A Novel Approach to Frontal Sinus Surgery: Treatment Algorithm Revisited

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Background: Access to the frontal sinus remains a challenging problem for the craniofacial surgeon. A wide array of techniques including minimally invasive endoscopic approaches have been described. Here we present our technique using medical modeling to gain fast and safe access for multiple indications.

Methods: Computer-aided surgery involves several distinct phases: planning, modeling, surgery, and evaluation. Computer-aided, precise cutting guides are designed preoperatively and allowed to perfectly outline and then cut the anterior table of the frontal sinus at its junction to the surrounding frontal bone. The outcomes are evaluated by postoperative three-dimensional computed tomography scan.

Results: Eight patients sustaining frontal sinus fractures were treated with the aid of medical modeling. Three patients (37.5%) had isolated anterior table fractures, and 4 (50%) had combined anterior and posterior table fractures, whereas 1 patient (12.5%) sustained isolated posterior table fractures. Operative times were significantly shorter using the cutting guides, and fracture reduction was more precise. There was no statistically significant difference in complication rates or overall patient satisfaction.

Conclusions: The surgical approach to the frontal sinus can be made more efficient, safe, and precise when using computer-aided medical modeling to create customized cutting guides.

Key Words: Frontal sinus surgery, computer-aided medical modeling, CT

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Frontal sinus fractures remain relatively rare events. This is mainly attributed to the strength of the frontal bone, the strongest facial bone, which requires up to 500 to 1500 lb of force to fracture. Such forces are typically generated only by motor vehicle collisions and assaults.[1] The incidence of frontal sinus fractures ranges from 10% to 15% of all facial fractures, and they often occur in combination with other facial fractures, such as orbital walls and nasal bones.[2] Diagnosis can be made clinically in cases where the frontal table is severely involved; however, computed tomographic (CT) scanning has become the criterion standard for both diagnosis and planning of surgery.[3]

Fracture type, comminution, degree of posterior table fracture, nasofrontal duct injury, neurologic status, and cerebrospinal fluid leak all influence patient management and have led to constant debate among surgeons.[4] As a result, multiple classification systems have been developed to aid in treatment of these rare bony fractures.

Uniquely, the frontal bone has both an anterior and posterior table, which, in addition to the nasofrontal duct, are variably involved in the injury pattern. Most commonly, in 2 of 3 cases, both the anterior and posterior tables are involved. Second most commonly, in about 1 of 3, the anterior table alone is involved, whereas isolated posterior wall fractures are extremely rare.[5] Fracture of the anterior wall poses mostly a cosmetic concern, whereas involvement of the posterior wall alone may lead to liquorrhea. The involvement of the nasofrontal duct is another important factor in determining treatment of frontal sinus factures, because chronic obstruction may lead to mucocele formation.

There are multiple techniques on how to surgically approach the frontal sinus. Various incision patterns including supraorbital and Killian-type incisions have been described, but are fraught with poor cosmetic outcomes and high complication rates, including forehead dysesthesias from injury to the supraorbital and supratrochlear nerves. For these reasons, most surgeons choose either a coronal incision or, rarely, direct access in cases of severe lacerations overlying the fracture. Once the frontal bone is exposed, again several techniques exist to gain access to the frontal sinus.

It has recently been shown that surgical planning and using computer-aided design/computer-aided manufacturing technology for craniofacial reconstruction allow for surgically efficient and highly predictable outcomes in both bony and soft-tissue reconstructions.[6] We hereby describe the use of this novel technique to gain access to the frontal sinus in 8 cases.

METHODS

Computer-aided surgery involves several distinct phases: planning, modeling, surgery, and evaluation. Planning begins with a high-resolution CT scan of the patient's craniofacial skeleton according to standard scanning protocols, which are usually part of any trauma or pre–craniofacial surgery workup. These images are then forwarded to the modeling company (Medical Modeling, Inc, Golden, CO), where the scans are converted into three-dimensional reconstructions of the craniomaxillofacial skeleton. A Web meeting between biomedical engineers from the modeling company and the surgical team is then held. During this interactive meeting, the surgeons can precisely outline where the borders of the frontal sinus are located. In cases of fractures, real-time cephalometric, volumetric, and linear analysis can be extrapolated as bony segments are being virtually manipulated. The goal is to create a cutting guide for the surgeon that allows for safe and rapid access to the entire frontal sinus while maximizing the size of the available bone segments and minimizing

