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Decompressive craniectomy and postoperative complication management in infants and toddlers with severe traumatic brain injuries

Clinical article

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Object. Infants with severe traumatic brain injury represent a therapeutic challenge. The internal absence of open space within the infant cranial vault makes volume increases poorly tolerated. This report presents 7 cases of decompressive craniectomy in infants with cerebral edema.

Methods. The authors reviewed the medical charts of infants with brain injuries who presented to Albany Medical Center Hospital between January 2004 and July 2007. Variables that were examined included patient age, physical examination results at admission, positive imaging findings, surgery performed, complications, requirement of permanent CSF diversion, and physical examination results at discharge and outpatient follow-up using the King's Outcome Scale for Childhood Head Injury. Seven infants met the inclusion criteria for the study. Six infants experienced nonaccidental trauma, and 1 had a large infarction of the middle cerebral artery territory secondary to a carotid dissection. At admission, all patients were minimally responsive, 4 had equal and minimally reactive pupils, 3 had anisocoria with the enlarged pupil on the same side as the brain lesion, and all had right-sided hemiparesis. Six patients received a left hemicraniectomy, whereas 1 received a left frontal craniectomy. In all cases, bone was cultured and stored at the bone bank.

Results. Postoperatively, 3 patients who developed draining CSF fistulas needed insertions of external ventricular drains, with incisions oversewn using nylon sutures and a liquid bonding agent. After prolonged CSF drainage and wound care, these patients all developed epidural and subdural empyemas necessitating surgical drainage and debridement. Methicillin-resistant *Staphylococcus aureus* was found in 2 patients and *Enterococcus* in the third. All patients developed hydrocephalus necessitating the insertion of a ventriculoperitoneal shunt, and all had bone replaced within 1–6 months from the time of the original operation. Two patients required reoperation due to bone resorption. At outpatient follow-up visits, all had scores of 3 or 4 on the King's Outcome Scale for Childhood Head Injury. Each patient was awake, interactive, and could sit, as well as either crawl or walk with assistance. All had persistent, improving right-sided hemiparesis and spasticity.

Conclusions. Despite poor initial examination results, infants with severe traumatic brain injury can safely undergo decompressive craniectomy with reasonable neurological recovery. Postoperative complications must be anticipated and treated appropriately. Due to the high rate of CSF fistulas encountered in this study, it appears reasonable to recommend both the suturing in of a dural augmentation graft and the placement of either a subdural drain or a ventriculostomy catheter to relieve pressure on the healing surgical incision. Also, one might want to consider using a T-shaped incision as opposed to the traditional reverse question mark-shaped incision because wound healing may be compromised due to the potential interruption of the circulation to the posterior and inferior limb with this latter incision. *(DOI: 10.3171/2008.12.PEDS08310)*

Key Words • complication • decompressive craniectomy • head trauma • outcome • traumatic brain injury

Infants with severe TBI represent a challenging patient population. Due to the relative absence of open space within the infant cranial vault, even small increases in volume are poorly tolerated. Wound closure can be problematic due to the thinness of an infant's skin and its inability to hold sutures if the wound edges are under tension.

Infants with severe TBI treated using a craniotomy present additional considerations. The brain can become edematous and expand rapidly through an open craniotomy defect, necessitating enlargement of the dural or bone opening, or in severe cases, resection of brain tissue. In

Abbreviations used in this paper: EVD = external ventricular drain; GCS = Glasgow Coma Scale; ICP = intracranial pressure; KOSCHI = King's Outcome Scale for Childhood Head Injury; MCA = middle cerebral artery; SDH = subdural hematoma; TBI = traumatic brain injury; VPS = ventriculoperitoneal shunt.

