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“Open-window” craniectomy for the removal of frontal sinus mucosa to prevent a delayed mucocele: illustrative case

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BACKGROUND Frontal craniotomies for a medial subfrontal approach necessitate crossing the frontal sinus. Large superior extensions of the frontal sinus into frontal bone can result in mucosal retention in a free craniotomy bone flap, leading to a delayed mucocele with significant associated morbidity. The authors describe an “open-window” craniectomy technique that permits mucosal removal under direct vision and maintains the inner table on the bone flap’s inferior side, helping to seal off the sinus opening with a pericranial flap.

OBSERVATIONS An illustrative case involving a medial right frontal craniotomy for a third ventricle mass in a patient with a large superior extension of the frontal sinus into frontal bone is presented. After creating a free frontal bone flap, the inner table was drilled out to the margins of the frontal sinus cavity and any remaining mucosa was cleared. A portion of the inner table above the bone flap’s inferior margin was left in place, resembling an open window when viewed from the inner table side. The remaining anterior and posterior wall of the flap inferiorly provided a matched surface for the opening into the remaining frontal sinus, which was covered by pericranium. Long-term follow-up indicated no major complications or delayed mucocele.

LESSONS The open-window craniectomy technique can be considered for frontal sinus violations in patients with large superior frontal bone extension.

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KEYWORDS mucocele; paranasal sinus; skull base reconstruction; rhinology; craniotomy; subfrontal approach

Paranasal sinuses, such as the frontal sinus, carry a propensity for the development of mucoceles in the setting of obstruction of the sinus drainage. Mucoceles can occur after surgery that violates the sinus, traumatic fracture to the sinus, and sinonasal infection or inflammation, among other factors.^{1,2}

Craniotomies in the frontal and frontotemporal region frequently necessitate opening the frontal sinus. In some of these cases, the sinus mucosa can get trapped intracranially, or postsurgical scar tissue can obstruct drainage. The secretory sinonasal mucosal lining leads to mucus production in a nondraining space, leading to the formation of a benign frontoethmoidal mucocele, which steadily and insidiously enlarges. These patients present with local swelling, pain, and cosmetic

deformity in the initial stages, which can later progress to complications with major morbidity, including frontal bone osteomyelitis, eyelid abscess, cellulitis, chronic sinusitis, mucopyocele, and subperiosteal abscess, which can even progress to vision abnormalities, vision loss, meningitis, or cerebral abscess.^{1,3–7} For established frontal sinus mucoceles, management strategies include obliteration of the frontal sinus, cranialization, and endoscopic marsupialization.^{8–10} However, no consensus exists regarding the superiority of one approach over the other, and this is compounded by the lack of direct comparative outcomes data.² Additionally, these therapeutic procedures also carry their own morbidity and mortality, as illustrated by a recent report of intracerebral hemorrhage following endoscopic marsupialization.¹¹ Meanwhile, a not

ABBREVIATIONS 3D = three-dimensional; MRI = magnetic resonance imaging.

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insignificant proportion of patients have a recurrence and/or require revision surgery, with a subset developing persistent postoperative pain.^{9,12–14} Therefore, preventive strategies in procedures with a heightened postoperative risk of mucocele development, as in neurosurgical cases of frontal sinus traversal, remain meaningful.

Surgeons performing craniotomies that result in a violation of the frontal sinus can either 1) occlude the frontal recess and obliterate the frontal sinus or 2) cranialize the frontal sinus by eradicating its posterior wall, removing or coagulating its mucosa, and facilitating the resting of the frontal lobe against the anterior table and floor of the sinus.^{15,16} However, the mucosa in the part of the sinus cavity connected to the nasal cavity does not need to be removed as the nasal-frontal duct is open. Meanwhile, the sinus mucosa within the free bone flap does need to be removed to prevent delayed mucocele formation once the frontal sinus opening is covered with pericranium and the opening in the frontal sinus is closed off. In the cases of large frontal sinus cavities extending superiorly in the frontal bone, it can be difficult to ensure the removal of all mucosae, as instruments cannot reach the apex of the sinus cavity and the surgeon cannot visualize the same apex of the cavity. These cases likely represent higher risks for mucocele formation, if not proactively managed.

In the reported case, we describe a technique that can reasonably prevent delayed mucocele formation. The method involves drilling out the inner table of the skull to expose the apex of high frontal sinus cavities while maintaining the posterior wall on the lower part of the free bone flap, a so-called “open-window” craniectomy, ensuring an airtight seal of the pericranial flap over the top of the frontal sinus opening. The mucosa of the bone flap is removed to prevent the

development of a mucocele, which can occur when viable sinus mucosa continues to secrete mucous with no avenue for drainage. The purpose of the “open window” is to allow access to the uppermost part of the sinus wall to remove mucosa, which cannot be done with standard craniotomy instrumentation.