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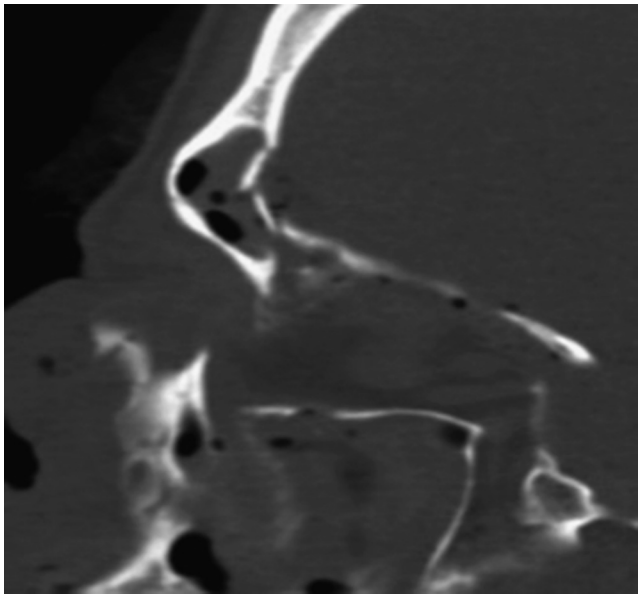

FIGURE 1. Preoperative CT scan.

further fracture dislocation. Further and most importantly, in cases of minimal or no fracture of the anterior table of the frontal sinus, the guide allows widest access to the sinus with minimal risk to injure the brain.

The modeling phase involves stereolithographic manufacturing of the planned components. This includes the generation of a model of the native craniofacial skeleton for intraoperative reference and to augment the education of residents, surgeons, and the patient. Together with the model, cutting guides that precisely match those created during the planning phase are produced. These cutting guides facilitate the osteotomy process and provide seamless transition between the frontal bone and entrance through the bone of the anterior table. The precision and speed to perform these osteotomies, which have to follow the often complex, anatomical pattern of the frontal sinus, are greatly improved and performed safely by utilizing this technique.

During the surgical phase, the cutting guide is then placed and secured to the craniofacial skeleton with monocortical depth screws into the frontal bone. These are designed not to interfere with the placement of osteosynthesis plates. This use of guidance technology,

FIGURE 2. Three-dimensional reconstruction. Note minimal anterior table involvement.

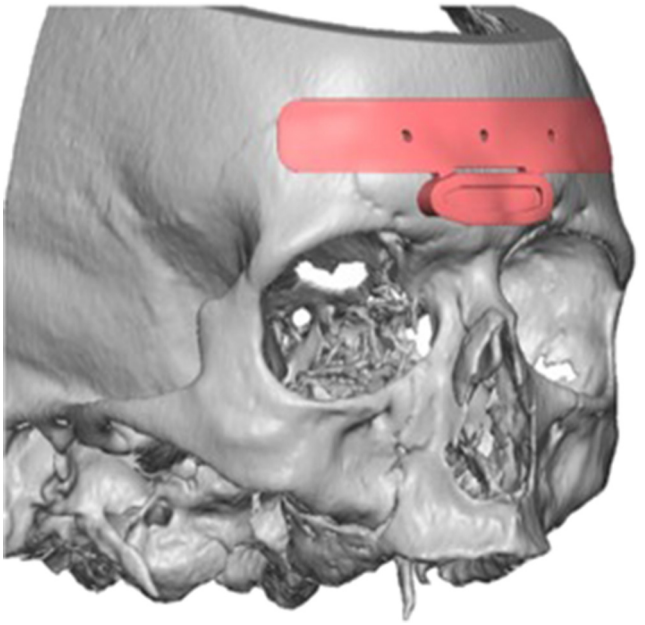

FIGURE 3. Virtual planning with bandeau template in place.

which integrates between the preoperative scan and the desired reconstruction, helps to guarantee bony repositioning by preplanning plate and osteotomy positioning.

