

# Modified Cranialization and Secondary Cranioplasty for Frontal Sinus Infection after Craniotomy: Technical Note

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## Abstract

Frontal sinus infection after incorrect treatment of an opened frontal sinus may require extended approaches. This article aims to introduce modified cranialization technique and secondary cranioplasty for frontal sinus infection involving the frontal sinus outflow tract after craniotomy. Eight patients with delayed onset frontal sinus infection involving frontal outflow tract after craniotomy were treated from 2008 to 2012. Debridement and cranialization involving the elimination of the frontal outflow tract was performed. Unilateral sinus cranialization combined with reduction of the non-affected contralateral sinus was carried out for the patients with unilateral sinusitis. A pericranial-frontalis muscle flap was used to separate the intracranial and extracranial spaces. Secondary cranioplasty with hydroxyapatite was performed approximately 3 months after the cranialization. The patients' original conditions included brain tumors (n = 3), frontal sinus fractures (n = 2), and subarachnoid hemorrhage (n = 3). The mean interval between the initial treatment and the onset of sinus infection was 23 years. The frontal sinus infection was bilateral in six cases and unilateral in two cases. Frontal sinus outflow tract was involved in sinus infection in every case. None of the patients suffered recurrent rhinogenic infections within the follow-up period (mean = 35 months) after the secondary cranioplasty. Aesthetic results were satisfactory in every case. Modified cranialization involving elimination of the frontal outflow tract is an alternative method for the patients with pathology in the frontal outflow tract after frontal craniotomy. Secondary cranioplasty provides an esthetically pleasing appearance in such cases.

Key words: cranialization, frontal outflow tract, frontal sinus infection, cranioplasty

## Introduction

Frontal sinus complications can develop many years after frontal sinus fractures or neurosurgical craniotomy involving the sinus.<sup>1–4)</sup> Artificial bone, such as methyl methacrylate is often used for cranioplasty in some of those cases. The management strategies for such cases are controversial. Revision of cranialization or obliteration, and endoscopic frontal sinusotomy should be considered as alternative methods for the management of the affected frontal sinus.<sup>4–6)</sup> However, open debridement and secondary reconstruction are generally needed to achieve better cosmetic results for the patients with contaminated alloplast and devitalized bone due to infection. Moreover, it is often difficult to remove granulation tissue or degenerated mucosa completely from the affected frontal outflow tract. The author describes a modified technique of cranialization procedure involving

extirpation of the frontal sinus outflow tract and secondary cranioplasty for patients with delayed onset sinus infections due to frontal craniotomy or frontal sinus fractures. The author believes this procedure is an alternative method for the frontal sinus infection involving frontal outflow tract and produces excellent cosmetic results via the use of alloplastic materials.

## Patients and Methods

Between November 2008 and September 2012, eight patients with delayed onset sinus infection after craniotomy were treated. The patients included five men and three women (mean age: 58 years). The patients' original conditions included brain tumors (n = 3), frontal sinus fractures (n = 2), and subarachnoid hemorrhage (n = 3). All of the patients had undergone prior neurosurgical treatment involving frontal craniotomy. The interval between the initial treatment and the onset of sinus

infection ranged from 12 years to 35 years (mean period: 23 years). Seven patients had forehead skin fistula with purulent discharge and had undergone cranioplasty with artificial bone. The remaining one patient had forehead swelling due to mucopyocele. The frontal sinus infection was bilateral in six cases and unilateral in two cases. Intraoperative findings showed the frontal sinus outflow tract was involved in sinus infection in every case. Suspected initial management of frontal sinus was obliteration in three and cranialization in one. In the remaining four cases, initial managements were unknown. The perioperative intravenous antibiotics were given in every case.

