure 5). After part of the flap was delivered, the distal end of the flap was grasped with blunt straight or curved instruments as to not injure the pedicle and enable further delivery into the Draf frontal sinusotomy. Given the narrow working space, visualization during this maneuver was limited. The flap is ideally delivered a few centimeters superiorly until it rests without tension or sliding. Manipulation of the flap within the Draf opening was necessary to ensure that it did not slide, thus providing a watertight seal.

Next, the proximal part of the flap was delivered through the buccal space, and microvascular technique was used for vascular anastomoses. The pedicle was then correctly oriented without kinks. If delivered correctly, the flap tended to sit safely in the defect so that no nasal packing

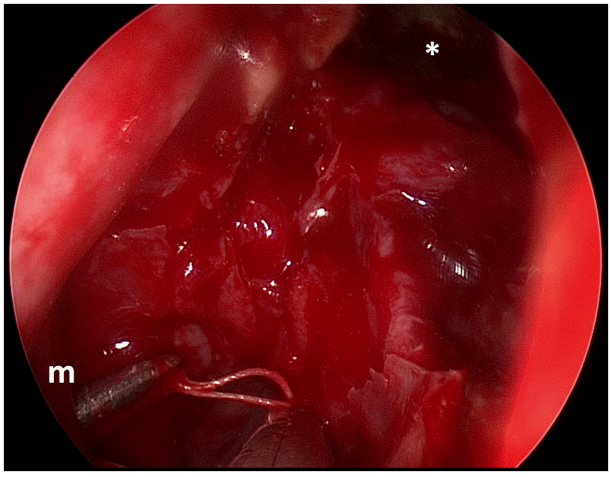

FIGURE 4. *After the flap is passed through the gingivobuccal incision and Caldwell-Luc antrostomy into the right maxillary sinus, the suture attached to the distal end is grasped and pulled endonasally to assist with the inset. Abbreviations: m, medial maxillectomy; ∗, frontal sinusotomy defect.*

FIGURE 5. *The distal end of the flap is pulled out of the nasal cavity to accommodate the proximal portion into the nasal cavity and then reinserted for advancement into the Draf frontal sinusotomy. (The participants consented to publication of his image.)*

was necessary for support. Endonasal hemostasis was achieved using a combination of electrocautery, HemaDerm (Medafor Inc, Minneapolis, Minnesota), and NasoPore packing (Stryker, Kalamazoo, Michigan), and Valsalva maneuvers were used to ensure resolution of CSF leak. The intraoral gingivobuccal incision was closed with resorbable sutures. Postoperatively, standard CSF precautions were employed including no nose blowing, open mouth sneezing, and no straining. Nasal saline spray was started immediately postoperatively, and saline irrigations were commenced after 3 to 4 d. Patients were started on an oral diet as soon as their mental status was deemed intact. In-office debridements of the sinonasal cavity were performed every 3 wk until the crusting burden was acceptable and mucociliary clearance returned.

RESULTS

Three patients underwent adipofascial RFFF reconstruction delivered to the frontal recess through Draf procedure using the described technique. Demographics and treatment details are shown in Table. All 3 flaps achieved successful separation of the intracranial space from the nasal cavity without signs of CSF leak at any time after the procedure, including at the time of last follow up (12, 14, and 16 mo). All flaps survived without flap-related complications. None of the patients reported any nasal obstruction or significant morbidity from the nose, including epistaxis and acute rhinosinusitis. All patients underwent 1 to 2 postoperative sinonasal debridements to clear crusting, debris, and packing. No patients suffered donor site wound complications.

One patient (ID #2) was readmitted 3 wk after his index surgery for a frontal epidural abscess that required external incision, drainage, and washout. It was suspected that retained bullet fragments contributed to the development of the abscess. The same patient (ID #2) underwent polyetheretherketone cranioplasty for his left frontotemporoparietal skull defect 5 mo after his RFFF reconstructive surgery and left buccal foreign body removal for a retained bullet 10 mo after his reconstruction, which were uncomplicated.

Postoperative imaging was performed in all 3 patients. All patients underwent interval head CT imaging during their index hospitalization to assess for resolution of pneumocephalus. Follow-up CT and magnetic resonance imaging was performed in all 3 patients 2 to 5 mo after reconstructive surgery (Figures 6-9).