In the evaluation phase, a postoperative CT is obtained. This is superimposed against the virtual treatment plan, and analysis is completed by the biomedical engineer. Deviation of the actual results compared with the virtual plan is measured in all planes and color coded for ease of viewing. This clearly identifies areas of success and error and allows correction in future operations.

RESULTS

Eight patients sustaining frontal sinus fractures were treated with the aid of medical modeling: Three patients (37.5%) had isolated

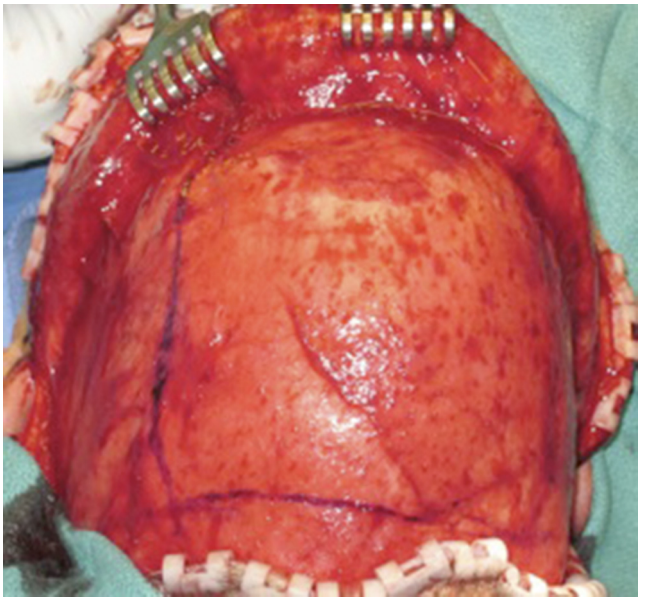

FIGURE 4. Intraoperative fracture exposure down to supraorbital rims via bicoronal incision including pericranial flap elevation.

anterior table fractures, and 4 (50%) had combined anterior and posterior table fractures, whereas 1 patient (12.5%) sustained isolated posterior table fractures.

A computer-aided, precise cutting guide was designed preoperatively as described above. This allowed us to perfectly outline and then cut the anterior table of the frontal sinus at its junction to the surrounding frontal bone, thereby protecting the brain while maximizing the size of the bone pieces as well as enhancing stable fixation. Follow-up in this series was 7.5 months, with a range from 4 to 15 months. There were no complications encountered.

Case example: A 53-year-old man presented after blunt trauma with a minimally displaced anterior table, as well as comminuted posterior table fractures (Fig. 1). No cerebrospinal fluid rhinorrhea was noted on clinical examination. The plan was to use medical modeling to manufacture a cutting guide as described above to facilitate access, exposure, and optimal fracture reduction. The three-dimensional reconstruction (Fig. 2) demonstrated how minimal the anterior table involvement was, making precise delineation of the borders of the frontal sinus, and hence access to it, significantly harder than in cases of severe comminution. Virtual planning shows the cutting guide, perfectly outlining the underlying frontal sinus, with the bandeau in place (Fig. 3). A coronal incision was made and a flap dissected in the subgaleal plane until the superior orbital rims were identified. The supraorbital and supratrochlear neurovascular bundles were identified and protected (Fig. 4). The cutting guide was then secured to the cranium (Fig. 5), a pericranial flap raised (Fig. 6), and access to the frontal sinus gained by cutting around the guide (Fig. 7). Using a periosteal elevators and a rongeur, the frontal sinus mucosa was carefully stripped off. The right-sided posterior table was noted to be anteriorly displaced and was carefully removed without tearing the underlying dura, which was noted to be intact with no exposed brain parenchyma. Next, the nasofrontal ducts were identified and obliterated with the pericranial flap. The anterior table was placed back into its position and secured with plates (Fig. 8). A postoperative CT scan shows obliteration of the sinus and integrity and good position of the anterior table (Figs. 9 and 10). Neurosurgery was on call but not required for this procedure, as cranialization for this fracture pattern was avoided.

DISCUSSION

Frontal sinus surgery remains challenging in both diagnosis and indication for treatment. Given the wide range of fracture patterns and possible complications, the 2 main questions remain: (1) which untreated fractures will lead to early or late onset complications and (2) by which approaches should fractures be addressed if surgical intervention is opted for?