### Surgical technique

In each patient, the coronal skin incision produced in the previous operation was used to obtain a skin flap by dissecting anteriorly along the subperiosteal plane to the level of the supraorbital rims. Artificial bone, foreign bodies, sequestrum, and granulation tissue were debrided with a high-speed drill and a rongeur. The posterior wall of the frontal sinus was taken down to the floor of the anterior cranial fossa, the bony septum within the sinus was removed, and the anterior wall of the sinus was removed down to a level above the nasofrontal suture. In the case with unilateral sinus infection, non-affected contralateral sinus was reduced and the frontal sinus outflow tract with healthy mucosa was left intact. Finally, the affected frontal sinus outflow tract was extirpated. First, the posterior wall of the frontal outflow tract was carefully removed to gain access to the superior portion of the bulla ethmoidalis. Care should be taken to avoid damaging the cribriform plate during this process; however, preoperative sagittal computed tomography (CT) scans can be used to aid navigation. After eliminating the posterior wall of the outflow tract, the anterior wall, which usually consists of thick bone, was also drilled. Finally, the medial and lateral walls of the tract were drilled. Preoperative coronal CT scans can aid navigation during the drilling of the outflow tract walls. After drilling the walls all the way around the tract, circular bony defects of more than 1 cm in diameter were made. When concomitant infected superior ethmoid air cells are visualized after extirpation of the outflow tract, additional debridement of the affected air cells are necessary. Finally, the normal nasal mucosa can be visualized through this bony defect. A pericranial-frontalis muscle flap measuring approximately less than 5 cm in width and 5 cm in length was used to separate the nasal cavity and intracranial cavity. The pericranial-frontalis muscle flap was raised and draped over the anterior cranial fossa to cover the

bony defect, before being secured to the dura mater using 4-0 nylon sutures (ETHILON; Ethicon, Inc., Somerville, Massachusetts, USA) or fibrin glue (Bolheal; Chemo-sero Therapeutic Institute, Kumamoto). In cases involving cerebrospinal fluid (CSF) leakage from the frontal lobe dura, the leaks may occur around the frontal base even with gentle drilling; therefore, the flap must be carefully placed on the nasal side of the frontal lobe dura to prevent postoperative CSF rhinorrhea after watertight closure of the dural tear. The key to this procedure is the removal of the anterior wall of the frontal sinus down to a level near to the frontonasal suture. This maneuver reduces the required length of the flap. Thus, this flap is even feasible in patients with forehead skin ulcers due to infection, which were present in seven of eight patients in our series. Finally, the skin wound and skin defect of the forehead was closed directly with a subcutaneous suction drain (Fig. 1). After confirming that the nasal cavity and paranasal sinuses were clear on postoperative CT scans obtained a few months after the cranialization, secondary cranioplasty was performed. The key to cranioplasty is to completely expose the frontal bony edge after dividing the pedicle of the pericranial-frontalis muscle flap without opening the nasal cavity. Hydroxyapatite paste or blocks were used for cranioplasty depending on the size of the bone defect.

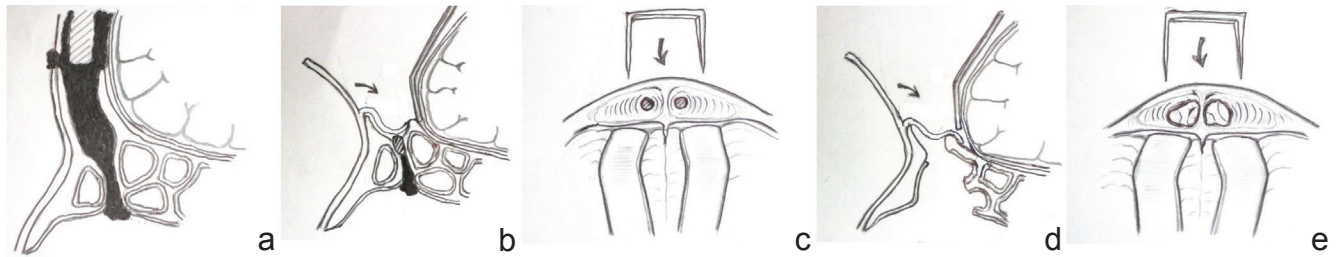
### Results

The intraoperative findings showed that sinus outflow tracts were stuffed with bone wax and methyl methacrylate in three patients who had undergone previous obliteration. In the other four patients whose previous managements were unknown, the sinus outflow tracts were obstructed by granulation tissue. Custom-made hydroxyapatite block was used for the cranioplasty in four cases, and hydroxyapatite paste was used in the other four cases. All patients achieved good forehead contours, and none of them suffered recurrent rhinogenic infections within the follow-up period ranged from 12 to 60 months (mean: 35 months) (Table 1).

