Titanium Mesh Repair of the Severely Comminuted Frontal Sinus Fracture

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Background: Severely comminuted frontal sinus fractures are difficult to contour and immobilize. Frequently, plates or wires are inadequate in fixing all fragments together, resulting in less than optimal outcomes. Advancements in the development of biomaterials have now made titanium mesh a new option for the repair of severely comminuted fractures.

Methods: Fourteen patients with severely comminuted frontal sinus fractures were treated with titanium mesh from 1994 to 1999. The fractures were reduced and immobilized using a simple algorithm: (1) Isolated anterior table fractures were repaired with reduced bony fragments attached to titanium mesh. (2) Anterior table fractures with nasofrontal duct involvement were repaired by sinus obliteration and anterior wall reconstruction with reduced bony fragments attached to titanium mesh. (3) Anterior and posterior table fractures with cerebrospinal fluid leak or displacement were treated with the cranialization of the sinus and anterior wall reconstruction with reduced bony fragments attached to titanium mesh.

Results: Of the 14 patients treated, 12 were available for postoperative evaluation. Parameters such as nasal function, cranial nerve V and VII function, cosmesis, and complications (hardware extrusions, sinusitis, meningitis, osteomyelitis, mucopyocele, brain abscess, pneumocephalus, and cerebrospinal fluid leak) were evaluated. All patients had good function of the superior division of cranial nerves V and VII. Two patients (16%) had minor wound infections, which resolved under treatment with antibiotics. All had excellent cosmetic results as measured by postreduction radiographs and personal and family perceptions of forehead contour.

Conclusion: Titanium mesh reconstruction of severely comminuted frontal sinus fractures has few complications while providing excellent forehead contour and cosmesis.


Frontal sinus fractures are relatively uncommon maxillofacial injury, making up only 5% to 12% of all facial fractures.1 Frontal sinus fractures are the result of a high-velocity injury; the anterior sinus wall can withstand between 800 to 2200 pounds of force before fracturing.2 Individuals sustaining frontal sinus fractures often have associated intracranial or multysystem injuries3 that take priority and often delay fracture repair. Delay or improper management of the fracture can result in significant morbidity, such as forehead deformity, meningitis, cerebrospinal fluid (CSF) leak, mucopyocele, pneumocephalus, or brain abscess.

Management of frontal sinus fractures has advanced considerably with the development of biomedical materials and new techniques in craniofacial sinus surgery. Historically, early repair was delayed and secondary deformities and late complications were frequent, often resulting in a depression of the forehead.7 Reidel-Schenke7 first described ablation of the anterior sinus wall in 1898. Later, Killian improved cosmesis by performing a similar operation while leaving a portion of the supraorbital rim.4 In 1921, Lynch6 devised the external frontoethmoidectomy and inserted a catheter into the sinus for prolonged drainage while preserving the frontal bone. The osteoplastic flap procedure, as reported by Bergara and Itoiz7 in 1955, hinged the anterior frontal sinus wall on an inferior pedicle of pericranium. This procedure allowed easy visualization of the damaged sinus, replacement of the bone on completion of the surgery, and improved forehead cosmesis. Goodale and Montgomery8 carried this procedure one step further as they recognized the importance of nasofrontal duct injury and often removed the sinus contents and...
PATIENTS, MATERIALS, AND METHODS

From March 1994 to October 1999, 14 cases of severely comminuted frontal sinus and superior orbital rim fractures were treated using titanium mesh in the Department of Otolaryngology, Wayne State University School of Medicine, Detroit, Mich. Patients ranged in age from 20 to 58 years with a mean age of 40.5 years. Of the initial 14 patients treated, 12 were available for follow-up. Eleven men and 1 woman were observed for a period of 5 to 48 months, with an average observation time of 22.3 months. The causes of injury included 4 motor vehicle crashes, 5 assaults, 1 fall, and 1 gunshot wound, and 1 pedestrian was struck by a motor vehicle. Four patients had an isolated anterior frontal wall fracture, 3 had anterior wall fractures with nasofrontal duct injury, and 5 had anterior and posterior wall fractures (Table 1).

An algorithm for the management of comminuted frontal sinus fractures has been developed and used in all cases, which is very similar to an algorithm developed by Rohrich and Holler.1 The algorithm is summarized as follows: (1) Comminuted anterior wall fractures with patent nasofrontal ducts and minimally disrupted frontal sinus mucosa are repaired using titanium mesh with attached bony fragments. (2) Comminuted anterior wall fractures with an injured nasofrontal duct are repaired by obliterating the frontal sinus and using titanium mesh with attached bony fragments to reconstruct the anterior wall. (3) Comminuted anterior and posterior wall fractures with displacement of the posterior wall are treated by cranializing the frontal sinus, repairing any dural injury (with assistance from the neurosurgical team), and reconstructing the anterior wall with titanium mesh and attached bony fragments.

