Endoscopic Repair of Isolated Anterior Table Frontal Sinus Fractures

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Background: Recently developed endoscopic brow-lifting techniques and instrumentation are being used for treatment of anterior table frontal sinus fractures. Potential endoscopic treatment options include fracture reduction with or without plating and fracture repair with hydroxyapatite bone cement (HA).

Objective: To evaluate the efficacy of miniplates and HA for repair of anterior table fractures.

Methods: Frontal sinus fractures were generated in 11 cadavers. Standard endoscopic brow-lifting techniques were used to visualize the fracture from above. A 1-cm Lynch incision was used to apply instrumentation from below. Fractures were repaired with either miniplate reduction or HA recontouring.

Results: All fractures were exposed without difficulty. Miniplates were applied in 5 specimens: 1 specimen had a complete reduction, 2 specimens had partial reductions, and 2 specimens had incomplete reductions. Bone cement was applied in 9 specimens: 4 specimens were rated as excellent and 5 specimens as good.

Conclusions: Frontal sinus fractures can be successfully exposed and repaired with an endoscopic technique. Endoscopic miniplate reduction of frontal sinus fractures can be accomplished. However, it is challenging, and success rates vary depending on fracture comminution. Endoscopic HA recontouring offered the best results, with good or excellent outcomes in all specimens.

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THE ANTERIOR table of the frontal sinus is composed of thick cortical bone, and is more resistant to fracture than any other facial bone. Consequently, frontal sinus fractures account for only 5% to 15% of maxillofacial injuries. They are commonly associated with motor vehicle crashes, sporting events, and assaults. The most common fracture pattern involves a combination of the anterior table, posterior table, and/or the frontal recess (67%). The treatment algorithm for these injuries is complex due to risks of brain injury, meningitis, cerebrospinal fluid fistula, and mucocele formation. Isolated anterior table injuries account for 33% of frontal sinus fractures. These injuries are believed to carry a low risk of long-term morbidity and primarily result in aesthetic deformities.

Historically, open reduction of isolated anterior table fractures has required a coronal incision for exposure, reduction, and rigid fixation. While the success rates are very high, the procedure results in postsurgical stigmata including a large scar, possible alopecia, paraesthesias, and, uncommonly, facial nerve injury. The recent development of instrumentation and techniques for endoscopic brow-lifting has allowed access to anterior table frontal sinus fractures, without the need for a coronal incision. Potential endoscopic treatment options for anterior table fractures include closed reduction without internal fixation, closed reduction with internal fixation (CRIF), and fracture camouflage with bone cement. This study was designed to evaluate endoscopic repair of anterior table frontal sinus fractures in a cadaver model using CRIF and fracture camouflage.

METHODS

Creation of Frontal Sinus Fractures

Eleven cadaveric heads (10 fresh, 1 formalin-fixed) were used. Each specimen had previously undergone functional endoscopic sinus surgery and frontal sinus trephine on the right side. To avoid the right frontal sinus trephination, or a stellate laceration at the proposed fracture site, a 3-cm, full-thickness, vertical skin incision was placed 2 cm above the left me-
dial brow. A limited area of periostium was elevated, and the rounded end of a ball-peen hammer was placed over the left frontal sinus. A second hammer was used to strike the ball-peen hammer and produce a depressed fracture approximately 1.5 to 2.5 cm in diameter and 3 to 5 mm deep (Figure 1A). The defects were easily palpable and resulted in a significant cosmetic deformity (Figure 1B). Care was taken to avoid creating large or “through and through” injuries; however, one fracture was so extensive that it was not amenable to endoscopic repair (specimen 10). The frontal incision was then closed with running 3-0 silk suture.

SURGICAL EXPOSURE

Each head was rigidly fixated in a Mayfield headholder. Three 1-cm vertical incisions were placed 1 to 1.5 cm behind the hairline in the central and parasagittal planes using standard endoscopic brow-lift techniques (Figure 2). The frontal sinus fracture was localized with palpation. An endoscopic periosteal elevator was placed through the central scalp incision and the frontal bone was exposed in a subperiosteal plane. The “blind” dissection was carried down to the orbital rims laterally and 1 to 2 cm above the fracture centrally. The assistant surgeon then introduced a 4.0-mm, 30° endoscope (with rigid endosheath) (Figure 3A) through the right lateral scalp incision. The primary surgeon then completed the dissection over the depressed bone fragments through the central and left lateral incisions. The primary surgeon generally operated with one instrument through the scalp incision and one hand on the forehead skin to palpate the fracture and instrument. At times, bimanual instrumentation was used. The assistant surgeon was intermittently required to move the endoscope between inci-

Figure 1. Endoscopic (A) and external (B) view of the depressed frontal sinus fracture.

