Early decompressive craniectomy for severe penetrating and closed head injury during wartime

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Object. Decompressive craniectomy has defined this era of damage-control wartime neurosurgery. Injuries that in previous conflicts were treated in an expectant manner are now aggressively decompressed at the far-forward Combat Support Hospital and transferred to Walter Reed Army Medical Center (WRAMC) and National Naval Medical Center (NNMC) in Bethesda for definitive care. The purpose of this paper is to examine the baseline characteristics of those injured warriors who received decompressive craniectomies. The importance of this procedure will be emphasized and guidance provided to current and future neurosurgeons deployed in theater.

Methods. The authors retrospectively searched a database for all soldiers injured in Operations Iraqi Freedom and Enduring Freedom between April 2003 and October 2008 at WRAMC and NNMC. Criteria for inclusion in this study included either a closed or penetrating head injury suffered during combat operations in either Iraq or Afghanistan with subsequent neurosurgical evaluation at NNMC or WRAMC. Exclusion criteria included all cases in which primary demographic data could not be verified. Primary outcome data included the type and mechanism of injury, Glasgow Coma Scale (GCS) score and injury severity score (ISS) at admission, and Glasgow Outcome Scale (GOS) score at discharge, 6 months, and 1–2 years.

Results. Four hundred eight patients presented with head injury during the study period. In this population, a total of 188 decompressive craniectomies were performed (154 for penetrating head injury, 22 for closed head injury, and 12 for unknown injury mechanism). Patients who underwent decompressive craniectomies in the combat theater had significantly lower initial GCS scores (7.7 ± 4.2 vs 10.8 ± 4.0, p < 0.05) and higher ISSs (32.5 ± 9.4 vs 26.8 ± 11.8, p < 0.05) than those who did not. When comparing the GOS scores at hospital discharge, 6 months, and 1–2 years after discharge, those receiving decompressive craniectomies had significantly lower scores (3.0 ± 0.9 vs 3.7 ± 0.9, 3.5 ± 1.2 vs 4.0 ± 1.0, and 3.7 ± 1.2 vs 4.4 ± 0.9, respectively) than those who did not undergo decompressive craniectomies. That said, intragroup analysis indicated consistent improvement for those with craniectomy with time, allowing them, on average, to participate in and improve from rehabilitation (p < 0.05). Overall, 83% of those for whom follow-up data are available achieved a 1-year GOS score of greater than 3.

Conclusions. This study of the provision of early decompressive craniectomy in a military population that sustained severe penetrating and closed head injuries represents one of the largest to date in both the civilian and military literature. The findings suggest that patients who undergo decompressive craniectomy had worse injuries than those receiving craniotomy and, while not achieving the same outcomes as those with a lesser injury, did improve with time. The authors recommend hemicraniectomy for damage control to protect patients from the effects of brain swelling during the long overseas transport to their definitive care, and it should be conducted with foresight concerning future complications and reconstructive surgical procedures. (DOI: 10.3171/2010.2.FOCUS1022)

Key Words • decompressive craniectomy • penetrating head injury • blast injury • Glasgow Outcome Scale

Brain injuries from military-grade weaponry differ significantly from those received in civilian settings. Not only are the destructive forces involved considerably higher (blast, high-caliber missile), but additional factors, including the effect of protective equipment (helmet, body armor), systemic injury burden, available resources in a war zone, and the intricacies of field and overseas transport, make diagnosis, treatment, and outcomes difficult and unpredictable. It is because of these variances that the approach to patients with brain injuries must, in many circumstances, diverge from that undertaken in civilian traumatic brain injury populations.
During the first 5 years of OIF and OEF, the vast majority of patients with severe closed and penetrating head injuries presented to the WRAMC in Washington, DC, and the NNMC in Bethesda, Maryland, for definitive care. This unique population has afforded an in-depth and timely study of the current approach to patients with severe closed and penetrating head injury during wartime. The purpose of this paper is therefore to evaluate the circumstances leading to and outcomes after decompressive hemicraniectomy. The importance of this procedure will be emphasized and guidelines provided for current and future neurosurgeons deployed in a war zone.

### Methods

This study was approved by the institutional review boards at NNMC and WRAMC. We conducted a retrospective review of all soldiers, sailors, airmen, and marines injured in Operations Iraqi and Enduring Freedom between April 2003 and October 2008 by searching the databases at WRAMC and NNMC. During the specified period, 513 consultations were performed by the neurosurgery service in the aforementioned population; of these, 408 patients met the inclusion criteria for this study. Criteria for inclusion included either a closed or penetrating head injury suffering during combat operations in either Iraq or Afghanistan in a patient who subsequently received a neurosurgical evaluation at NNMC or WRAMC. Exclusion criteria included all patients for whom primary demographic data could not be verified.

