Cranioplasty complications following wartime decompressive craniectomy

FREDERICK L. STEPHENS, M.D., CORREY M. MOSSOP, M.D., RANDY S. BELL, M.D.,
TEODORO TIGNO JR., M.D., MICHAEL K. ROSNER, M.D., ANAND KUMAR, M.D.,
LEON E. MOORES, M.D., AND ROCCO A. ARMONDA, M.D.

Department of Neurosurgery, Walter Reed Army Medical Center, Washington, DC; and Department of Neurosurgery, National Naval Medical Center, Bethesda, Maryland

Object. In support of Operation Iraqi Freedom (OIF) and Operation Enduring Freedom-Afghanistan (OEF-A), military neurosurgeons in the combat theater are faced with the daunting task of stabilizing patients in such a way as to prevent irreversible neurological injury from cerebral edema while simultaneously allowing for prolonged transport stateside (5000–7000 miles). It is in this setting that decompressive craniectomy has become a mainstay of far-forward neurosurgical management of traumatic brain injury (TBI).

As such, institutional experience with cranioplasty at the Walter Reed Army Medical Center (WRAMC) and the National Naval Medical Center (NNMC) has expanded concomitantly. Battlefield blast explosions create cavity injury zones that often extend beyond the border of the exposed surface wound, and this situation has created unique reconstruction challenges not often seen in civilian TBI. The loss of both soft-tissue and skull base support along with the need for cranial vault reconstruction requires a multidisciplinary approach involving neurosurgery, plastics, oral-maxillofacial surgery, and ophthalmology. With this situation in mind, the authors of this paper endeavored to review the cranial reconstruction complications encountered in these combat-related injuries.

Methods. A retrospective database review was conducted for all soldiers injured in OIF and OEF-A who had undergone decompressive craniectomy with subsequent cranioplasty between April 2002 and October 2008 at the WRAMC and NNMC. During this time, both facilities received a total of 408 OIF/OEF-A patients with severe head injuries; 188 of these patients underwent decompressive craniectomies in the theater before transfer to the US. Criteria for inclusion in this study consisted of either a closed or a penetrating head injury sustained in combat operations, resulting in the performance of a decompressive craniectomy and subsequent cranioplasty at either the WRAMC or NNMC. Excluded from the study were patients for whom primary demographic data could not be verified. Demographic data, indications for craniectomy, as well as preoperative, intraoperative, and postoperative parameters following cranioplasty, were recorded. Perioperative and postoperative complications were also recorded.

Results. One hundred eight patients (male/female ratio 107:1) met the inclusion criteria for this study, 93 with a penetrating head injury and 15 with a closed head injury. Explosive blast injury was the predominant mechanism of injury, occurring in 72 patients (67%). The average time that elapsed between injury and cranioplasty was 190 days (range 7–546 days). An overall complication rate of 24% was identified. The prevalence of perioperative infection (12%), seizure (7.4%), and extraaxial hematoma formation (7.4%) was noted. Twelve patients (11%) required prosthetic removal because of either extraaxial hematoma formation or infection. Eight of the 13 cases of infection involved cranioplasties performed between 90 and 270 days from the date of injury (p = 0.06).

Conclusions. This study represents the largest to date in which cranioplasty and its complications have been evaluated in a trauma population that underwent decompressive craniectomy. The overall complication rate of 24% is consistent with rates reported in the literature (16–34%); however, the perioperative infection rate of 12% is higher than the rates reported in other studies. This difference is likely related to aspects of the initial injury pattern—such as skull base injury, orbitofacial fractures, sinus injuries, persistent fluid collection, and CSF leakage—which can predispose these patients to infection. (DOI: 10.3171/2010.2.FOCUS1026)