Illustrative Case

History and Examination

A 50-year-old male presented with headache and symptoms of pituitary failure at a quaternary care hospital in North America. Magnetic resonance imaging (MRI) revealed a third ventricle mass without hydrocephalus (Fig. 1A and B). A translamina terminalis open biopsy via a right frontal craniotomy as recommended.

Operative Course

The craniotomy cut through the midportion of a large right frontal sinus cavity. On opening the frontal sinus, the nasal side of the sinus was filled with an absorbable gelatin sponge and no mucosa was removed. After the biopsy and frozen section, further resection was performed. At the end of the tumor removal, after closure of the dura, a pericranial flap was turned down over the frontal sinus opening. On the free bone flap side, inspection confirmed a significantly high sinus cavity within the diploic space. It was not possible to reach the apex with a hemostat or a small cutting burr on the drill. Turning the bone flap over, the inner table was removed with a round cutting burr to the medial and lateral margins of the sinus, following these margins superiorly to the apex of the sinus cavity (Fig. 2), leaving the back wall intact for 5 mm above the inferior margin of the bone flap. The bone flap was then secured in compression on

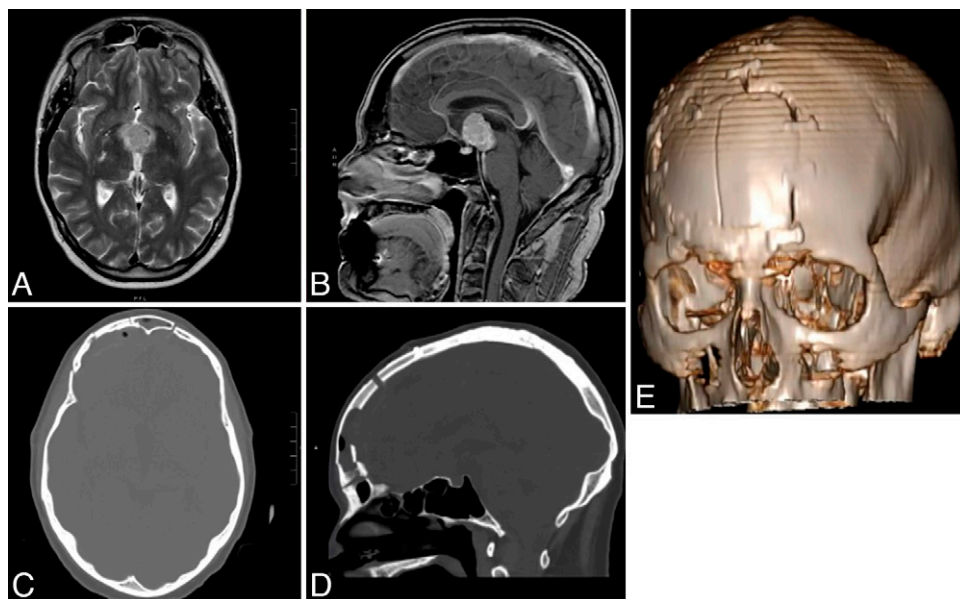


FIG. 1. A and B: Preoperative MRI scans demonstrating a third ventricle mass, which was addressed with an open biopsy via a right frontal craniotomy through the lamina terminalis. The craniotomy cut through the midportion of a large right frontal sinus cavity. After excision and dural closure, a pericranial flap was turned down over the frontal sinus opening. The inner table was drilled out to the margins of the frontal sinus cavity, and any remaining mucosa was cleared. A portion of the inner table above the bone flap's inferior margin was left in place, resembling an open window. **C and D:** Postoperative computed tomography (CT) scans after excision. **E:** 3D CT reconstruction-based imaging of the open window on the right.