DISCUSSION

The treatment paradigm for frontal sinus defects, both traumatic and iatrogenic, has evolved over the last few decades. In general, a more conservative approach has been adopted due to increased ability to serially observe with imaging and/or endoscopy,[16] increased technical ability to safely perform endonasal surgery at the nasofrontal recess,[1,4] and increased understanding of frontal sinus pathology.[7,17] Frontal sinus cranialization and reconstruction with bifrontal pericranium or other grafts remain the treatment of choice to repair complex frontal sinus fractures and/or defects after surgery for tumors or other pathologies.[7] The main objectives with this technique are to completely remove all the mucosal elements from the frontal sinus and create separation between the anterior cranial fossa and the nasal cavity. The aim is to prevent short- and long-term sequelae such as CSF leak or mucocele or mucopyocele development, which may be life-threatening. Although the technique has a high success rate, persistent CSF leak after the procedure is possible and can be troublesome to repair.[10]

TABLE. Patient Characteristics, Treatment Details, and Outcomes

ID	Age/sex	Etiology	Access to frontal sinus	Prior Sx	Prior medical Tx	Result	Complications	# Nasal debride-ments	Follow-up	Status
1	69/M	Anaplastic meningioma	Draf III	Bifrontal craniotomy x2, open cranialization	XRT, GK	Successful separation, resolved CSF leak	None	2	12 mo	AWD
2	42/M	GSW trauma	Bilateral Draf IIb	Hemicraniectomy, open cranialization	None	Successful separation, resolved CSF leak	Left frontal epidural abscess s/p external I&D	1	14 mo	Alive, NED
3	43/M	MCC trauma	Draf III	Bifrontal craniotomy, open cranialization	None	Successful separation, resolved CSF leak	None	2	16 mo	Alive, NED

ID, identification; M, male; GSW, gunshot wound; MCC, motorcycle collision; Sx, surgery; Tx, treatment; XRT, external beam radiation therapy; GK, gamma knife; CSF, cerebrospinal fluid; I&D, incision & drainage; mo, months; AWD, alive with disease; NED, no evidence of disease.

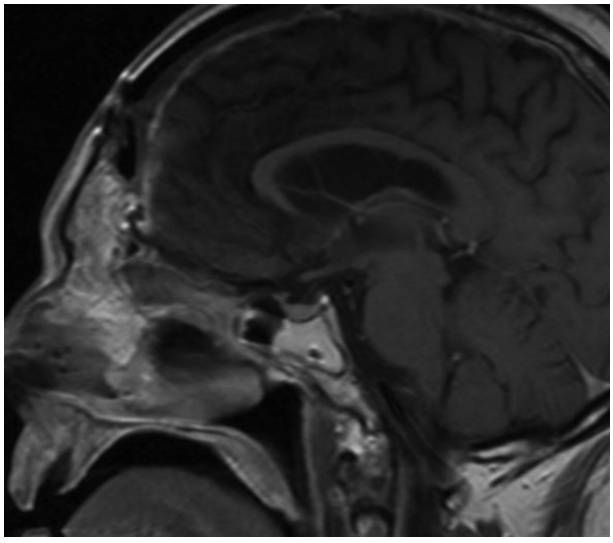

FIGURE 6. *Case ID #1's sagittal T1-weighted MRI with contrast showing the adipofascial flap wedged through the nasofrontal recess and filling the frontal sinus at the site of skull base defect.*

FIGURE 7. *Case ID #1's coronal CT without contrast showing the flap filling the Draf III cavity and pedicle running inferolaterally toward the left maxillary sinus. Abbreviation: p, pedicle.*

Multiple reconstructive options for persistent CSF leak after disruption of the anterior cranial fossa and breach of the frontal sinus have been proposed. For plugging of the nasofrontal duct during craniotomy, a multitude of materials have been proposed including vascularized and non-vascularized options. Abdominal fat, cancellous bone, temporalis fascia or muscle have all been used with success.[7] The most commonly used vascularized tissue is the pericranial flap.[10] Although nonvascularized tissue has been used with good outcomes, vascularized flaps have some distinct advantages.[18] The inherent blood supply of local vascularized flaps enhances the potential for adherence of the flap to surrounding structures for ultimate watertight healing. In addition, vascularized flaps are theoretically more resistant to infection due to their blood supply. Unfortunately, there are few local flap options in proximity to the frontal sinus, and disruption of the pedicle of the pericranial flap through trauma, previous surgery, or radiation may prevent its use. Other vascularized reconstructive options from above through a frontal craniotomy were deemed suboptimal in this patient population due to additional morbidity and the lack of nearby vasculature for anastomosis secondary to disruption of the superficial temporal vessels.