TABLE 1: King's Outcome Scale for Childhood Head Injury scale

Score	Category	Characteristics
1	death	
2	vegetative	
3	severe disability	3a: the child is at least intermittently able to move part of the body/eyes to command or make purposeful spontaneous movements, may be fully conscious & able to communicate but not yet able to carry out any self-care activities such as feeding 3b: implies a continuing high level of dependency, but the child can assist in daily activities
4	moderate disability	4a: the child is mostly independent but needs a degree of supervision/actual help for physical or behavioral problems 4b: the child is age appropriately independent but has residual problems w/ learning/behavior or neurological sequelae affecting function
5	good recovery	5a: this should only be assigned if the head injury has resulted in a new condition that does not interfere w/ the child's well-being &/or functioning; for example, minor headaches not interfering w/ social or school functioning; abnormalities on brain scan w/out any detectable new problem; prophylactic anticonvulsants in the absence of clinical seizures; unsightly scarring of face/head likely to need cosmetic surgery at some stage; or mild neurological asymmetry but no evidence of effect on function of limb. Includes isolated change in hand dominance in a young child 5b: implies that the information available is that the child has made a complete recovery w/ no detectable sequelae from the head injury

this report, we present our experience in treating infants whose injuries necessitated decompressive craniectomy for severe cerebral edema.

Methods

Patient Population

We received institutional review board approval to perform a retrospective review of the medical charts of all infants with severe TBI who presented to Albany Medical Center Hospital between January 2004 and July 2007. Children whose injuries did not require a decompressive craniectomy were not included in this review. Of those children meeting the criteria for this review, we focused on the variables of patient age, physical examination results at admission, positive findings on imaging studies, operation performed, postoperative complications including infections and an unscheduled return to the operating room, requirement of permanent CSF diversion, and physical examination results at discharge and at outpatient follow-up visits. We used the KOSCHI[1] scale as a measure of outcome, in which the following scores were given: 1, death; 2, vegetative; 3, severe disability; 4, moderate disability; and 5, good recovery (Table 1).

Seven infants ranging in age from 2 to 24 months met the study inclusion criteria (Table 2). Six of these infants experienced nonaccidental trauma, whereas 1 had a large MCA territory infarction. Consent to operate was obtained from the parents when they were present, and in the remaining cases administrative consent was obtained. At admission, all patients were minimally responsive, 4 had equal and minimally reactive pupils, 3 had anisocoria with the enlarged pupil on the same side as the brain lesion, and all had right-sided hemiparesis with varying levels of severity (Table 2). The decision to perform a craniectomy was made based on each patient's declining physical examination results in the setting of the radiological findings of unilateral hemispheric edema with midline shift, along with subfalcine and uncal herniation with brainstem compression. Intracranial pressure monitoring was not performed in any of

TABLE 2: Patient physical examination and radiological findings at the time of admission*

Case No.	Age (mos)	Presenting Symptoms†	Radiological FIndings
1	2	rt-sided hemiparesis (withdrawal), seizing, anisocoria	lt SDH, edema, minimal shift
2	9	rt-sided hemiparesis (flexion), pupils equal & minimally reactive	rt ICH, SDH, SAH, shift
3	15	rt-sided hemiparesis (withdrawal), anisocoria	rt SAH, IVH, SDH, parietal fracture
4	23	rt-sided hemiparesis (flexion), seizing, pupils equal & minimally reactive	lt SDH, edema, shift
5	12	rt-sided hemiparesis (flexion), pupils equal & minimally reactive	lt MCA infarction
6	12	rt-sided hemiparesis (withdrawal), anisocoria	lt SDH
7	24	rt-sided hemiparesis, seizing, pupils equal & minimally reactive	lt SDH

* ICH = intracerebral hemorrhage; IVH = intraventricular hemorrhage; SAH = subarachnoid hemorrhage.
† Withdrawal and flexion refer to the patient's best motor scores on the GCS.

the patients prior to performing the craniectomy because each child had physical examination findings suggesting a possible progressive herniation syndrome, and the authors believed that urgent decompression was more likely to be clinically efficacious than medical management in reducing the potentially elevated ICP. Each patient was brought to the operating room within 1 hour of admission to the emergency department.