Figure 2. Illustration of midline and parasagittal hairline incisions, as well as limited Lynch incision used for exposure of the frontal bone.

Figure 3. A, Rigid 4-mm, 30° endoscope, and endosheath with guarded tip. B, Transcutaneous trochar used for application of screws. C, Synthes CRS bone cement gun (Synthes, Paoli, Pa) used for endoscopic application of bone cement.
sions to allow the primary surgeon a better angle over the intrinsic forehead curvature. Care was taken to avoid fragmentation of any depressed or comminuted bone segments. Finally, a 1-cm limited Lynch incision was placed inferomedial to the left medial brow (Figure 2). Dissection was carried superiorly to join the upper dissection cavity. Care was taken to avoid injury to the supra trochlear neurovascular pedicle.

The cadaver heads were separated into 2 treatment groups. Group A (cadavers 1-5) underwent endoscopic CRIF using 1.3-mm miniplates. After completion of the CRIF, any specimens with residual deformity from group A were endoscopically recontoured with hydroxyapatite bone cement (HA) (ie, added to group B). Group B (cadavers 6-11) underwent only fracture camouflage with HA.

MINIPLATE APPLICATION AND FRACTURE REDUCTION (GROUP A)

After visualization of the fracture, a 1.3-mm titanium microplate (Synthes, Paoli, Pa) was introduced through the Lynch incision. The appropriate length was visualized, and the plate was removed and trimmed. The plate was then reintroduced and stabilized with a hemostat. All plates spanned the fracture, with one hole on stable bone at either end. A transcutaneous trochar was then placed through the forehead skin over the fracture site. The best site for trochar placement was determined by endoscopic visualization of a 27-gauge needle passed through the forehead skin just above the plate. A 3-mm stab incision was placed in a central location over the plate that would allow placement of all the screws without the need for a second stab. A transcutaneous trochar was inserted and the central stylet was removed (Figure 3B). The drill was passed through the trochar, and a distal hole was drilled on stable bone while irrigating from above. A 6-mm screw was placed through the trochar to stabilize the plate over the center of the defect. A second 6-mm screw was placed in the distal hole on the opposite end of the plate. The plate was then rigidly fixated, spanning the bony depression, with a 2- to 5-mm gap between the plate and the depressed bone fragment(s) (Figure 4). Four-to 6-mm screws were applied in the central portion of the plate and the bone fragment(s) were “lagged” up to the plate. The reduction was graded as complete (good bone reduction with minimal bony irregularity); partial (limited bone reduction, with moderate residual deformity); or incomplete (minimal bone movement or comminution of bone fragments).

BONE CEMENT (GROUP B)

Synthes CRS hydroxyapatite bone cement was prepared and loaded into the application gun (Figure 3C). The application trochar was inserted through the Lynch incision with endoscopic visualization from above. The tip was advanced to the cephalic portion of the defect. While moving in a horizontal sweeping motion, the gun was retracted and the cement was applied (Figure 5). The defect was slightly overfilled by approximately 20% (Figure 6). A Ballenger elevator was used to “trowel” the bone cement smooth over the defect (Figure 7). Excess bone cement was removed with a Frasier suction.

The bone cement was allowed to partially harden for 10 to 15 minutes. Because the specimens were kept at (or below) room temperature, the chemical hardening process was retarded. To expedite the hardening process, a standard coronal exposure was performed. Care was taken to avoid disruption or deformity of the cement while the flap was raised. Each specimen was then placed under a heat lamp for approximately 20 minutes until the HA was hard. Each specimen was then examined, photographed, and graded for contour and symmetry. The specimens were classified as excellent (having excellent symmetry with the contralateral side); good (having excellent symmetry with mild surface irregularities that were not visible through the skin); or poor (asymmetry that was visible through the skin).

RESULTS

FRACTURE EXPOSURE

Standard endoscopic brow-lifting techniques were used to expose all isolated anterior table fractures. Fractures in specimens 1 to 9 and 11 were stable and no further disruption or comminution occurred with the exposure. Speci-
men 10 had an unacceptably large fracture for endoscopic techniques and was excluded from the analysis.

MINIPLATE APPLICATION

Miniplates were applied to 5 specimens. One specimen had a complete reduction with minimal irregularity (some bone loss was noted at the superior margin) (Figure 8). Two specimens had partial reductions with mild to moderate residual deformity (Figure 9). Two specimens had incomplete reductions with comminution of the depressed bone fragment (Figure 10).