Abstracted data included age at the time of initial injury, sex, type of injury (closed head injury or penetrating head injury), mechanism of injury (explosive blast injury, motor vehicle accident, and so on), initial GCS score, and admission ISS (numerical summation score categorizing the extent of trauma by body system) associated with one’s initial injury. Also measured was the amount of time spent in the ICU, GCS and GOS scores at discharge, and GOS score at 6 months and 1–2 years following discharge.

Direct comparisons were then performed to determine the differences between those patients undergoing decompressive craniectomy and those who did not. The relationships between the 2 groups with respect to age at the time of initial injury, initial GCS score, and ISS score in those who did and did not undergo the decompressive craniectomy were examined. We also examined the impact conferred by decompressive craniectomy upon ICU time, discharge GCS/GOS score, and GOS score at 6 months and 1–2 years after discharge.

### Statistical Analysis

The Statistical Package for the Social Sciences (version 14) was used to perform all inferential statistical analyses. Data were analyzed and results expressed as mean ± 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 were analyzed for all data including age at the time of initial injury, initial GCS score/ISS, ICU time, discharge GCS/ GOS score, and GOS score at 6 months and 1–2 years after discharge using chi-square tests for categorical variables and ANOVA for continuous variables.

### Results

During the specified 5-year period examined, 513 consultations were performed by the neurosurgery service concerning all wartime-related neurotrauma. Four hundred eight patients met the inclusion criteria for this study (male/female ratio 401:7; 228 with penetrating brain injury, 139 with closed head injury, and 41 not specified). Of these 408 patients meeting the inclusion criteria for this study, 188 presented having had decompressive craniectomies performed while in the combat theater for severe penetrating and closed head injuries (154 with penetrating head injury, 22 with closed head injury, and 12 unknown mechanism) (Table 1). Blast was the predominant mechanism of injury (Table 1).

Several trends emerged when examining for differences in this population compared with those who did not receive decompressive craniectomies (Table 2). While there were no significant differences in the age (26.2 ± 7.4 vs 27.5 ± 7.5 years, p > 0.05) or evacuation times (6.7 ± 7.3 vs 8.1 ± 10.6 days, p > 0.05) between those who did and did not receive decompressive craniectomies, respectively, there were significant differences in all other parameters studied. Patients undergoing decompressive...
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**Table 2: Summary of statistical comparisons between patients with and without decompressive craniectomy**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cranectomy</th>
<th>No Cranectomy</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean age (yrs)</td>
<td>26.1 ± 7.4</td>
<td>27.5 ± 7.5</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>presenting score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCS</td>
<td>7.7 ± 4.2</td>
<td>10.08 ± 4.0</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>ISS</td>
<td>32.5 ± 9.4</td>
<td>26.8 ± 11.8</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>ICU stay (days)</td>
<td>19.4 ± 31.5</td>
<td>7.3 ± 10.4</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>discharge score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCS</td>
<td>13.2 ± 3.1</td>
<td>14.7 ± 2.25</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>GOS*</td>
<td>3.0 ± 0.9</td>
<td>3.7 ± 0.9</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>6-mo GOS score*</td>
<td>3.5 ± 1.2</td>
<td>4.0 ± 1.0</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>1-yr GOS score*</td>
<td>3.7 ± 1.2</td>
<td>4.4 ± 0.9</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

* With the exception of p values, numbers reflect the mean ± SD.

Historical approaches to the most severely injured patients during wartime have consisted mainly of conservatively expectant approaches largely secondary to resource, technique, and technological limitations. The current conflicts have seen a considerable paradigm shift, adopting an aggressive approach consisting of rapid far-forward cranial decompression with watertight dural closure followed by rapid overseas evacuation to continental US hospitals. It is this approach, accompanied by the subsequent aggressive critical care management, that has resulted in meaningful survival in a population previously characterized by death and disability.7

**Evolution of the Approach to Severe Traumatic Brain Injury and the Emergence of Decompressive Craniectomy**

The modern approach to patients with severe head injury during wartime was pioneered by Dr. Harvey Cushing during World War I.9 His initial approach, characterized by aggressive cranial debridement carried through the Vietnam era.10,11,15 A subsequent shift to local debridement and closure occurred during the Israeli/Lebanon conflict following analysis by Brandvold et al.16 that indicated that aggressive cerebral debridement may have resulted in worse outcomes. It is important to remember that each of these conflicts occurred in the era predating routine, far-forward use of CT scanning.

