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FOCUS SESSION

Greenstick fracture-hinge decompressive craniotomy in infants: illustrative case and literature review of techniques for decompressive craniotomy without bone removal

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Abstract

Purpose We present the potential usefulness of a greenstick fracture-hinge decompressive craniotomy, a variant of a hinge-craniotomy, as an alternative technique for use with a decompressive craniectomy (DC) in infants. A literature review of hinge-craniotomy procedures and technical variants is also provided, with a focus on complications associated with a DC peculiar to infants and children.

Methods Illustrative case presentation along with literature review.

Result Significant rates of complications associated with a DC and subsequent cranioplasty have been reported, such as bone flap resorption, hydrocephalus, cerebrospinal fluid collection, and infection, especially in infants. A hinge-craniotomy is an older technique reported to have potential usefulness with some modifications, though concerns have been raised about adequate decompression and definitive indications.

Conclusion A DC procedure performed in children, especially infants, includes a significantly high risk of various complications; thus, a hinge-craniotomy technique is worthwhile for consideration to avoid such complications. Additional studies are required to clarify whether this technique may contribute to reduce complications related to a DC in infants and children.

Keywords Abusive head trauma · Acute subdural hematoma · Children · Decompressive craniotomy · Decompressive craniectomy · Hinge-craniotomy · Infant

Abbreviations

ASDH	Acute subdural hematoma
CT	Computed tomography
CSF	Cerebrospinal fluid
DC	Decompressive craniectomy
ICP	Intracranial pressure

Introduction

Complications related to a cranioplasty following a decompressive craniectomy (DC) procedure occur much more often in children than adults [1, 2], with the risk extremely high in the first year of life [3]. A decompressive hinge-craniotomy is an older technique generally used to avoid a cranioplasty and potential associated complications, though most reports have only included adult patients. We report here use of a greenstick fracture-hinge decompressive craniotomy, a variant of a hinge-craniotomy, for treatment of a 4-month-old infant with an acute subdural hematoma (ASDH) with impending brain herniation. The potential benefits of a hinge-craniotomy are discussed along with a review of techniques utilized for a decompressive craniotomy without bone removal, as well as complications associated with a DC in infants and children.

Traditional decompressive craniectomy and associated complications

A DC for children is performed for control of refractory intracranial hypertension regardless of the first tier maximum medical management, though only limited evidence of its effectiveness has been shown [4–10]. The common etiology related to

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the underlying cause of refractory intracranial hypertension is traumatic brain injury with or without mass lesions. A hemicraniectomy combined with dural decompression is a representative procedure. However, when the bone flap is left out following a DC, methods for flap storage, timing, and materials in allograft cranioplasty cases should be carefully considered along with subsequent potential complications [11].

Hydrocephalus and subdural fluid collection occur as complications associated with a DC in patients with traumatic brain injury, especially children [12–14], with impaired cerebrospinal fluid (CSF) dynamics considered to be a possible pathogenic factor. Such CSF disorders can lead to a complicated cranioplasty with CSF diversion procedures, such as external ventricular drainage and a ventriculoperitoneal shunt, which induce increased risks of infection and bone flap resorption [13, 14]. For pediatric patients undergoing a cranioplasty, infection and bone flap resorption are of great concern, with rates of 10.5% and 21.7%, respectively, reported in a recent multicenter retrospective study of 240 patients [15]. A cranioplasty following a DC is not a straightforward surgical procedure when performed in children, especially infants, as significant associated complications have been reported [2]. Following an initial autologous bone cranioplasty, bone flap resorption was reported to occur at a rate of 66.7% in 18 pediatric patients less than 15 years old and was especially high in those younger than 8 years [1]. Grand et al. noted a 50% rate of bone flap resorption requiring a reoperation, an unacceptably high rate for that complication in children undergoing an autologous cranioplasty [16]. Bowers et al. also reported a 50% rate of bone flap resorption in 54 pediatric patients, with those 2.5 years or younger at greater risk [17]. Those results were supported by a recent study that showed a higher risk of age-dependent occurrence of bone flap resorption in younger patients [15]. In infants, a cranioplasty must be performed with special attention given to growth-related dislocation, as the most rapid skull growth period is the first year of life [18]. The skull continues to grow rapidly until 3 years old, indicating the appropriate timing for cranial repair. However, a delayed cranioplasty raises several concerns regarding safety, as well as cosmetic problems and a higher rate of complications as compared with a procedure performed earlier [11]. Although an autologous cranioplasty is the gold standard for growing skulls in children less than 3 years old, storage of the removed bone flap in abdominal subcutaneous space is restricted in small children, while its cryopreservation is associated with a higher incidence of bone flap resorption [19].

Abusive head trauma cases are increasingly being reported and an issue of public concern [20–22]. In addition to ASDH, contusions, diffuse axonal injury caused by impact or angular deceleration force, ischemic insult due to seizure, hypoxia, and hypoperfusion are suggested to be contributing factors, while the pathophysiology remains to be elucidated. Unfortunately, infants are the most common victims of abusive head trauma, with higher rates of mortality reported for younger patients [20, 22]. DC and intracranial pressure (ICP) monitoring play important roles for neurosurgical management following abusive head trauma [22].