BONE CEMENT REPAIR

Bone cement repair was attempted in 9 specimens: all 5 specimens in group B and 4 of the 5 specimens in group A that had residual deformity after CRIF. The repairs were rated as excellent in 4 specimens (45%). They had excellent symmetry and contour compared with the contralateral, uninjured side (Figure 7). Five specimens were rated as good (55%). They had excellent symmetry, but mild surface irregularities, which were not visible through the skin (Figure 11). No specimens were rated as poor.
Endoscopic sinus surgery was described in the late 1970s and became the standard of care in the 1980s. Since then, the indications for endoscopic head and neck surgery have been expanding. Current applications include otology (middle ear endoscopy), skull base surgery (pituitary, cerebrospinal fluid leak, optic nerve decompression), ophthalmology (dacrocystorhinostomy), facial plastic surgery (brow-lift), neck surgery (thyroid, parathyroid, node biopsy), and, most recently, facial trauma.

General requirements for endoscopic surgery include the ability to surgically obtain and maintain an optical cavity, insert a fiberoptic endoscope, sustain adequate hemostasis, and apply instrumentation. At least 2 points of access are generally required. The advantages of endoscopic surgery include more accurate visualization, minimal external incisions, visualization around corners, reduced soft tissue dissection, reduced hospital stay, and improved teaching. Disadvantages include a moderate learning curve, narrow field of view, poor depth perception, current lack of dedicated instrumentation, and the fact that the surgeon cannot operate bimanually without an assistant.

Endoscopy was initially used in facial plastic surgery for forehead rejuvenation. Currently, endoscopic brow-lifts have nearly replaced traditional open approaches. Many surgeons are beginning to use endoscopic techniques for rejuvenation of the midface. Early endoscopic applications in facial trauma include treatment of orbital blowout fractures, zygomaticomaxillary complex fractures, and subcondylar fractures. Several authors have presented case reports describing endoscopic repair of frontal sinus fractures; however, the literature contains no cadaver studies evaluating the utility of endoscopy in the repair of isolated anterior table, frontal sinus fractures. This study was designed to evaluate endoscopic exposure and reduction of frontal sinus fractures, application of miniplates, and camouflage of frontal sinus fractures with bone cement.

Endoscopic repair of frontal sinus fractures can be divided into 4 basic areas: exposure, reduction, fixation, and camouflage. All fractures require adequate exposure for repair. Fractures planned for reduction may or may not need fixation depending on the stability of the bone fragments. Fractures undergoing camouflage require no reduction or fixation.

FRAC TURE EXPOSURE

Endoscopic brow-lifting techniques have been well described previously. There are, however, several points that merit repeating. Vertical scalp incisions should be placed 1 to 1.5 cm behind the hairline to obtain the most advantageous position for endoscopic visualization. Incisions placed further back in the hairline will make it difficult to instrument around the intrinsic forehead curvature. “Blind” elevation of the periosteum above the fracture will save time. Dissection over the fracture and orbital rim should proceed with endoscopic visualization to avoid fracture comminution or injury to the supratrochlear and supraorbital nerves. It is important to have an assistant surgeon experienced in endoscopic surgical technique, who can anticipate and move the endoscope into appropriate locations. This reduces operating time and surgeon frustration.

Any discussion of frontal sinus fracture repair necessitates an understanding of the physical properties of the frontal bone. The frontal bone has an intrinsic convexity. As a perpendicular force is applied, the convex shape is flattened. The bone undergoes compression until it releases into a concave shape (Figure 12A). Reduction of the fracture necessitates that the bone fragments pass back through the compressive phase as they return to a normal position (Figure 12B). With fracture comminution, the interfragmentary resistance can be so low, that the compressive phase is nonexistent. When this occurs, the fragments will not remain in reduction without internal fixation.

Figure 10. Endoscopic view of incomplete “lag” reduction with comminution of depressed bone segment.

Figure 11. Endoscopic view of a hydroxyapatite bone cement repair rated as “good.” Irregularities were palpable, but not visible.
A rigid endosheath with a guarded tip is essential to maintain an optical cavity and avoid smearing the scope with blood (Figure 3A). The surgeon must be familiar with frontal anatomy and surgical endoscopy. He or she must have a mental picture of the overall size and shape of the fracture, as well as its relationship to the orbital rims, roof, and glabella. Endoscopic magnification can easily fool the surgeon into thinking the dissection is complete before the most inferior aspect of the fracture has been reached. Meticulous surgical technique must be used to successfully raise the periosteum off the depressed bone fragments.