Key Words • cranioplasty • craniectomy • traumatic brain injury

The management of traumatic brain injury in the combat theater during OIF and OEF-A presents a unique challenge given the austere environment in which the military neurosurgeon finds himself. Forward neurosurgical treatment of traumatic brain injury has been defined in this era by immediate decompressive craniectomy. This procedure has become established to prevent irreversible neurological injury from cerebral edema associated with blast-induced injury during stateside transport, which can involve more than 7000 miles. Principles of damage-control neurosurgery are applied and include decompressing the brainstem, achieving homeostasis, and restoring anatomical continuity of the skull base when possible. The violent force of a blast...
explosion creates a complex cavitary injury zone that extends beyond the limits of the disrupted surface wounds. Reconstructing these patients presents unique challenges not commonly seen in the civilian sector. The loss of both a functioning soft-tissue envelope and skull base support as well as cranial vault disruption requires the multidisciplinary work of neurosurgery, reconstructive plastics, oral-maxillofacial surgery, and ophthalmological surgery. Craniofacial-orbital reconstruction in each patient must be individualized for the specific injury pattern. Our purpose in this report was to review the cranial reconstruction complications encountered in these combat casualties and to introduce strategies to avoid and manage such challenging cases.

Methods

Study Design

A retrospective database review was conducted for all soldiers injured in OIF and OEF-A who had undergone decompressive craniectomy and subsequent cranioplasty between April 2002 and October 2008 at the WRAMC and NNMC. During this time, both facilities received a total of 408 OIF and OEF-A patients with head injuries, 188 of whom underwent decompressive craniectomies in the combat theater before transfer to the US. Criteria for inclusion in our study consisted of either a closed or a penetrating head injury sustained in combat operations, resulting in the performance of a decompressive craniectomy and subsequent cranioplasty at either the WRAMC or NNMC. Excluded were all those patients for whom primary demographic data could not be verified. Also excluded from the study were patients initially hospitalized at the WRAMC or NNMC for an initial injury but who underwent cranioplasty at an outside facility.

Abstracted data included age at the time of initial

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>mean age (yrs)</td>
<td>26 ± 6.4</td>
</tr>
<tr>
<td>mean initial GCS score</td>
<td>7.5 ± 4.0</td>
</tr>
<tr>
<td>mean time interval to cranioplasty (days)</td>
<td>190 ± 91</td>
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>No. of Patients (%)</th>
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<tbody>
<tr>
<td>injury type</td>
<td></td>
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<tr>
<td>penetrating head injury</td>
<td>93 (86)</td>
</tr>
<tr>
<td>closed head injury</td>
<td>15 (14)</td>
</tr>
<tr>
<td>mechanism of injury</td>
<td></td>
</tr>
<tr>
<td>explosive blast</td>
<td>72 (67)</td>
</tr>
<tr>
<td>gunshot wound</td>
<td>30 (28)</td>
</tr>
<tr>
<td>motor vehicle accident</td>
<td>3 (2.7)</td>
</tr>
<tr>
<td>helicopter crash</td>
<td>1 (0.9)</td>
</tr>
<tr>
<td>fall</td>
<td>1 (0.9)</td>
</tr>
<tr>
<td>stabbing</td>
<td>1 (0.9)</td>
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</table>

**TABLE 2: Injury types and mechanisms**

**TABLE 1: Patient demographics**

**Fig. 1.** Noncontrast CT scans (A–C), radiograph (D), and photograph (E) obtained in a 29-year-old service member who sustained a penetrating brain injury due to an improvised explosive device, showing a large metallic fragment lodged in the interhemispheric fissure (A and D). This case illustrates several factors thought to contribute to cranioplasty infections, such as orbitofacial fractures (B), injuries involving the sinuses (C), and overlying soft-tissue defects due to burns or traumatic disruption (E). The soldier did require a latissimus-free flap to recreate the soft-tissue envelope due to tissue loss from his burns, degloving injury, and scalp ischemia.
Cranioplasty complications

Fig. 2. Non–contrast-enhanced CT scans obtained in a 22-year-old service member who sustained a severe penetrating head injury due to a grenade blast. Preoperative image (left) showing the cranial defects associated with his bilateral decompressive craniectomies. On postoperative Day 2 (approximately 6 hours after the discontinuation of a subgaleal drain) the patient went into status epilepticus, and an emergently performed CT scan (right) revealed a large epidural collection exerting mass effect upon the left frontoparietal region. He was emergently transported to the operating room for decompression; however, he died on postoperative Day 9 due to secondary neurological complications of the epidural collection.