Based on the aforementioned higher risk of complications and difficulties associated with DC, special considerations are required for surgical decompressive procedures in infants and children, as compared to adults. A decompressive craniotomy without bone removal may have potential usefulness as a surgical decompressive procedure for infants and children. In an illustrative infant case with abusive head trauma, with details presented following, we used a greenstick fracture-hinge decompressive craniotomy technique, a technical variant of a hinge-craniotomy procedure, which may have potential usefulness as a surgical decompression procedure to control raised intracranial pressure and reduce complications associated with a DC in infants.

Review of current techniques for decompressive craniotomy in children

Various surgical bony decompressive procedures for treating brain edema and refractory intracranial hypertension have been reported, following the initial description by Kocker in 1901 [23]. A DC, also referred to as a hemicraniectomy, is presently accepted as a traditional neurosurgical procedure for removal of a large frontotemporoparietal bone flap. A bifrontal decompressive craniectomy, which is an extended frontal bony decompression that includes the anterior and middle cranial fossae, is also included as part of the procedure. We reviewed DC surgical techniques used to treat children reported in English up to December 2018 in searches of PubMed using the terms “decompressive craniectomy AND children” and “decompressive craniotomy AND children”. Since few clinical studies of DC for children have been reported, those for adults were also searched and included in our review as potential available techniques. Differences regarding surgical approaches, such as unilateral, bilateral, subtemporal, and bifrontal DC, are not included as technical aspects in this report, as we focused on surgical techniques for a decompressive craniotomy without bone removal. Relevant reports regarding techniques for decompressive craniotomy without bone removal are summarized in Table 1. Because of the small number of cases, lack of control subjects, heterogeneous etiology, and varying degrees of severity, clinical outcomes are described based on ICP value and survival rate.

Hinge-craniotomy and technical variants

The concept of a hinge-craniotomy procedure is thought to have been derived from Wagner’s flap, described in literature

Table 1 Summary of reported techniques for decompressive craniotomy without bone removal

Year	Authors	No. of cases	Age[a]	Etiology	DC technique	Additional procedures	Complications				Outcome
							Infection	Bone flap resorption	Hydrocephalus	Other	
2003	Figaji at al.	3	11	Assault	Decompressive craniotomy		NO	NO	NO		Survived
			12	TBI	Decompressive craniotomy		NO	NO	NO		Survived
			5	TBI	Decompressive craniotomy		NO	NO	NO		Survived
2007	Ko et al.	16	23–77 (mean 51)	TBI CVD	In situ hinge-craniotomy	CSF drainage Refasten hinge	NO	NO	NO		ICP < 22 mmHg
2007	Schmidt et al.	25	Mean 38 ± 16	TBI	Hinge-craniotomy		YES 1 (4%)	NO	N/A	Cosmetic problem: 1 (4%)	OS 52%
2009	Kenning et al.	20	Mean 50 ± 15	TBI CVD	Hinge-craniotomy		N/A	N/A	N/A	Reoperation: 3 (15%)	ICP:12.0 ± 5.6 mmHg, in-hospital survival: 75%
2010	Valenca et al.	5	18–59 (mean 40)	TBI: 2 CVD: 3	In-window craniotomy		NO	NO	YES (CSF shunt in 1 case)		OS: 100%
2011	Mracek et al.	20	8–75 (mean 42)	TBI CVD	Osteoplastic decompressive craniotomy	Additional bone flap removal 2 (10%)	NO	NO	NO		OS: 80%
2015	Silav et al.	1	12 months	TBI	DC with preservation of split bone flaps under scalp	Cranioplasty	NO	NO	NO		Survived
2016	Adeleye et al.	40	21–75 (mean 38)	TBI	Temporal muscle hinge decompressive craniotomy		YES 1 (2.5%)	NO	YES 1: 2.5%	Bone flap depression: 2 (5%)	In-hospital survival: 70%
2017	Gutman et al.	57	Mean 37 ± 23	TBI	Floating anchored craniotomy	CSF drainage 2 (3.5%)	YES 2 (3.5%)	NO	NO	Inadequate decompression: 1 (1.8%) SDH: 1 (1.8%) Subgaleal hematoma: 1 (1.8%)	OS: 77% ICP reduction: 15.4 ± 7.4 mmHg
	Present case	1	4 months	Abusive head trauma ASDH	Greenstick fracture-hinge decompressive craniotomy		NO	NO	NO		Survived ICP < 20 mmHg

TBI includes subdural hematoma, epidural hematoma, and contusion. CVD includes cerebral infarction, intracerebral hemorrhage, arteriovenous malformation, and cerebral venous sinus thrombosis

NA not available, ASDH acute subdural hematoma, TBI traumatic brain injury, OS overall survival, CSF cerebrospinal fluid, CVD cerebrovascular disease, ICP intracranial pressure