The current conflict has seen the application of modern medical technique and technology in a way not previously available. Highly trained corpsmen and medics, often under direct enemy fire, rapidly resuscitate (through intubation, initiation of intravenous fluids) injured warriors within minutes of their injury. These patients are then rapidly evacuated to a Combat Support Hospital where CT scanning and neurological evaluation are possible. Cranial decompression, in these circumstances, often occurs within the first 2–3 hours accompanied by ICP monitoring or ventricular drainage. Preliminary analysis of this approach was performed by our group in 2006.4 At that time, just over 2 years into OIF, it became apparent that the most severely brain-injured patients were receiving appropriate decompression and that, at discharge from the hospital, the decompression was independently associated with improvement.

This extensive use of decompressive craniectomy following the most severe closed and penetrating head injury in these conflicts likely resulted from the necessities of medical evacuation transport. Following their resuscitation at the Combat Support Hospital, patients are placed on Combat Casualty Air Transport planes with critical care capabilities, but without direct neurosurgical supervision. These flights navigate half the globe, often during the time when cerebral swelling and increased ICP occur. It is therefore important to note that many of these operations might not have been performed if the added element of immediate air-transport to higher levels of care were not necessary. That said, 13 of the 188 patients who underwent decompressive craniectomy did so after arrival in the continental US. Seven of these patients received either craniotomy or burr hole evacuation of hematoma in...
the theater prior to transport. This highlights the unpredictable and often delayed nature of intractable ICP abnormalities in this population.

Effect of Early Decompressive Craniectomy: Outcomes

The results from our initial study have held true based on this longer-term study. As expected, for most parameters, individuals undergoing decompressive craniectomy differed from those who did not. This is reflected by the fact that both centrally (presenting GCS score) and systemically (ISS), those receiving decompressive craniectomy were worse off than those who did not. The difference in GOS scores was present at all time points; however, it must be stressed that, on average, those who required a decompressive craniectomy were able to participate in rehabilitation at discharge. Additional and subsequent improvement was seen in both groups at all time points.

Some important observational analyses were also conducted concerning the extent of injury. As expected, those with bilateral hemispheric injury fared worse than those with unilateral injury. What is interesting is that those with bilateral injury still, on average, were functionally able to participate in rehabilitation at 6–12 months (GOS score > 3). Four of the patients with bilateral injury had penetrating fragment tracks that traversed the ventricle. In all cases, these patients recovered meaningful survival, achieving functional rehabilitation status (Table 1).

While decompressive craniectomy has experienced resurgence in the civilian world in recent years, most of the reports have concerned closed head injury or stroke. It is therefore difficult to make direct comparisons between the current experience and previously published data. To our knowledge, this is the only report representing the study of outcomes in the setting of early cranial decompression for penetrating head injury.

Overall, these wartime patients, and the circumstances surrounding their injuries, differ substantially from their civilian counterparts. Penetrating fragment injury accompanied by blast overpressure was the predominant injury mechanism (Table 1). With respect to civilian penetrating head injury, most are missile (bullet) injuries, and the vast majority (approximately 90%) seen in the civilian environment result in death prior to emergency room admission or very early in their hospital stay. The improved survival in this military population is likely the result, in part, of immediate battlefield resuscitation (that is, within minutes of injury). The contribution of protective cranial and body armor in a group of largely healthy people must also not be understated. What must also be remembered is that this study represents only the patients who survived their original injury to reach the hospital; it does not include the denominator of all patients who were injured on the battlefield (killed in action) or died of wounds at the combat support hospital. Overall, application of the data discussed in this paper to the civilian experience must be done with considerable care.

Technical Considerations: Recommendations Concerning Patient Selection, Operative Plan, and Reconstruction

Prior to the performance of a decompressive craniectomy in this environment, several points should be considered. Planning for future surgeries and the inevitable complications that accompany any severe head injury is
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The posterior aspect of the midline limb of the incision is carried just to the cartilage at the anterior aspect of the pinna. The posterior aspect of the midline limb of the incision is carried as low as is required for exposure.

Fig. 3. Photograph showing the planned “Kempe” incision. The inferior limb is carried just to the cartilage at the anterior aspect of the pinna. The posterior aspect of the midline limb of the incision is carried as low as is required for exposure.

not only prudent, but can mean the difference between a good or poor recovery. The following recommendations are based on the problems encountered during definitive management of patients in this setting.