With increased multidisciplinary care of these patients, endonasal vascularized local flaps such as the nasoseptal flap has been used for repair along the anterior cranial fossa.[19,20] Unfortunately, most of these axial flaps receive their blood supply

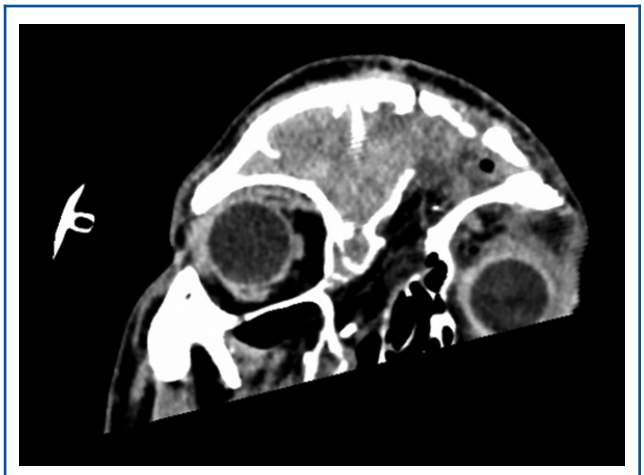

FIGURE 8. *Case ID #2's coronal CT without contrast showing the adipofascial flap filling the left Draf IIb cavity.*

FIGURE 9. *Case ID #2's axial CT showing the flap filling the left frontal sinus and frontal recess.*

from various branches of the sphenopalatine artery, which is located in the posterior nasal cavity. The nasoseptal flap, the most commonly used flap, is limited in its arc of rotation towards the frontal recess. In addition, the anterior portion of the flap, which is the most critical for the repair, is located the furthest from its vascular pedicle.[20] For rare cases of persistent CSF leak after previous resection or trauma along the anterior cranial fossa, free tissue transfer has been described.[21] Endoscopic free tissue transfer using the Caldwell-Luc/transbuccal corridor was initially described by Sinha et al[22] and later refined by Kang et al and Pipkorn et al.[23,24] These techniques relied on a previous defect along the anterior cranial fossa where the flap could be positioned. Preoperative discussion among our multidisciplinary team determined that endoscopic endonasal free tissue transfer is a substantially robust yet less invasive reconstructive option compared to more traditional open techniques in these patients. In this report, we combined this technique with the creation of a Draf sinusotomy to gain access to the ablated frontal sinus to instead "plug the hole" from the bottom.

Limitations

This study has several limitations. This is a limited case series performed at a single tertiary care institution by a single surgeon. In addition, this technique requires expertize in not only microvascular reconstruction and familiarity of the neck but also proficiency in endoscopic endonasal techniques in order to perform Draf sinusotomy procedures. Lastly, postoperative outcomes were unable to be compared to non-vascularized techniques. Despite these limitations, RFFF reconstruction of the frontal sinus anterior skull base region delivered via Caldwell-Luc approach to the maxillary sinus and a Draf frontal sinusotomy may offer a robust closure technique for reconstruction and sealing of CSF leaks that otherwise can be challenging to manage.

CONCLUSION

Although technically challenging, endoscopic endonasal adipofascial radial forearm free tissue transfer is a feasible option in select patients with complex anterior cranial fossa defects through the frontal sinus that have exhausted vascularized reconstructive options from above, such as the bifrontal pericranial flap. The technique was highly successful in resolving persistent CSF leaks with limited surgical morbidity and is an option to consider for difficult situations in which other reconstruction options may be limited. The technique's utility warrants confirmation by other surgeons in multidisciplinary centers.

Funding

This study did not receive any funding or financial support.

Disclosures

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article. Dr Lee has received support from the National Institute on Deafness and Other Communication Disorders of the NIH under Award Number 5T32DC000022-30 and by the National Center for Advancing Translational Sciences of the NIH under Award Number UL1TR002345. Dr Chicoine received funding from 1) IMRIS Inc for an unrestricted educational grant to support an iMRI database and outcomes analysis project, the IMRIS Muliticenter intraoperative MRI Neurosurgery Database (I-MiND), 2) The Head for the Cure Foundation, 3) Mrs Carol Rossfeld and The Alex & Alice Aboussie Family Charitable Foundation, 4) an unrestricted educational grant from the Subcortical Surgery Grant Program, and 5) Research Support from Barbara and George Holtzman.

REFERENCES

1. Jones V, Virgin F, Riley K, Woodworth BA. Changing paradigms in frontal sinus cerebrospinal fluid leak repair. *Int Forum Allergy Rhinol.* 2012;2(3):227-232.