### Case Report

#### Case 7: Sinus infection 20 years after cerebral aneurysm clipping

A 66-year-old woman was treated with a left frontotemporal craniotomy for a ruptured cerebral aneurysm. Her postoperative course was uneventful. However, 20 years later she was referred to our hospital with symptoms of purulent discharge from a forehead fistula. The detailed information about the



**Fig. 1** A schematic illustration of the cranialization technique. **a:** Sagittal view of the frontal sinus shows frontal sinus infection which involves the frontal sinus outflow tract after frontal craniotomy. *Blackened part* shows the affected area. **b, c:** Original cranialization in which all vestiges of sinus mucosa are removed with the bur and the mucosa of the frontal sinus outflow tract is dissected into the ostia and inverted upon itself. The tract is then plugged with muscle graft (*shaded part*) and pericranial-frontalis muscle flap is draped on the floor of the sinus as a protective supportive cover. There is a possibility of leaving a focus of infection (*blackened part*) into the tract. **d, e:** Modified cranialization in which all vestiges of sinus mucosa are removed with the bur and the frontal sinus outflow tract is eliminated after drilling the walls all the way around the tract. The pericranial-frontalis muscle flap is draped to cover the bony defect and the tip of the flap is placed beneath the dura.

**Table 1** Patient's summary

Case	Age (yr)	Sex	Original condition	Previous management of frontal sinus (artificial bone)	Years elapsed*	Affected sinuses	Cranioplasty	Follow-up (mo)
1	47	F	BT	Cranialization (methyl methacrylate)	12	Bilateral	HA block	60
2	43	M	FSF	Obliteration (methyl methacrylate)	25	Bilateral	HA block	50
3	48	M	BT	Unknown (methyl methacrylate)	21	Unilateral	HA paste	48
4	71	M	FSF	Obliteration (methyl methacrylate)	35	Bilateral	HA paste	43
5	58	F	BT	Obliteration (methyl methacrylate)	20	Bilateral	HA paste	40
6	77	M	SAH	Unknown (autologous bone)	25	Unilateral	HA block	17
7	66	F	SAH	Unknown (methyl methacrylate and titanium)	20	Unilateral	HA block	14
8	61	M	SAH	Unknown (methyl methacrylate)	26	Bilateral	HA paste	12

\*Time from initial surgery to frontal sinus complications. BT: brain tumor, F: female, FSF: frontal sinus fracture, HA: hydroxyapatite, M: male, SAH: subarachnoid hemorrhage.

management of frontal sinus at previous craniotomy was not obtained. And she also had contralateral frontotemporal craniotomy for the treatment of a cerebral aneurysm several years ago. Computed tomography demonstrated a left frontal sinus infection and an obstructed right frontal outflow tract. Debridement was performed via the previous coronal incision and titanium mesh and methyl methacrylate which were used for previous cranioplasty were completely removed. The left frontal sinus outflow tract was filled with the granulation tissue. It was