Surgical Technique

In all 7 cases, the decompressive craniectomy surgery was performed by 1 of the authors (M.A.A. or J.B.W.). To treat diffuse cerebral edema, all patients received a left hemicraniectomy (Fig. 1). Five of the 6 patients with nonaccidental trauma had small SDHs ranging in size from 4 to 6 mm, with massive underlying cerebral edema and uncal herniation. One patient experienced cerebral edema due to a large MCA infarction secondary to carotid artery dissection. All of the SDHs were on the left side and all were evacuated.

We performed a wide unilateral craniectomy in all cases on the side ipsilateral to the lesion. A reverse question mark-shaped incision was used, followed by removal of bone in the frontal, temporal, and parietal regions, extending the craniectomy to the floor of the middle fossa. The dura mater was opened widely in a stellate fashion to the edges of the craniotomy defect, and DuraGen (Integra LifeSciences Corp.) onlay dural substitute was used in all cases

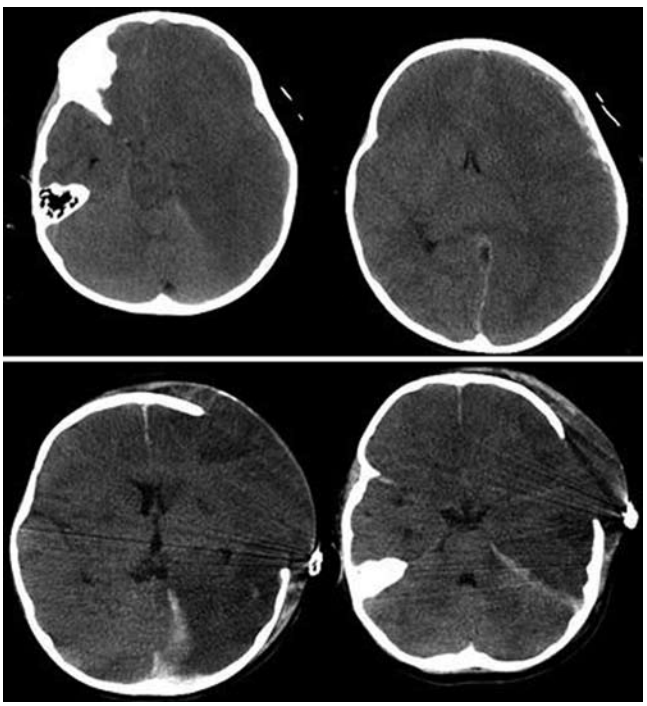

FIG. 1. Case 4. Preoperative *(upper)* and postoperative *(lower)* CT scans. *Upper:* Initial noncontrast head CT scans of a 23-month-old girl showing left hemispheric edema, midline shift, effacement of the basal cisterns, and a small left-frontal SDH. *Lower:* Images obtained 48 hours after left decompressive craniectomy showing resolution of midline shift and opening of the basal cisterns. Note herniation of brain tissue through the craniectomy defect, as well as ischemic left frontal and occipital lobes.

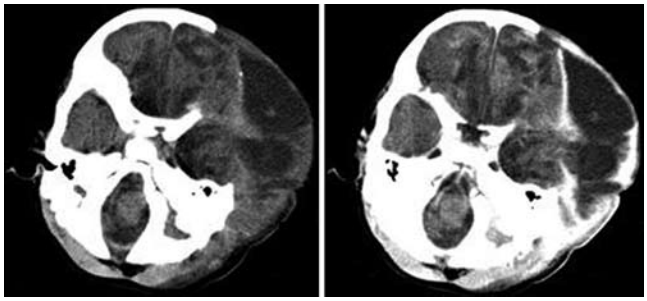

FIG. 2. Case 7. Postoperative CT scans. *Left:* Noncontrast head CT scan obtained in a 24-month-old boy 3 weeks after a left decompressive craniectomy showing a large extraaxial fluid collection. *Right:* Head CT scan with contrast administration in the same patient showing contrast enhancement in the extraaxial fluid, indicating infection.