Fig. 3. Cranial reconstruction algorithm.

injury, sex, type of injury (closed head or penetrating head injury), mechanism of injury (explosive blast injury, motor vehicle accident, and so forth), initial GCS score, admission Injury Severity Score (a scoring system that provides an overall score in patients with multiple injuries), the presence or absence of CSF leakage, and CNS infection associated with a patient’s initial injury. We also noted the time interval between initial injury and cranioplasty (days), the cranioplasty prosthesis material, the presence or absence of extraaxial hematoma formation (defined as either a subgaleal, epidural, or subdural hematoma judged by a qualified neuroradiologist to be out of the range of typical postoperative radiographic findings), new-onset seizure or infection associated with a patient’s cranioplasty, and the GOS score at 1–2 years after injury.

Direct comparisons were then made to determine the differences between groups of patients. The effects of the presence or absence of extraaxial hematoma formation, seizure activity, infection, and the need to reverse or revise the cranioplasty prosthesis on patient outcome were compared. The impact of prior CSF leakage, CNS infection, systemic infection, and time interval from a patient’s initial injury to cranioplasty on the prevalence of cranioplasty-associated complications was also examined. Initial GCS scores and the time interval from initial injury to cranioplasty were stratified to determine if a pattern of effect on other outcome variables could be elucidated.

Statistical Analysis

The Statistical Package for the Social Sciences, version 14 (SPSS, Inc.) was used to perform all inferential statistical analyses. Data were analyzed and results were expressed as the means ± SD for all descriptive variables. Percentages for descriptive variables were calculated and expressed as a function of the total number of patients in the study. Comparability between subpopulations in this study was analyzed using chi-square tests for categorical variables and logistic regression models for continuous variables.

Results

Demographics and Medical Characteristics

We identified 108 patients who underwent cranial reconstruction at the WRAMC and NNMC due to trauma sustained in OIF/OEF-A, accounting for the performance of 117 cranioplasties. The cohort had a mean age of 26 ± 6.4 years (Table 1), 99% were male (107 patients), and 86% had sustained penetrating head injuries (93 patients; Table 2 and Figs. 1–3). Explosive blast injury (72 cases [67%]) was the predominant mechanism of injury. Other injury mechanisms included high-caliber gunshot wounds (30 cases [28%]), motor vehicle accidents (3 cases), helicopter crash (1 case), falling (1 case), and stabbing (1 case). The average GCS score on initial presentation in the combat theater was 7.5 ± 4.0 with a mean Injury Severity Score 33 ± 9.1. The mean time interval from the date of injury to cranioplasty was 190 ± 91 days. Of the 117 cranioplasties performed, the prosthesis material was
Complications and Outcomes

An overall complication rate of 24% was identified (Tables 3–5). The prevalence of perioperative infection (13 patients [12%]), seizure (8 patients [7.4%]), and extraaxial hematoma formation (8 patients [7.4%]) was characterized. Twelve patients (11%) required prosthesis removal due to either extraaxial hematoma formation (3 patients) or infection (9 patients).

Chi-square tests were performed to evaluate the effects of injury type, precranioplasty CSF leakage, or CNS infection on the need to revise or reverse a cranioplasty. No significant associations were found between these factors and the risk for cranioplasty failure. Moreover, when the time from injury until cranioplasty was stratified by 90-day intervals, there was no statistically significant difference in the prevalence of complications or the need to revise or reverse a cranioplasty. However, the increased prevalence of infection (8 of 13 cases) with cranioplasties performed between 90 and 270 days after the initial injury approached but did not reach statistical significance (p = 0.061).

Notably, with regard to prosthesis material, there was no significant difference in the rates of reversal or revision in polymethylmethacrylate versus woven titanium mesh prostheses. Moreover, the initial GCS score (when stratified into quartiles) had no statistically significant effect on the prevalence of extraaxial hematoma, seizure, infection, or reversal after cranioplasty. The mean GOS score was 4.0 ± 0.93 at 1–2 years after injury. Finally, chi-square tests were again performed to evaluate the effects of extraaxial hematoma formation, seizure, and infection associated with cranioplasty on the GOS score at 1–2 years after injury. None of these factors significantly affected the GOS score at 1–2 years after injury.