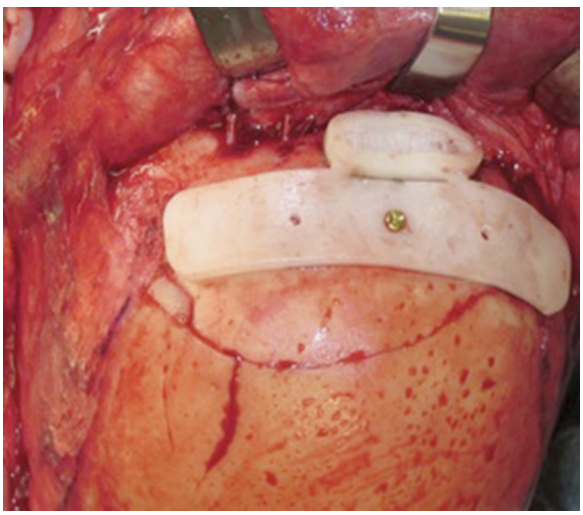

FIGURE 5. Cutting guide in place and secured to cranium. Preservation of supraorbital and supratrochlear vessels and nerves.

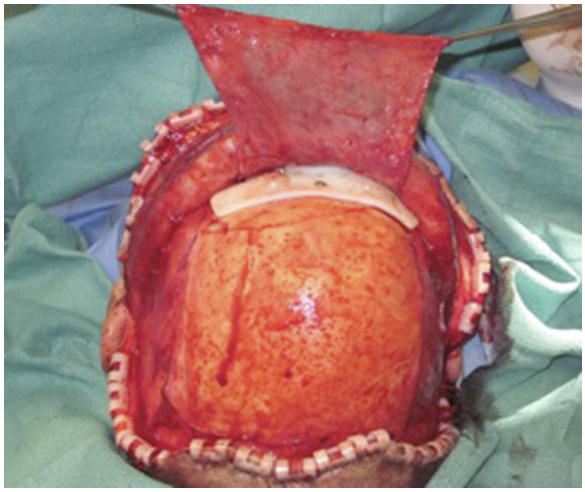

FIGURE 6. Pericranial flap elevation.

One of the largest studies by Rodriguez et al[7] concluded that patients without radiographic evidence of nasofrontal outflow tract involvement may be observed, whereas those with nasofrontal outflow tract injury with obstruction must be treated by either obliteration or cranialization. Furthermore, they stated that there is no role for obliteration with fat or osteoneogenesis.[7]

Whenever the posterior wall is fractured in isolation, the anterior table should be cut as close as possible to the surrounding frontal bone to gain the widest access possible. In 1955, Bergara and Itoiz[8] described how to use plain radiographs to outline the dimensions of the frontal sinus before creating burr holes and out-fracturing the anterior table downward like a trapdoor while maintaining its inferior periosteal attachments. The other, more reliable option has been to perform a frontal craniotomy and gain access to the fractured posterior table through a full intracranial approach. Endoscopic-assisted reduction of frontal bone fracture has been advocated but is mostly of value for minimally displaced low anterior table fractures.[9,10]

We found that by using the outlined medical modeling–aided method, the time needed for exposure of the frontal sinus was significantly shortened, whereas precision and safety are greatly improved.

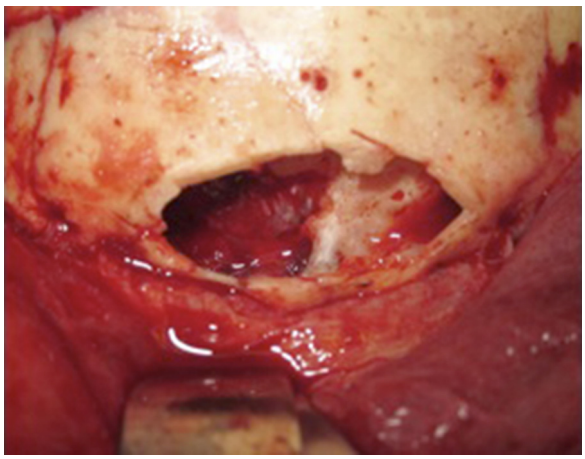

FIGURE 7. Sinus after removal of the anterior table by cutting around the guide.