**Early Decision Making.** Surgical planning starts with patient selection. The patients who received early decompressive craniectomy in this study excluded those in whom the fragment track penetrated the zona fatalis (midline skull base, thalamus, brainstem). Translateral ventricular lesions, if accompanied by a good presenting GCS score, should not necessarily exclude possible decompression in this population (Table 1). Attempts to ascertain ICP (ICP monitor or external ventricular drain) should be initiated prior to decompression (excluding patients with large intracerebral or extraxial hematomas). It is also important to remember that the concomitant presence of traumatic cerebrovascular and spinal column injury can modify or complicate the operative plan in many patients.5,6

**Operative Plan.** If the decision has been made to perform a decompressive craniectomy, every effort should be made to make the bone removal as large as possible. The recommendation is that the size of the decompression be, at a minimum, 14 cm (anteroposterior) by 12 cm (superoinferior) if the intention is to perform a frontotemporoparietal craniotomy (Fig. 1). If extensive anterior cranial fossa disruption, bifrontal injury, or transventricular fragment trajectories are present, one can perform an extensive bifrontal craniotomy with sinus cranialization (Fig. 2). Although not specifically referred to in this study, there were circumstances in which limited decompressions resulted in the need for additional bone removal or initiation of moderate hypothermia to control refractory intracranial hypertension on arrival in the continental US. Further work by our group will quantify the relationship between the size of decompression, ICP, and outcomes.

Head CT scans must also be thoroughly examined prior to operative intervention to determine the extent of skull base and sinus disruption. Should either of these conditions be present, every effort should be made to “cranialize” the disrupted sinus and/or repair the skull base disruption at the time of the original intervention. This is supported by previous analyses strongly linking CSF leak with meningitis.2,5

**Cranial Reconstruction.** Although it is often not the responsibility of the battlefield neurosurgeon to subsequently perform the reconstruction, several initial maneuvers can aid in the future cranioplasty procedure. Most neurosurgeons have adopted a reverse question mark-shaped incision to initiate a trauma flap. In the setting of frontotemporoparietal decompressions, the incision initially described by Dr. Ludwig Kempe, and reinitiated in this conflict by Dr. Jonathan Martin (Fig. 3), has the advantage of preserving, in most cases, both the occipital and superficial temporal artery angiosomes.17 This aids wound healing both initially and following future reconstructive procedures.

In the setting of penetrating injury, the skin, bone, dura mater, and brain are violated. Though surgically difficult, reestablishing some form of dural continuity (vascularized pericranium, tensor fascia lata, and so on) in the setting of both skull base injury and sinus disruption has the advantage of initially reducing the incidence of CSF leak while subsequently providing a stable connective tissue barrier for dissection should future reconstructive procedures be necessary. Onlay graft materials like Duragen, while sufficient over the convexity, may not be sufficient as a sole reconstructive material over the skull base.

With respect to bone removal, the general recommendation is that it not be saved or implanted in the abdomen. Just over one-half of the patients with severe CNS injury had concomitant systemic infectious processes of some type.5 When evaluating a source of infection, the inevitable fluid collection surrounding abdominal bone implantation could not be definitively excluded as a source. This resulted in explantation and discarding of the bone in almost every case. While subsequent synthetic implants are not ideal, the technology concerning their construction has improved dramatically.

**Conclusions**

Cranial decompression following severe closed and penetrating brain injury during OIF and OEF resulted in meaningful survival in many cases. This form of damage-control neurosurgery facilitated transport of the wounded patient over long distances without direct neurosurgical supervision. While aspects of this aggressive approach may be applicable to civilian settings, it is important to remember that these patients are different from civilian trauma patients. They are, by and large, younger and healthier than the average civilian trauma patient, and despite the significantly increased forces involved (higher-caliber missiles, blast, and blast fragmentation injury), they are outfitted with significant protective gear that shields them from some of the damage.

With respect to ongoing and future conflicts, several recommendations are appropriate. First, early, aggressive cranial decompression should be considered in almost every case of penetrating and in most cases of closed head
injury. This excludes patients with injuries traversing the “zona fatalis.” Second, every effort should be made, at the time of the initial operation, to ensure a watertight dural closure and adequate cranialization of violated sinuses. Third, in every case of penetrating head injury in theater, the removed bone should be discarded. Overall, the approach by the neurosurgeon should take into account the future critical and operative care the patient will receive.

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 Navy, the United States Army, the Department of Defense, or the United States Government.

Author contributions to the study and manuscript preparation include the following. Conception and design: Bell, Armonda. Acquisition of data: Bell, Mossop, Dirks, Stephens, Mulligan, Ecker, Neal, Kumar, Tigno. Analysis and interpretation of data: Bell, Mossop, Dirks, Stephens, Ecker, Neal, Kumar, Tigno, Armonda. Drafting the article: Bell, Mossop. Critically revising the article: Bell, Stephens, Mulligan, Ecker, Armonda. Reviewed final version of the manuscript and approved it for submission: Bell, Armonda. Statistical analysis: Tigno. Administrative/technical/material support: Bell, Mulligan, Armonda. Study supervision: Bell, Armonda.

The authors certify that all individuals who qualify as authors have been listed; that the document represents valid work; that if they used information derived from another source, they obtained all necessary approvals to use it and made appropriate acknowledgments in the document; and that each takes public responsibility for it.

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References


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