Discussion

While much has been written on the surgical indications and techniques for cranioplasty, relatively little has been written specifically regarding the complications of this procedure. Additionally, those authors looking at cranioplasty complications have had a smaller cohort of patients presenting with penetrating head injuries, making the results of our study particularly unique. The present study of cranioplasty and its complications in a trauma population undergoing decompressive craniectomy represents the largest analysis to date. Moreover, it may serve to reignite debate regarding the optimal time interval from craniectomy to cranioplasty specifically within a population undergoing craniectomies for penetrating head trauma.

Complications Associated With Cranioplasty

The overall complication rate of 24% in our study is commensurate with prior authors’ findings. In their recent work on complications associated with cranioplasty, Gooch et al. reported an overall complication rate of 34%, with bifrontal cranioplasty as the only statistically significant factor associated with the need for reoperation. This finding is not surprising given the potential anatomical communication with the frontal sinus; a prior study has shown an increased risk of infection to be associated with violation of this space. The infection rate of 12% in our study is higher than that reported by Gooch and colleagues, likely reflecting the nature of these complex craniofacial injuries, such as soft-tissue, bony framework, and intracranial injuries.

With regard to the observed prevalence of seizures (8 patients [7.4%]), 5 patients experienced a seizure within the first 7 days following cranioplasty, whereas the other 3 had seizures after this time interval. Five patients in this group had a history of seizures and were taking either Keppra or Dilantin at the time of cranioplasty; the 3 patients with no history of seizures received Keppra postoperatively. While it may appear that the rate of seizures in our population is higher than that observed in Gooch and colleagues’ cohort of patients (1 case [1.6%]), it must be remembered that we account for both early and delayed seizures as well as cases with a history of seizures from the initial trauma. If patients with a history of seizures are excluded, the 3 cases of new-onset seizures compare favorably with prior reports.

Complications Requiring Reoperation

In our cohort, 12 patients (11%) required prosthesis removal because of either extraaxial hematoma formation (3 patients) or infection (9 patients). These 12 patients requiring reoperation constituted 41% of those experiencing complications related to cranioplasty. While this figure is lower than that reported by Gooch et al., it is still a high rate of reoperation.

Nine of 13 patients experiencing infectious complications required reoperation. The most common offending

### Table 3: Complication rates

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<thead>
<tr>
<th>Complication</th>
<th>No. (%)</th>
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<tbody>
<tr>
<td>infection</td>
<td>13 (12.0)</td>
</tr>
<tr>
<td>seizure</td>
<td>8 (7.40)</td>
</tr>
<tr>
<td>extraaxial hematoma</td>
<td>8 (7.40)</td>
</tr>
<tr>
<td>death</td>
<td>1 (0.93)</td>
</tr>
<tr>
<td>total</td>
<td>29 (24.0)</td>
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</tbody>
</table>

### Table 4: Effects of time interval to cranioplasty on infection rates

<table>
<thead>
<tr>
<th>Time Interval (days)</th>
<th>No. (%)</th>
</tr>
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<tbody>
<tr>
<td>0–90</td>
<td>1 (7.7)</td>
</tr>
<tr>
<td>90–180</td>
<td>4 (30.8)</td>
</tr>
<tr>
<td>180–270</td>
<td>4 (30.8)</td>
</tr>
<tr>
<td>270–360</td>
<td>1 (7.7)</td>
</tr>
<tr>
<td>&gt;360</td>
<td>3 (23.1)</td>
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organism was methicillin-resistant *Staphylococcus aureus* (2 patients), with *Acinetobacter* species, *Enterococcus faecalis*, *Candida albicans*, and *S. aureus* each causing 1; in 3 patients the causative organism was unknown. In the 5 instances in which patients’ Gram stains were positive, they were started on empirical antimicrobial treatment with cultures that subsequently proved to be negative.