Following surgery, patient cosmesis, nasal function, and cranial nerve V and VII function were evaluated. Postoperative complications were recorded. The adequacy of frontal bone reduction and fixation was measured using postreducing radiographs. Cosmesis was evaluated by patient and family grading based on a 4-point scale (0, no deformity compared with the pre-injury state; 1, mild deformity; 2, moderate deformity; and 3, severe deformity). Nasal function was evaluated by anterior nasal endoscopy and rhinoscopy. Results were measured on a 4-point scale (0, no intranasal obstruction and/or deformity; 1, mild intranasal obstruction/deformity; 2, moderate intranasal obstruction/deformity; and 3, severe nasal obstruction/deformity). The function of the supraorbital division of the trigeminal nerve was measured postoperatively using a 3-point scale (0, no change compared with the preoperative sensation; 1, decreased or altered sensation compared with the preoperative sensation; and 2, loss of sensation). Function of the facial nerve was measured postoperatively using a 3-point scale (0, no change compared with the preoperative function; 1, weakened function compared with the preoperative function; and 2, loss of function).

Complications were checked intermittently during the postoperative course. Specific sequelae of meningitis, CSF leak, sinusitis, brain abscess, mesh extrusion, mucopyocele, headache, and periorbital infection were identified and recorded. Subsequent treatments were evaluated, and length of follow-up was determined.

<table>
<thead>
<tr>
<th>Patient No./Sex/Age, y</th>
<th>Mechanism of Injury</th>
<th>Fracture</th>
<th>Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/M/58</td>
<td>Assault</td>
<td>AW</td>
<td>TMAW</td>
</tr>
<tr>
<td>2/M/46</td>
<td>MVC</td>
<td>AW + NFD</td>
<td>TMAW + OBS</td>
</tr>
<tr>
<td>3/M/43</td>
<td>MVC</td>
<td>AW + PW</td>
<td>TMAW + Cr</td>
</tr>
<tr>
<td>4/M/27</td>
<td>MVC</td>
<td>AW + PW</td>
<td>TMAW + Cr</td>
</tr>
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<td>5/F/34</td>
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<td>AW</td>
<td>TMAW</td>
</tr>
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<td>AW + PW</td>
<td>TMAW + Cr</td>
</tr>
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<td>GSW</td>
<td>AW + NFD</td>
<td>TMAW + OBS</td>
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<tr>
<td>12/M/41</td>
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<td>AW</td>
<td>TMAW</td>
</tr>
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</table>

*AW indicates anterior wall fracture; TMAW, titanium mesh repair of anterior wall; MVC, motor vehicle crash; OBS, obliteration of sinus; PW, posterior wall fracture; Cr, cranialization of posterior wall and dural repair; PMV, pedestrian struck by motor vehicle; NFD, nasofrontal duct injury; and GSW, gunshot wound.

Aesthetic results were based on postreconstruction radiographs and patient and family grades. Postoperative computed tomographic (CT) scans were obtained in 11 of 12 patients, and 1 patient had a plain film facial series. All postoperative radiographs revealed excellent reduction. Postoperative forehead contour was given a patient and family grade of 0 for all 12 patients (Table 2).

RESULTS

COSMESIS

Aesthetic results were based on postreconstruction radiographs and patient and family grades. Postoperative computed tomographic (CT) scans were obtained in 11 of 12 patients, and 1 patient had a plain film facial series. All postoperative radiographs revealed excellent reduction. Postoperative forehead contour was given a patient and family grade of 0 for all 12 patients (Table 2).
FUNCTION

Nasal function was evaluated postoperatively and graded on a 4-point scale based on anterior endoscopic examination. Eleven (92%) of 12 patients had no intranasal obstruction/deformity and 1 (8%) of 12 had mild intranasal obstruction/deformity. Trigeminal nerve (cranial nerve V) function was preserved in all 12 patients. Facial nerve (cranial nerve VII) function was also preserved in all 12 patients (Table 2).

COMPLICATIONS

Postoperative complications were measured and 2 (17%) of 12 patients with wound infections (Table 2). These infections occurred at 6 and 8 weeks postrepair. Each resolved with a course of antibiotics. Headaches occurred in 1 (8%) of 12 patients postoperatively (Table 2). Follow-up CT scans in this individual have not revealed any evidence of infection, and the site of pain is in the temporal region, distant from the site of frontal sinus reconstruction. Presently, this patient is being treated by a neu-}

Table 2. Outcomes, Complications, and Follow-up*

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Cosmesis†</th>
<th>Nasal Function‡</th>
<th>CNV§</th>
<th>CNVII¶</th>
<th>Complications</th>
<th>Follow-up, mo</th>
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<tr>
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<td>0</td>
<td>Wound cellulitis</td>
<td>23</td>
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<tr>
<td>12</td>
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<td>0</td>
<td>0</td>
<td>None</td>
<td>5</td>
</tr>
</tbody>
</table>

* CNV indicates cranial nerve V function; CNVII, cranial nerve VII function.
†0 indicates no deformity compared with the pre-injury state; 1, severe deformity; 2, moderate deformity; and 3, severe deformity.
‡0 indicates no intranasal obstruction and/or deformity; 1, mild intranasal obstruction/deformity; 2, moderate intranasal obstruction/deformity; and 3, severe nasal obstruction/deformity.
§0 indicates no change compared with preoperative sensation; 1, decreased or altered sensation compared with preoperative sensation; and 2, loss of sensation.
¶0 indicates no change in function compared with preoperative function; 1, weakened function compared with preoperative function; and 2, loss of function.