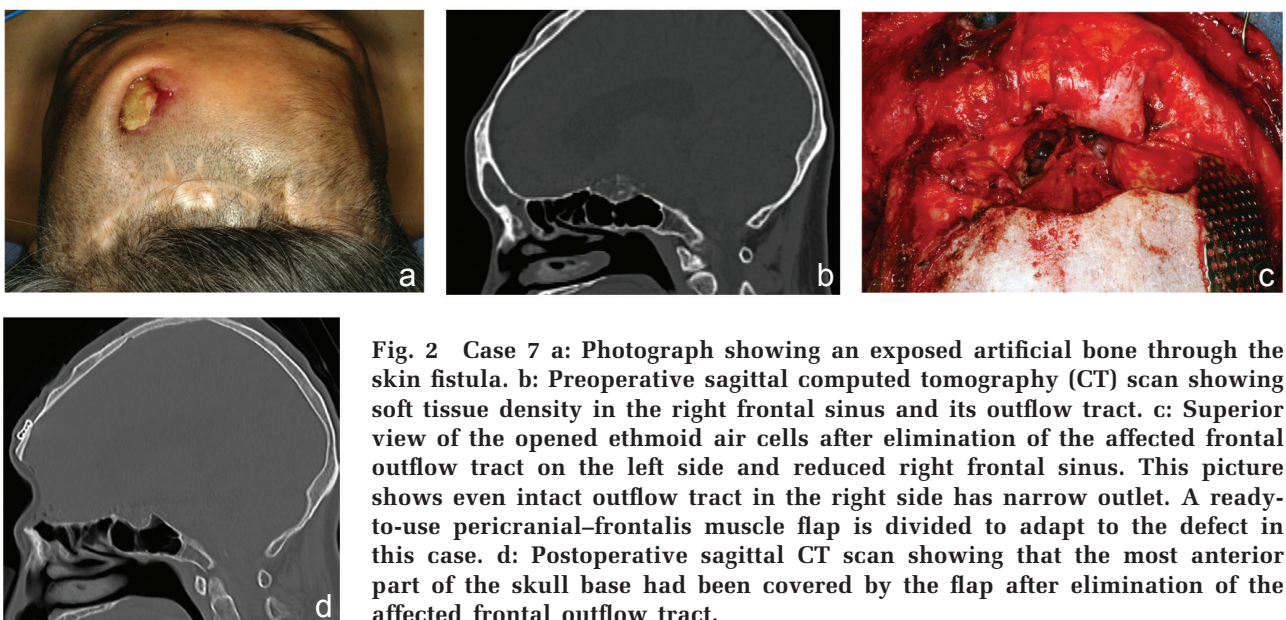
difficult to remove the granulation tissue completely from the duct because of its narrow recess. The right frontal sinus outflow tract displayed normal mucosa. After extirpation of the left frontal sinus outflow tract by using the technique described above, the non-affected right frontal sinus was reduced and its outflow tract was left intact. A pericranial-frontalis muscle flap was elevated and it was draped for separation of the nasal cavity and the intracranial space bilaterally. The forehead skin defect was closed directly. Postoperative CT scan showed that frontal

sinus outflow tract had been eliminated and that the most anterior part of the skull base had been covered with the flap (Fig. 1). Secondary cranioplasty with custom-made hydroxyapatite block was performed at 2 postoperative months. The anterior frontal bone margins encasing the craniectomy defect were exposed completely without entering the nasal cavity during the cranioplasty. A postoperative sagittal CT scans showed that frontal sinus outflow tract had been eliminated and that the most anterior part of the skull base had been covered with the flap. The artificial bone and nasal cavity were completely separated by the pericranial-frontalis muscle flap. The patient has been uneventful postoperatively (Fig. 2).

### Discussion

Frontal sinus complications many years after frontal sinus fractures or neurosurgical craniotomy involving the sinus are rare. Cranialization or obliteration, and endoscopic frontal sinusotomy should be considered as alternative methods for the management of the affected frontal sinus.<sup>4-6)</sup> For patients with contaminated alloplast and devitalized bone due to infection, open debridement and secondary reconstruction is necessary to achieve better cosmetic results. Although meticulous removal of the sinus mucosa is the most important step in revision of cranialization or obliteration, not only remains of sinus but also affected frontal sinus outflow tract should be considered as the potential origin of infection for those patients.