Three of 8 patients experiencing a postoperative hematoma (defined as either a subgaleal, epidural, or subdural hematoma judged by a trained neuroradiologist to be outside of normal postsurgical changes) required reoperation. Notably, on postoperative Day 2 approximately 6 hours after the removal of a subgaleal drain, 1 patient demonstrated a rapid neurological decline. A head CT scan revealed a hyperacute epidural hematoma for which the patient was emergently taken back to the operating room. This patient died on postoperative Day 9 due to secondary neurological complications of his epidural hematoma.

**Patient Outcomes**

Cranioplasty is considered not only cosmetic but also therapeutic for continued neurological recovery, especially reversing the effects of the “syndrome of the trephine,” which is defined as neurological deterioration in patients with large cranial defects that subsequently improve with cranioplasty. Although we are conducting a study aimed at separating the syndrome of the trephine from posttraumatic stress disorder, we have noted an incidence of approximately 30% for the syndrome of the trephine. Ongoing progressive neurological improvement has occurred in the majority of patients through Years 1, 2, and 3 of follow-up. Historically, improvement continued in similar injuries for 5–7 years. Of note, the mean GOS score at 1–2 years after injury in this series of patients was 4.0 ± 0.93, with no significant associations between the incidence of complications and eventual outcome. This result suggests that most of this cohort were able to attain functional independence despite a moderate degree of disability. The practical and ethical considerations in a control group without cranial reconstruction limits the traditional statistical analysis.

**Study Limitations**

It is important to remember that this study represents a preliminary analysis of a wartime population managed at 2 hospitals and does not include patients, albeit a small number of cases (< 30), who underwent cranioplasties at institutions outside the WRAMC or NNMC. The duration of the follow-up has also revealed delayed infections associated with invasive scalp or head and neck interventions; such cases included patients who underwent hair implantation (1 patient), body piercing (2 patients), and tattooing (1 patient) during the follow-up. Additionally, 2 cranial implant infections were associated with the spread of delayed orbital and maxillofacial infections. One case included the infection of a maxillary acrylic implant at 5 years after treatment. Our study is described (Class III), and all observations apply to this study population only. Also, given its retrospective nature, this study is subject to the typical shortcomings associated with this format, including the loss of patient data, inadequate follow-up, and variable surgical techniques and/or materials. Note, however, that our data do provide valuable insights into the complications seen with cranioplasty in a unique population afflicted with severe multidimensional blast, blunt, and penetrating wartime traumas. Longitudinal studies of this patient cohort will educate us further on the ideal timing and type of cranial reconstruction to avoid complications.

**Conclusions**

Currently, cranial reconstruction cases are divided into those with or without associated orbitomaxillofacial injuries. A staged approach with early maxillofacial reconstruction followed by delayed cranial reconstruction has been applied. If the supraorbital bar is disrupted, then a staged approach is used to reconstruct the orbital band with autologous bone. Cranial reconstruction is then performed in a delayed manner by using autologous split-thickness bone or woven titanium mesh. Autologous bone is preferred in cases in which the skull base or air sinuses may be in contact with the implant. The avoidance of complications by making cranial implants more resistant to infection remains one of our ultimate objectives. A variety of strategies are being studied to include antibiotic-embedded implants as well as a more natural biologically active implant that allows integration with the surrounding cranial vault and skull base. As a nation and a military medical service, we are forever indebted to the men and women of our armed forces for service and sacrifice and are obligated to improve their care throughout their lifetime.

**Disclosure**

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

The views expressed in this manuscript do not represent the official policy or opinion of the United States Army, the United States Navy, the Department of Defense, or the United States Government.

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Analysis and interpretation of data: FL Stephens, RS Bell. Drafting the article: FL Stephens. Critically revising the article: MK Rosner, RA Armonda. Reviewed final version of the manuscript and approved it for submission: RA Armonda. Study supervision: MK Rosner, LE Moores, RA Armonda.

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References


Address correspondence to: Frederick L. Stephens, M.D., Department of Neurosurgery, Walter Reed Army Medical Center, Washington, DC 20307. email: frederick.stephens@us.army.mil.