Complete endoscopic exposure was accomplished in all 11 fractures. The ease of periosteal elevation was a function of how rigid the depressed fragments remained. Fractures with minimal comminution, and a high degree of interfragmentary resistance, remained stable and were easily exposed. Highly comminuted fractures, with minimal interfragmentary resistance, were extremely difficult to expose. In a clinical setting, patients with marked comminution would be identified preoperatively with computed tomography, and would require an open approach.

FRACTURE REDUCTION AND FIXATION

Fracture reduction can be accomplished from a distance through the previously described scalp incisions, or via a direct percutaneous stab incision in the forehead. Scalp incisions are much more challenging to use. The intrinsic curvature of the frontal bone limits the surgeon's ability to instrument the fracture segments. The angle of approach limits application of perpendicular forces to the bone fragments. The direct percutaneous approach requires a small stab incision, but is much more useful. It allows the surgeon to instrument the bone fragments directly, and apply a much greater force to the reduction. Two different percutaneous approaches include (1) application of miniplates to “lag” the bone segments back into position (CRIF), and (2) the use of transcutaneous reduction screws to manipulate one or more bone fragments and reduce the entire fracture (closed reduction without internal fixation). Both techniques have advantages and disadvantages.

Miniplate CRIF offers rigid fixation once the fractures are reduced. Unfortunately, miniplate insertion and manipulation is challenging. It can require a limited Lynch incision to control the plate (Figure 2). This incision is used clinically for frontal sinus trephination, and allows access to the frontal bone from below while avoiding the intrinsic forehead curvature. Unfortunately, it results in a visible scar (particularly in younger patients) and a significant risk of postoperative paraesthesias.

Miniplates were successfully bent, inserted, and applied in 5 of 5 specimens. However, the degree of comminution dictated the success of the repair. One specimen (20%) had a moderate amount of comminution and interfragmentary resistance. Despite a small amount of bone loss on the superior aspect of the fracture (which is magnified by the endoscopic view), the reduction was rated as complete (Figure 8). Two specimens (40%) had minimal comminution and marked fracture compression. Plate application resulted in good screw purchase, but the high degree of interfragmentary resistance resulted in only partial bone reduction and a moderate residual deformity (Figure 9). Two specimens (40%) had more significant comminution and destabilization of the bone fragments. Miniplate application resulted in further comminution of the bone fragments, with marked residual deformity (Figure 10).

Others14-16 have described endoscopic reduction of isolated fractures with the use of miniplates. Unfortunately, CRIF had limited success in our cadaveric model (20%). The discrepancy in success rates is most likely related to fracture selection. The previous authors likely chose fractures for the high likelihood of success with an endoscopic repair. However, it also may be related to our cadaveric model. The cortical bone was noticeably softer than vascularized bone, and appeared to have less resistance to comminution when screws were applied.

Transcutaneous reduction screws do not require a Lynch incision, and they offer more control of the bone...
fragments. After completion of the study, the primary author (E.B.S.) has evaluated reduction screws in the clinical setting with limited success (Figure 13). Unfortunately, reduction screws are bigger than miniplate screws, and can result in further fracture comminution. If there is not enough interfragmentary resistance, adjacent bone fragments may not follow the fixed fragment, and it may tear away. Finally, no rigid fixation is left in place. The reduction relies on interfragmentary resistance to overcome all soft tissue compressive forces once the endoscope and screw are removed.

FRACTURE CAMOUFLAGE

Fracture camouflage uses HA to recontour the frontal bone defect without attempting to reduce the fracture. This alleviates the need to manipulate and potentially destabilize bone fragments. It also offers an opportunity for a late repair, which has several advantages. Facial fractures are generally repaired within 1 to 10 days of the injury. Further delay results in bone remodeling, which makes surgical repair more difficult. This time window (1-10 days) often necessitates a decision for repair of frontal sinus fractures prior to the resolution of all forehead swelling. If the goal is not to repair the fracture, but to simply camouflage it, then a delay of 6 to 8 months for complete resolution of soft tissue edema is not detrimental. With this approach, some patients will avoid surgical repair altogether, because the defect is not apparent or does not cause significant aesthetic deformity (Figure 14).