to provide coverage of the cerebral hemisphere. The incision was closed using interrupted 3-0 Vicryl sutures (Ethicon Inc.) for the galea, and a running, locked 3-0 Ethilon nylon suture (Ethicon Inc.) for the skin in 6 cases, whereas staples were used in 1 case. The bone flaps were cultured and then cryopreserved in the Albany Medical Center Bone Bank.

Results

Postoperatively, 3 patients developed CSF fistulas that drained through the surgical incision. The fistula always occurred at the point along the reverse question mark-shaped incision, posterior to the ear where the incision curved superiorly. In these patients there was also a small area of wound breakdown and necrosis at this site. An EVD was placed in all of these patients, and the incisions were oversewn using nylon suture and sealed with Dermabond (Ethicon, Inc.). Lumbar drainage was not used in any patient in this series. After a prolonged course of CSF drainage and wound care, each of these patients developed epidural and subdural empyemas necessitating surgical drainage and debridement (Fig. 2). Methicillin-resistant *Staphylococcus aureus* was found in 2 patients, and *Enterococcus* in the third.

All of the patients developed hydrocephalus, based on imaging studies showing an enlarging ventricular system out of proportion to posttraumatic cerebral volume loss with or without a large extraaxial CSF collection, and based on clinical findings of persistent fullness or enlarging cranial defects (Fig. 3). All of the patients received VPSs, and the mean time to cranioplasty was 2.8 months. Two of the children developed bone resorption, which necessitated removal of the remaining bone. These children are currently undergoing observation and will have a prosthetic bone plate applied in the future.

At the time of discharge, all patients were scored on the KOSCHI as 3a or 3b (Table 3). All had required gastrostomy tubes for enteral feeding. Two patients were classified as requiring total care, and the remainder were awake and interactive but with persistent dense right-sided hemiparesis. At outpatient follow-up visits ranging from 1.5 months to 2 years after the surgery, all patients had a KOSCHI score of 3b or 4a (Table 3). Each child was awake, interactive, and able to sit and either crawl or walk

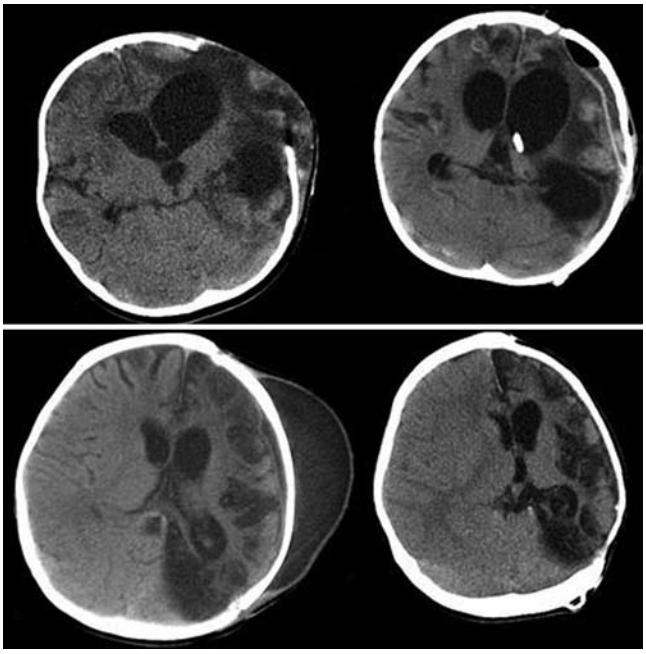

FIG. 3. Cases 3 *(upper)* and 5 *(lower)*. Noncontrast head CT scans obtained in 2 patients. *Upper:* Images showing enlargement of the ventricular system before *(left)* and after *(right)* placement of a left VPS and cranioplasty. *Lower:* Images showing a large subgaleal CSF collection before *(left)* and after *(right)* placement of a left VPS.

with assistance. All of the children showed persistent but improving right-sided hemiparesis and spasticity.