REPORT OF CASES

Case 1: Repair of the Anterior Frontal Sinus Wall With Titanium Mesh

A 58-year-old man was assaulted with a bottle and incurred a severely comminuted anterior frontal sinus wall fracture (Figure 1), nasal fractures, and left zygomaticomaxillary complex fracture. He underwent open reduction and internal fixation of his frontal sinus fractures using titanium mesh with attached bony fragments for the frontal bone reconstruction. He has been observed postoperatively for 26 months and has had no intracranial complications. Postoperative CT scans revealed excellent reconstruction (Figure 2), and his forehead contour is unchanged compared with the pre-injury state.
Case 2: Repair of the Anterior Frontal Sinus Wall With Titanium Mesh and Management of the Nasofrontal Duct Injury With Obliteration

A 46-year-old man injured during a motor vehicle crash sustained a severely comminuted anterior frontal sinus wall fracture with bony fragments collapsing the nasofrontal duct (Figure 3). In addition, he sustained right orbital floor and nasal bone fractures. He underwent repair of his facial fractures. The frontal sinus was cleared of mucosa, obliterated with fat, and titanium mesh applied to the anterior wall to stabilize the bony fragments. He has been observed postoperatively for 20 months and has had no complications. Postoperative CT scans revealed good reduction (Figure 4) and the forehead contour is unchanged compared with the pre-injury state.

Case 3: Repair of the Anterior Frontal Sinus Wall With Titanium Mesh and Cranialization of the Posterior Wall

A 43-year-old man was an unrestrained driver in a motor vehicle crash and sustained severely comminuted anterior and posterior frontal sinus wall fractures and dural laceration (Figure 5). The anterior wall was reconstructed using titanium mesh. The posterior wall was cranialized and the dural tear repaired by the neurosurgery service using a pericranial patch (Figure 6). He has been observed for 20 months and has had 1 episode of wound cellulitis, which was treated with a course of antibiotics. Postoperative CT scans revealed good reduction, and forehead contour is unchanged compared with the pre-injury state.

COMMENT

Titanium mesh was originally developed during the Vietnam War to repair craniofacial defects. Since its initial use, refinements have reduced the thickness, increased the strength, and improved the malleability of the material. Studies have documented its use in mandibular, maxillary, zygomatic, orbital, and calvarial reconstruction. Repair of frontal bone defects using titanium mesh has been reported by several authors, but long-term outcomes are lacking.

There are several advantages with using titanium mesh to reconstruct craniofacial and calvarial defects. Titanium has excellent biocompatibility and generates
minimal inflammatory reaction.\(^2\)\(^2\) Furthermore, titanium is safe and produces minimal imaging artifact on magnetic resonance imaging and CT scanning.\(^2\)\(^1\) Ti- tanium mesh is easy to shape and contour while providing reasonable stability. Small bony fragments may be individually attached to the mesh by simply drilling a hole and lag screwing the bone to the mesh, reducing the need for a bone graft.\(^2\)\(^5\)

Our approach to frontal sinus repair has closely followed the technique previously described by Rohrich and Hollier.\(^8\) In their study, isolated anterior table fractures were left untreated if there was no displacement. If displacement was present, the patient was evaluated for involvement of the nasofrontal duct. If the nasofrontal duct was not involved, the fracture was reduced and stabilized. If the fracture involved the nasofrontal duct, sinus obliteration was performed in addition to reduction and stabilization. If the anterior and posterior walls were fractured but minimally displaced with a CSF leak that did not stop with conservative medical management, the posterior wall was cranialized and the leak repaired. If the posterior wall was displaced greater than 1 table width with a CSF leak, the wall was cranialized.

For comminuted fractures of the anterior wall, all of our repairs were performed with titanium mesh. All posterior wall fractures were cranialized because of CSF leak and/or displacement of the wall. If there was no CSF leak and/or displacement, then repair of the anterior wall was sufficient.

**CONCLUSIONS**

We concluded the following: (1) Severely comminuted frontal sinus fractures may be easily reconstructed using titanium mesh, which provides excellent forehead contour. (2) Titanium mesh is easy to handle and provides good strength, stability, and surface for bone fragment stabilization. (3) There have been no intracranial complications over the past 5 years using titanium mesh to reconstruct comminuted frontal sinus fractures.

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