Cranialization of the frontal sinus was first described in 1978 by Donald and Bernstein.<sup>7)</sup> The original procedure involved removing the posterior table of the sinus and all vestiges of the sinus mucosa. Regarding the frontal sinus outflow tract, the mucosa of the tract was dissected up to the sinus ostium and then inverted upon itself into the nasal cavity. The tract was then plugged with muscle grafts. Therefore, the bony frontal sinus outflow tract or frontal recess is generally preserved and plugged with muscle, fascia, and/or bone tissue following the inversion of the duct mucosa into the nasal cavity. On the other hand, Manolidis and Hollier reported a cranialization method in which the frontal sinus outflow tract was destroyed with punch forceps and a zone of injury was created in the superior ethmoid air cells for the patients with comminuted frontal sinus fractures involving the frontal outflow tract.<sup>8)</sup> It seems that this procedure is also applicable for the patient who had sinus infection involving the sinus outflow tract without normal mucosa. This procedure may decrease the risk of delayed complication due to the following pathology in the remnant frontal outflow tract. Therefore, if preoperative CT scans show that the frontal outflow tract is involved in the sinus infection and also infection spreads to the ethmoid sinus, or intraoperative findings show that the frontal outflow tract is obstructed with granulation tissue or foreign body material without normal mucosa, eliminating the affected frontal outflow tract seems more definitive method to prevent recurrence of infection.<sup>9)</sup> In addition, we need to consider the



**Fig. 2** Case 7 a: Photograph showing an exposed artificial bone through the skin fistula. b: Preoperative sagittal computed tomography (CT) scan showing soft tissue density in the right frontal sinus and its outflow tract. c: Superior view of the opened ethmoid air cells after elimination of the affected frontal outflow tract on the left side and reduced right frontal sinus. This picture shows even intact outflow tract in the right side has narrow outlet. A ready-to-use pericranial-frontalis muscle flap is divided to adapt to the defect in this case. d: Postoperative sagittal CT scan showing that the most anterior part of the skull base had been covered by the flap after elimination of the affected frontal outflow tract.

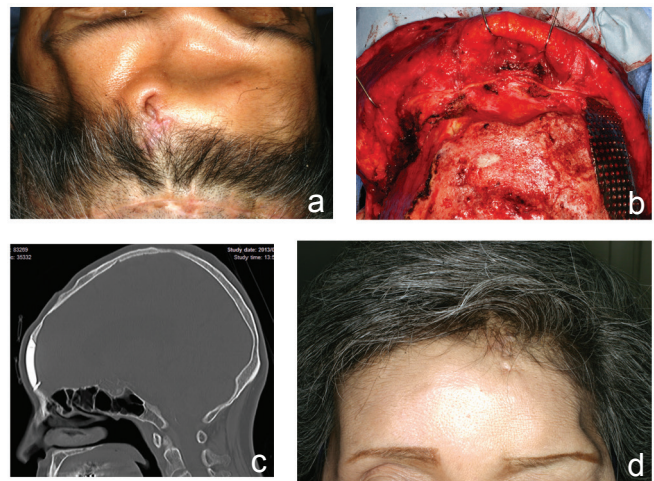
fact that the frontal sinus outflow tract displays significant anatomical variations in its width, length, and shape. Its diameter can range from more than 10 mm to less than 1 mm. Its length also varies and can reach up to 2 cm.<sup>10)</sup> Considering these variations, there is a possibility of leaving a focus of infection if the contaminated frontal outflow tract without normal mucosa is preserved.

Multidirectional CT scans are useful for evaluating the structures adjacent to the frontal outflow tract prior to intraoperative drilling.<sup>11)</sup> Generally, the posterior wall of the tract can be removed, and the anterior ethmoid bulla can be opened.<sup>12)</sup> The anterior wall, which usually consists of an area of thick bone called the nasal beak, can also be drilled. Although the lateral wall of the tract is often defined by the lamina papyracea of the orbit, it is sometimes defined by the medial wall of the ethmoidal infundibular cells and can be opened.<sup>12)</sup> Finally, the medial wall of the tract is defined by the vertical attachment of the middle turbinate and can be drilled. The frontal intersinus septal cells are found in the septum between the two frontal sinuses in roughly one-third of the population and can be opened.<sup>13)</sup> During this procedure, care should be taken to avoid damaging the cribriform plate. CSF leakage from the frontal lobe dura is not always inevitable, even during gentle drilling. If CSF leakage developed intraoperatively, the flap draped over the anterior skull base defects should be placed on the nasal side of the dural tears after the watertight repair of the tears. In our series, there was no CSF rhinorrhea after the debridement. Although endoscopic surgery is an efficient way of removing frontal sinus outflow tract,<sup>12)</sup> the endoscopic management of CSF leakage might be difficult.