Disadvantages of hydroxyapatite fracture camouflage are primarily related to the implant. Any foreign material has the risk of infection and extrusion. The long-term efficacy of HA remains to be proven. However, early clinical experience has shown HA to be safe when used for onlay applications. We and others have noted a tendency for micorfractures when the material is feathered out thinly at the periphery of a defect. This could lead to cracking, flaking, inflammation, and ultimately extrusion of the implant. Internal extravasation of the material into the frontal sinus is also a possibility. A 6- to 8-month delay before repair, as described above, would result in fibrosis of the fracture segments and reduce the risk of internal extravasation. Close clinical follow-up, including computed tomographic scans, is mandatory.

Endoscopic application of the HA was rapid and effective through the limited Lynch incision. Several patterns of application were tested, and the most efficient application technique was (1) insertion of the application trochar to the superior aspect of the defect, (2) initiation of cement application, and (3) slow removal of the trochar with a horizontal sweeping motion (Figure 5). The defect was overfilled by approximately 20% (Figure 6). A Ballenger elevator was then used to spread the cement smooth with a single “trowelling” motion (Figure 6). Excess bone cement was pushed to the periphery and removed with a suction before it hardened. The most effective trowelling motion evolved with a moderate learning curve. Multiple passes, or attempts to smooth the cement after it started to harden resulted in fragmen-
tion and surface irregularities. The technique produced 4 specimens (45%) with an extremely smooth contour that were rated as excellent (Figure 7). These specimens had minimal surface irregularities, excellent symmetry, and it was difficult to palpate the cement through the skin. Five specimens (55%) were rated as good (Figure 11). These specimens often required application of additional bone cement, or repeated attempts at recontouring after the first pass. Some specimens underwent rasping through the Lynch incision to smooth the irregularities. All 5 specimens rated as good had minimally palpable irregularities through the skin, but there was excellent symmetry and no visible external deformity.

Clinically, the same technique can be used through traditional hairline incisions alone. However the surgeon must manipulate the bone cement from a greater distance. A catheter can be placed over the tip of the Synthes CRS bone cement gun and threaded through the scalp incision. Endoscopic graspers can then be used to apply the cement as described above. An endoscopic brow periosteal elevator can be used to smooth the cement. Excess cement would then be suctioned away. We found smoothing and rasping the bone cement from the Lynch incision moderately challenging. It would likely be more difficult if performed from a hairline incision.

OPERATING TIME

The exact operating times for each specimen were not recorded in this study. However, they were noted to vary depending on the complexity of the fracture. Specimens that underwent CRIF often took over an hour to complete. While specimens treated with fracture camouflage were generally completed in 30 to 45 minutes. Direct extrapolation to the clinical setting is difficult, but the potential for reduced operating times compared with a standard coronal approach seems likely.

FUTURE DIRECTIONS

Dedicated instrumentation will allow the surgeon to expose and repair frontal sinus fractures much more rapidly and efficiently. Instruments currently under consideration include transcutaneous trochars, more efficient reduction screws, and modifications of current endoscopic brow sets such as rasps and reduction hooks.

Binocular endoscopes exist, but have limited use in the head and neck because of their large diameter. As the technology advances, binocular endoscopes will likely reduce in size and offer the surgeon an added benefit of depth perception.

Voice-activated robotic scope holders are currently in use for laparoscopic surgery. Robotic stabilization of the endoscope for head and neck procedures may provide a more stable visual field of view, free the surgical field for easier bimanual instrumentation, and eliminate the need for an experienced assistant surgeon.

Endoscopic repair of moderately displaced (1-5 mm), isolated anterior table frontal sinus fractures is feasible in a cadaver model. Fractures in 11 cadaveric specimens were successfully exposed. Manipulation and reduction of fracture fragments is difficult and development of dedicated instrumentation may make this more feasible. Application of miniplates can be accomplished endoscopically through a limited Lynch incision and stab incisions for application of screws. However, only 1 (20%) of the miniplate repairs was rated as complete. Four (80%) were rated as incomplete or partial reductions with fragmentation of the bone, and residual aesthetic deformities. Bone fragmentation may have been related to the brittle nature of cadaveric bone. The overall success of miniplate repair was directly related to the degree of fracture comminution, and amount of interfragmentary resistance present between bone fragments. Careful patient selection would likely improve the clinical success rate.

Application of bone cement, to camouflage the defects, was found to be the most effective method for endoscopic repair of these injuries. Four repairs were rated as excellent (45%) and 5 were rated as good (55%). No repairs were rated as poor. Future development of dedicated instrumentation will likely make this procedure more efficient and clinically successful.

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Synthes donated the CRS bone cement and the miniplates.

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