Discussion

Standardized treatment protocols have been suggested for the management of severe pediatric brain injury.[2] Generally accepted first-tier therapies include CSF drainage using a ventricular catheter, mild hyperventilation, and the use of osmotic diuretics such as mannitol. Second-tier therapies include barbiturate coma, hypothermia, and controlled lumbar drainage of CSF in addition to ventricular drainage. These therapies may provide clinical benefit in specific cases but they also carry some risk to the patient. For example, barbiturate coma may lead to hypokalemia[8] and whole-body hypothermia can be complicated by sepsis, thrombocytopenia, cardiac arrhythmias, and decreased bowel function.[3,9,11]

In recent years, there have been reports demonstrating favorable outcomes in patients with pediatric head injury after decompressive craniectomy.[12] However, the limited number of patients enrolled in these studies makes it difficult to achieve sufficient statistical power and for readers to form any definitive conclusions. Also, there are no studies or case series directed specifically at the infant and toddler age group, so it is difficult to make any direct comparisons to data already present in the literature.

In a study by Polin et al.,[10] bifrontal decompressive craniectomy was performed for pediatric patients with severe head injuries. These investigators used a cohort control matching protocol from the Traumatic Coma Data Bank and used a conditional logistic regression analysis comparing 92 control patients with the population who underwent decompressive craniectomy. They found a favorable outcome for the decompressive craniectomy group that was statistically significant when compared with medical management of elevated ICPs. They also reported that medical management alone carried a 3.86-fold greater risk for poor outcome than did decompressive craniectomy.

TABLE 3: Patient KOSCHI score at discharge and at 1-year follow-up

Case No.	Age (mos)	KOSCHI Score	
		Discharge	1-yr Follow-Up
1	2	3a	3b
2	9	3b	4a
3	15	3a	3b
4	23	3b	4a
5	12	3b	4b
6	12	3a	3b
7	24	3a	4a

Rutigliano et al.[13] presented data on 30 patients with a mean GCS score of 8, and ranging in age from 3 to 13 years. Six patients with ICP > 20 cm H_2O for 1–6 hours required decompressive craniectomy. All patients survived to hospital discharge, and 5 of the 6 patients left the hospital either functionally independent or with some form of minimal assistance. These authors found no significant association between risk factors (such as CT results or initial GCS score) and prognosis.

More recently, a study conducted by Kan and colleagues[6] involved 51 children with a mean age of 6.6 years and severe TBI who underwent decompressive craniectomy for malignant ICP alone or for removal of an associated mass lesion. Nonaccidental trauma was the most common mechanism of injury and represented 23.5% of all cases. Of the 35 survivors, 40% developed shunt-dependent hydrocephalus, 20% developed posttraumatic epilepsy, and 31.4% died. Their study reported that at the last follow-up examination, 19 had a KOSCHI score of 5, 11 had a score of 4, 3 had a score of 3, and 2 had a score of 2.

Lastly, Jagannathan et al.[5] performed a retrospective review of 23 craniectomies performed in children with a mean age of 11.9 years (range 2–19 years). One patient (4%) died intraoperatively and 6 patients (26%) died postoperatively. The mean Glasgow Outcome Scale score at the 2-year follow-up examination was 4.2 (median 5). At the most recent follow-up examination, 13 (81%) of 16 survivors had returned to school and only 3 survivors (19%) were dependent on caregivers.