2. Bell RB, Dierks EJ, Brar P, Potter JK, Potter BE. A protocol for the management of frontal sinus fractures emphasizing sinus preservation. *J Oral Maxillofac Surg*. 2007;65(5):825-839.
3. Chen KT, Chen CT, Mardini S, Tsay PK, Chen YR. Frontal sinus fractures: a treatment algorithm and assessment of outcomes based on 78 clinical cases. *Plast Reconstr Surg*. 2006;118(2):457-468.
4. Elkahwagi M, Eldegwi A. What Is the Role of the Endoscope in the Sinus Preservation Management of Frontal Sinus Fractures? *J Oral Maxillofac Surg*. 2020;78(10):1811.e1811-1811.e1819.
5. Schramm VL, Maroon JC. Sinus complications of frontal craniotomy. *Laryngoscope*. 1979;89(9):1436-1445.
6. Meetze K, Palmer JN, Schlosser RJ. Frontal sinus complications after frontal craniotomy. *Laryngoscope*. 2004;114(5):945-948.
7. Strong EB. Frontal sinus fractures: current concepts. *Craniomaxillofac Trauma Reconstr*. 2009;2(3-4):161-175.
8. Donald PJ. Neurosurgery: Skull Base Craniofacial Trauma. *J Neurol Surg B Skull Base*. 2016;77(05):412-418.
9. Ravindra VM, Neil JA, Shah LM, Schmidt RH, Bisson EF. Surgical management of traumatic frontal sinus fractures: case series from a single institution and literature review. *Surg Neurol Int*. 2015;6:141.
10. Donath A, Sindwani R. Frontal sinus cranialization using the pericranial flap: an added layer of protection. *Laryngoscope*. 2006;116(9):1585-1588.
11. Dang RP, Roland LT, Sharon JD, Doering M, Chicoine MR, Pipkorn P. Pedicle corridors and vessel options for free flap reconstruction following endoscopic endonasal skull base surgery: a systematic review. *J Neurol Surg B Skull Base*. 2021;82(2):196-201.
12. Draf W. Endonasal micro-endoscopic frontal sinus surgery, the Fulda concept. *Oper Tech Otolaryngol Head Neck Surg*. 1991;2(4):234-240.
13. Gross WE, Gross CW, Becker D, Moore D, Phillips D. Modified transnasal endoscopic Lothrop procedure as an alternative to frontal sinus obliteration. *Otolaryngol Head Neck Surg*. 1995;113(4):427-434.
14. Crocetta FM, Farneti P, Sollini G, et al. Endoscopic management of frontal sinus diseases after frontal craniotomy: a case series and review of the literature. *Eur Arch Otorhinolaryngol*. 2021;278(4):1035-1045.
15. Turner JH, Vaezeafshar R, Hwang PH. Indications and outcomes for Draf IIB frontal sinus surgery. *Am J Rhinol Allergy*. 2016;30(1):70-73.
16. Dedhia RD, Morisada MV, Tollefson TT, Strong EB. Contemporary management of frontal sinus fractures. *Curr Opin Otolaryngol Head Neck Surg*. 2019;27(4):253-260.
17. Banks C, Grayson J, Cho DY, Woodworth BA. Frontal sinus fractures and cerebrospinal fluid leaks: a change in surgical paradigm. *Curr Opin Otolaryngol Head Neck Surg*. 2020;28(1):52-60.
18. Harvey RJ, Parmar P, Sacks R, Zanation AM. Endoscopic skull base reconstruction of large dural defects: a systematic review of published evidence. *Laryngoscope*. 2012;122(2):452-459.
19. Fortes FS, Carrau RL, Snyderman CH, et al. The posterior pedicle inferior turbinate flap: a new vascularized flap for skull base reconstruction. *Laryngoscope*. 2007;117(8):1329-1332.
20. Pinheiro-Neto CD, Snyderman CH. Nasoseptal flap. *Adv Otorhinolaryngol*. 2013;74:42-55.
21. Bell EB, Cohen ER, Sargi Z, Leibowitz J. Free tissue reconstruction of the anterior skull base: a review. *World J Otorhinolaryngol Head Neck Surg*. 2020;6(2):132-136.
22. Sinha P, Desai SC, Ha DH, Chicoine MR, Haughey BH. Extracranial radial forearm free flap closure of refractory cerebrospinal fluid leaks: a novel hybrid transantral-endoscopic approach. *Oper Neurosurg*. 2012;71(Suppl_2):ons219-ons226.
23. Kang SY, Eskander A, Hachem RA, et al. Salvage skull base reconstruction in the endoscopic era: Vastus lateralis free tissue transfer. *Head Neck*. 2018;40(4):E45-E52.
24. Pipkorn P, Lee JJ, Zenga J, Chicoine MR. Endoscopic adipofascial radial forearm free flap reconstruction of the skull base: a technical update. *J Neurol Surg B Skull Base*. 2020;82(Suppl 3):e243-e247.