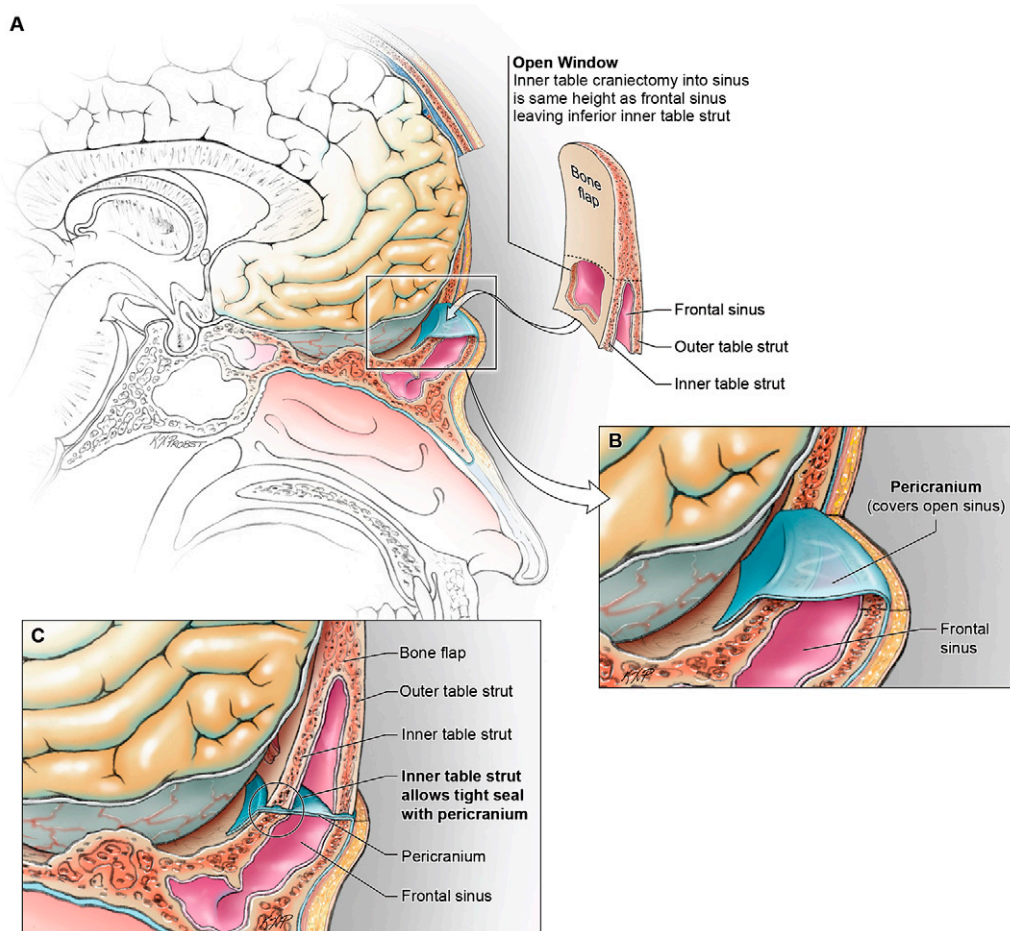


FIG. 2. Illustration of the open window frontal craniotomy technique.

the supra-orbital margin where the pericranial flap was covering the frontal sinus opening, providing a tight seal to prevent the pneumocephalus that may have occurred if the posterior inferior margin of the frontal bone on the free bone flap side had been removed.

Postoperative Course

Postoperative imaging revealed good alignment of the bone edges and no evidence of epidural or subdural air (Fig. 1C and D). The postoperative course was uneventful, and there was no cerebrospinal fluid leakage. A three-dimensional (3D) reconstruction of the bone revealed the open-window craniectomy on the inner table side (Fig. 1E). Follow-up revealed satisfactory clinical outcomes, with no evidence of delayed mucocele formation several years after surgery.

Patient Informed Consent

The necessary patient informed consent was obtained in this study.

Discussion

Violation of the frontal sinus can occur during craniotomy with the sinonasal mucosa either trapped intracranially or the associated inflammatory scar blocking sinus drainage, which can lead to the

development of a frontal sinus mucocele.^{1–4,8} No universally accepted management technique exists, with endoscopic marsupialization; obliteration with fat, fascia, muscle, pericranial flap, acellular dermal matrix, bone, hydroxyapatite cement, or methyl methacrylate; and cranialization with staged cranioplasty as prior reported procedures for frontal sinus mucocele.^{2,12,17–28} Courson et al.,⁸ in 2014, reported on trends in the management of frontal sinus mucoceles across 1975–2012 and noted the increasing adoption of endoscopic techniques with similar complication and recurrence rates. A 2023 systematic review reported no differences across clinical outcomes upon comparing autologous fat versus hydroxyapatite cement for frontal sinus obliteration.²⁹

Mucocele development can occur postprocedure from 3 months to 36 years (mean 14.5 years), as reported by Farag et al.² in 2020 in their own institutional data from the United States. Meanwhile, pooled results from a systematic review of the literature indicated that the mean time from craniotomy to a symptomatic mucocele was nearly 14 years (range 0.3–35 years).^{1–3,30} Given the time horizon for the development of this complication, anticipatory steps during frontal craniotomy remain essential for preventing mucocele development and limiting the need for additional surgical procedures.^{2,8} Although the best way to prevent this scenario remains complete avoidance of frontal sinus violation, purposeful or unintended violations do

frequently occur.² This work described the novel technique of open-window frontal craniectomy in cases of frontal sinus violation to prevent the delayed development of a mucocele.