The author prefers to use vascularized tissue to form the anterior part of the skull base as it seems that vascularized tissue is more reliable and induces mucosal re-epithelization on the nasal side more quickly than non-vascularized grafts. The author recommends using a pericranial-frontalis muscle flap if possible, even in patients with forehead skin fistulae due to infection. After removing the anterior table of the frontal sinus to a level near to the frontonasal suture, we found that a square flap of less than 5 cm × 5 cm was required to cover the defect. It was possible to raise the pericranial-frontalis muscle flap in all of our cases involving forehead skin fistulae due to frontal sinus infection. Again, the author recommends using a pericranial-frontalis muscle flap rather than a pericranial flap because pericranial flaps might not retain a sufficient blood supply after previous operations and infections. However, free tissue transfer would be

necessary if the patient has a large skin defect on the midline. Bone grafts are not necessary because the circular bone defects after elimination of frontal outflow tract measure less than 2 cm in diameter.<sup>14)</sup> However, the patient should not be allowed to blow their nose after cranialization for a few months until the following cranioplasty to avoid life-threatening pneumocephalus.<sup>15,16)</sup>

Secondary cranioplasty is preferable after confirming that the infection has been eliminated using CT scans. There is no guarantee of complete infection elimination even after cranialization. Thus, careful evaluation of the extradural space is necessary during the secondary cranioplasty. When residual mucosal tissue or osteomyelitis is suspected during cranioplasty, additional debridement should be performed simultaneously. Secondary cranioplasty should be performed as early as possible to ensure the patient's quality of life. Two or three months is an appropriate interval between the cranialization and secondary cranioplasty because the pericranial-frontalis muscle flap will have been sufficiently vascularized by the surrounding tissue, and hence, it will be possible to separate it from its pedicle without fear of vascularity (Fig. 3). Multidirectional CT scans are mandatory for evaluating



**Fig. 3** a: Photograph showing prominent depression of the patient's forehead before cranial reconstruction. b: The edge of the frontal bone defect was completely exposed after the pedicle of the pericranial-frontalis muscle flap had been divided without entering the nasal cavity during the cranial reconstruction. c: Postoperative sagittal computed tomography (CT) scan after cranial reconstruction showing that the most anterior part of the skull base had been covered by the flap after elimination of the affected frontal outflow tract. Artificial bone and nasal cavity are separated by the flap. d: Photograph acquired at one year after cranial reconstruction demonstrating the restoration of the patient's forehead contours.

the postoperative status of the nasal cavity and paranasal sinuses before cranioplasty. Several alloplastic materials have been proposed to be useful for cranioplasty. However, if small gap between the artificial bone and the host bone remains, it might become prominent due to relatively thin skin after using pericranial-frontalis muscle flap. Therefore, we use hydroxyapatite because of its osteoconductivity, which causes the host bone to grow into the implant. The author believes that this advantage can reduce the future irregularity of the forehead. And every patient in our series never experienced any irregularity of the forehead during the follow-up periods. Hydroxyapatite is available in paste and block forms, and the optimal choice depends on the size of the defect. Since intracranial cavity and nasal cavity are separated by the pericranial-frontalis muscle flap during the secondary cranioplasty, there is no risk of upward infection from the nasal cavity. No recurrent rhinogenic infections developed within follow-up periods in our series. However, long-term follow-up is mandatory for cases involving delayed onset sinus complications.

### Conflicts of Interest Disclosure

The author has no personal, financial, or institutional interest in any of the drugs, materials, or devices in the article.

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