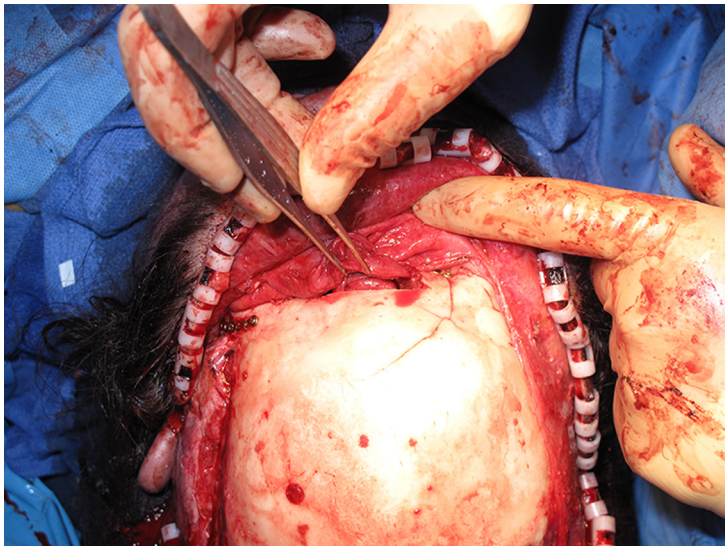

FIGURE 8. Sinus obliteration with pericranial flap.

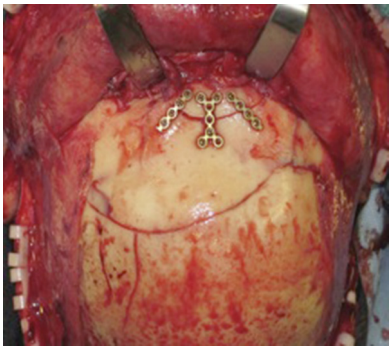

FIGURE 9. Fracture fixation.

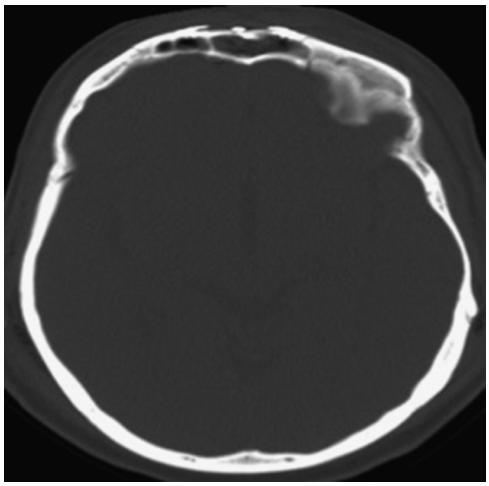

FIGURE 10. Postoperative CT scan showing optimal fracture reduction and obliterated frontal sinus.

In select cases, this meticulously guided approach can help to avoid a craniotomy and improve outcome. Computer-aided surgical approaches initially seemed too expensive for many indications; however, given shortened operative times and hospital length of stay, it can be more cost-efficient in the long run.

Virtual surgical planning and model design provide the ability to visualize complex operations. This can enhance outcomes by providing safe and precise access to difficult areas such as the frontal sinus. Virtual planning, for certain patients, may offer a paradigm shift in the treatment pattern of frontal sinus fractures and may be most helpful in cases of (1) minimally displaced anterior wall fractures, where access to the frontal sinus is required to either examine or treat the nasofrontal duct; (2) precise extracranially guided access to the frontal sinus for various indications (ie, mucoceles, obliteration, etc); (3) isolated posterior wall fractures (to possibly prevent the need for exposure via craniotomy); and (4) access to the cranial base.

In summary, virtual surgical planning and model design provide the ability to visualize the oftentimes complex operation and enhance outcomes by providing safe and precise access to difficult areas such as the frontal sinus. This may, for certain patients, offer a paradigm shift in the treatment pattern by performing extracranially guided obliteration of the frontal sinus.

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