A common belief among neurosurgeons is that the mucosa on the nasal side of the sinus needs to be removed or exenterated. Because the nasofrontal duct is open preoperatively and will remain so postoperatively, mucous produced by the sinus will drain, and there is no risk of mucocele formation. However, if viable mucosa is left in the free bone flap and the sinus cavity gets closed off with a pericranial flap, then the mucus produced will not drain and a mucocele in the bone flap may develop over time.

Removing the retained mucosa in a free bone flap can be difficult when the apex of the sinus cavity is high up in the frontal bone. Removing a window in the inner table to the margins of the sinus cavity in the free bone flap, that is, the open window illustrated in this case, allows for complete visualization and removal of sinus mucosa. Leaving 5 mm of intact inner table bone above the inferior craniotomy outline provides for a tight seal of the pericranial flap closing off the nasal cavity side of the frontal sinus, as demonstrated in the illustrations in Fig. 2. Removing the inner table all the way down through the inner margin of the free bone flap would not allow for a bony buttress against the posterior wall of the sinus on the nasal side, increasing the chance for the accumulation of epidural air. To note, the frontal craniotomy flap is placed in compression along the supra-orbital bar in the short term so that the seal is tight enough to prevent cerebrospinal fluid from entering the sinus or air from entering the intracranial compartment.

Primary or secondary cranialization of the frontal sinus for either the prevention or treatment of a delayed mucocele has been reported previously.^{2,15,30,31} The technique reported here does not involve cranialization of the frontal sinus by removing the back wall of the sinus down to the floor to the anterior cranial fossa, as this prevents sealing of the sinus opening by the pericranial flap without the use of additional autologous tissue, such as fat.

Takeuchi et al.¹⁶ have reported single-institution outcomes from Japan regarding the use of a direct suture technique of the violated frontal sinus mucosa to keep the nasofrontal duct patent and seal the mucosa completely. In this technique, after the posterior wall of the sinus has been eradicated, the mucosal membrane is meticulously removed away from the wall, and the margin of its orifice is marked with pyoktanin blue. The sinus cavity is packed with fat combined with fibrin glue, and the mucosa is closed with 7–0 monofilament sutures, with the utilization of fibrin glue-soaked Gelfoam. Across 103 patients undergoing bifrontal craniotomy, these authors reported a complication rate of 1% with this technique.¹⁶ Efforts at preventing delayed complications of a frontal sinus violation thus remain meaningful.

Observations

This case demonstrates the technique of an open-window craniectomy for the removal of frontal sinus mucosa (Fig. 1) for the prevention of delayed mucocele development. Removing the inner table of the bone flap to the margins of the sinus while preserving the lower 5 mm permits complete removal of the sinus mucosa in the bone flap and a tight seal over the pericranium covering the frontal sinus opening on the nasal side, as illustrated in Fig. 2. This strategy can be considered for craniotomies across the frontal sinus in patients with a large superior extension into the frontal bone.

Lessons

Openings into the frontal sinus are common in craniotomies of the anterior cranial fossa, potentially leading to the early or delayed development of mucocele, which carries significant morbidity. This article described a method for the removal of frontal sinus mucosa in cases of a free frontal bone flap where the superior extent of the sinus is high. The key considerations in this technique include removing the inner table window to the margins of the sinus cavity in the free bone flap and leaving 5 mm of intact inner table bone above the inferior craniotomy outline.

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Disclosures

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

Author Contributions

Conception and design: McDermott, Rutledge. Acquisition of data: McDermott, Rutledge, Niehaus. Analysis and interpretation of data: Rutledge, Villaneuva-Meyer. Drafting the article: McDermott, Rutledge, Ozair. Critically revising the article: McDermott, Rutledge, Ozair, Villaneuva-Meyer. Reviewed submitted version of manuscript: Rutledge, Ozair, Villaneuva-Meyer, Niehaus. Approved the final version of the manuscript on behalf of all authors: McDermott. Administrative/technical/material support: McDermott, Villaneuva-Meyer.

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