When compared with follow-up data in the above studies, our outcomes are comparable and encouraging, at least at the time points currently reached. Hopefully, the 7 patients we are reporting on will continue to improve with prolonged courses of physical and occupational therapy. In contrast to the above studies, there are reports in the literature that specifically address the management of SDH in infants, although these studies do not focus on infants requiring a decompressive craniectomy.

In a report by Miyake and associates,[7] the outcomes in infants with both accidental and nonaccidental trauma

were compared. Most of the children underwent a craniotomy for evacuation of an SDH. In the nonaccidental trauma group at the 32-month follow-up, these investigators found that 54% were described as severely handicapped and 31% were moderately handicapped, with 1 death. In the comparison group, 67% of the patients were believed to be normal, 11% were only mildly neurologically damaged, 11% had severe neurological damage, and 1 patient died.

Similarly, Golden and Maliawan[4] showed that, in general, infants with nonaccidental head trauma generally had a poor outcome: 31% died, 23% had a good outcome, and the remainder recovered with neurological impairment of varying types and degrees. As stated previously, these studies did not address the need for decompressive craniectomy, so comparison of our data with theirs is somewhat difficult.

The timing of decompressive craniectomy varies widely in the reported studies. There is no true consensus regarding an optimal time to perform a decompressive craniectomy, although there is evidence that better outcomes might be achieved with earlier surgical intervention.

Regarding postoperative wound infections, in our 3 patients who developed subdural empyemas the scalp was very difficult to close because of brain edema. In fact, the scalp could only be closed after resecting portions of the frontal and temporal lobes. The dura was left open with application of an onlay dural substitute (Duragen). All 3 patients developed CSF fistulas that drained through the surgical incision. We had tried to manage fistulas with oversewing of the incisions and application of Dermabond, neither of which solved the problem. In retrospect, it appears reasonable to recommend the suturing in of a dural augmentation graft, because a more watertight closure is possible. Also, the placement of either a subdural drain or a ventriculostomy catheter at the time of the initial operation may be beneficial in relieving pressure on the surgical incision, allowing for better healing. However, in the setting of a grossly edematous brain with collapsed ventricles, an EVD may be difficult to place. If a temporal lobectomy has been performed with an opening into the lateral ventricle, placing the EVD catheter into the middle fossa should aid in diversion of CSF. With respect to the choice of the reverse question mark-shaped incision, it is possible that by extending the inferior limb of the incision posteriorly we compromised the vasculature to the scalp in that region, which could have contributed to the wound breakdown and CSF fistulas that occurred in that portion of the incision. This could potentially be avoided by using a T-shaped incision, similar to that used for a hemispherectomy. As of this writing, we have not used the T-shaped incision in the setting of trauma.

Kan et al.[6] experienced subgaleal and subdural empyema formation in 8.6% of their patients. The infections required multiple surgical drainage procedures and delayed cranioplasty. In both cases, the scalp was also difficult to close at the time of decompressive craniectomy because of brain edema. Jagannathan et al.[5] reported 1 case of meningitis. Kan and colleagues[6] reported 1 case of bone resorption necessitating additional cranioplasty.

Conclusions

Decompressive craniectomy, although an aggressive surgical procedure, is indicated for infants with severe TBIs who exhibit signs of increased ICP and declining neurological examination results. Based on our experience and results, we believe that infants and toddlers can safely undergo decompressive craniectomy with reasonable neurological recovery, despite poor initial findings on preoperative examination.

This patient series is small, and the follow-up duration is relatively short, so the long-term implications of this therapy are currently unknown. We did experience a high rate of postoperative complications, mostly due to the difficulty of scalp closure in these cases, but all complications were managed in an acceptable manner. Postoperative complications must be anticipated and treated appropriately.

The current neurosurgical literature is lacking in reports addressing severe head trauma in infants and toddlers. Therefore, it is our hope that future research may use multicenter prospective methods that would allow for enrollment of enough patients to reach sufficient statistical power and comparison of treatments for TBI in this challenging and vulnerable population.

Disclaimer

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

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