[a] Age is shown in years, unless otherwise indicated

as early as 1889 [24]. In clinical applications for neurosurgery in the modern era, hinge-craniotomy techniques have been used to treat adults with various etiologies, including traumatic brain injury and cerebrovascular disease, since 2007 [25–30]. Creation of a hinge allows the swollen brain to bulge out in accordance with the extent of intracranial pressure. Potential advantages of associated techniques are avoidance of additional surgical procedures and associated complications arising from a cranioplasty, as well as sinking flap syndrome that can develop with bone flap absence. In 2007, Ko et al. reported an in situ hinge-craniotomy technique, in which a hinge joint is created where the inferior edge of the bone flap is fixed with a straight titanium plate to the cranium [25]. Postoperative control of ICP was reported to be within a normal range in a subgroup of adult cases, though several concerns were raised in regard to adequate decompression, indications, and long-term outcomes. Schmidt et al. also reported a hinge-craniotomy technique, in which a hinge joint was created between the free bone flap and skull using a titanium Y-shaped plate [26]. Kenning et al. noted comparable outcomes regarding ICP control and in-hospital survival rate in a retrospective comparative study of hinge-craniotomy and DC procedures [27]. Also, Valenca et al. reported an "in-window" craniotomy technique consisting of two separated free bone flaps with hinge joints created using synthetic non-absorbable sutures on both sides [28]. They also noted a potential advantage of avoidance of hemicraniectomy-associated bleeding caused by greater shear stress between the swollen brain and craniotomy edge, which was observed following a traditional DC. Furthermore, brain swelling can be exaggerated by occlusion of veins between the swollen brain and dural edge. To prevent such venous occlusion, Csokay et al. reported a vascular tunnel technique, in which they placed pillars made of rolled hemostatic sponge on both sides of the bridging and cortical veins at the site of a durotomy [31, 32]. In this respect, Kenning et al. speculated that brain edema and expansion are exaggerated by rapid cerebral decompression in cases with a traditional DC as compared to a hinge-craniotomy based on extracerebral herniation index analysis [27]. Instead of plates and screws, the temporal muscle can also be utilized as a hinge. An osteoplastic craniotomy can be performed with temporal muscle or pericranium tissue left attached to the bone flap [29, 30, 33]. However, in one of those reports, additional bone flap removal was required in 2 of 20 cases during postoperative ICP monitoring [29].

Another concern related to a hinge-craniotomy technique is cosmetic problems including bone flap depression following resolution of brain swelling. The hinged craniotomy may undergo bony remodeling in children. Similar observation can be found in operated craniosynostosis cases, especially in the first year of life. Fixation of titanium plates and screws on a hinged bone flap is an option to prevent bone flap depression in adults [26, 27]. For children, an absorbable plate is preferable, though may not be available at every institution, especially in developing countries with limited equipment available. In adult cases, oblique bone cutting using a Gigli saw has been utilized to prevent bone flap depression [29]. Also, Gutman et al. reported a decompression technique with a floating anchored craniotomy, in which a bone flap was placed without creating a hinge [34]. With that technique, the bone flap with affixed titanium plates returns to the craniectomy site after resolution of brain swelling, while it is left floating should brain swelling persist.

A DC has been reported to be an effective surgical procedure to reduce raised ICP, though only a limited number of child cases have been reported [35, 36]. Figaji et al. presented results of DC and decompressive craniotomy procedures for severe traumatic brain injury in five pediatric cases, ranging in age from 5 to 11 years [37]. Notably, they suggested the potential usefulness of a decompressive craniotomy without compromising the area of decompression where the bone flap is loosely placed after raising. As compared with adults, a thinner bone flap in children may not cause a significant mass effect under an elastic scalp. In adults, drilling of the inner table of the skull and incision of the galea (i.e., a galeatomy) have been used to create additional space during an in situ hinge-craniotomy procedure [25]. Additionally, Silav et al. reported a unique technique for storing split bone flaps under the subgaleal space adjacent to the DC site in infants [38]. An advantage of that technique is bone flap storage without the compromise of decompression, though a later autologous cranioplasty is required using the same scalp incision. From experiences of complications associated with cranioplasty procedures in children, Martin et al. and Frassanito et al. suggested a hinge-craniotomy as an alternative to prevent bone flap resorption [1, 3]. Importantly, care must be taken to prevent a wound hematoma in the subgaleal and epidural spaces, as well as temporal muscle bleeding, which can lead to inadequate decompression [29], while meticulous hemostasis with placement of surgical drainage can reduce the risk of such complications. A dural incision and duraplasty using autologous tissues, such as pericranium and temporal fascia tissues, or artificial dura substitutes, are generally considered for utilization as dural decompression procedures. Decompressive duraplasty techniques to create multiple mesh- or lattice-like dural fenestrations in adult and pediatric patients have also been reported [39–41]. Additionally, Adamo et al. recommended a T-shaped scalp incision and watertight closure of the dura for a traditional DC, as they noted a high rate of postoperative complications associated with a CSF fistula that led to subsequent poor wound healing and infection in children less than 2 years of age [14].

A hinge-craniotomy technique cannot be applied for cases with excessive brain swelling encountered during exploration, as scalp closure is difficult and further resection of swollen brain tissue may be required. A silicone sheet was used for

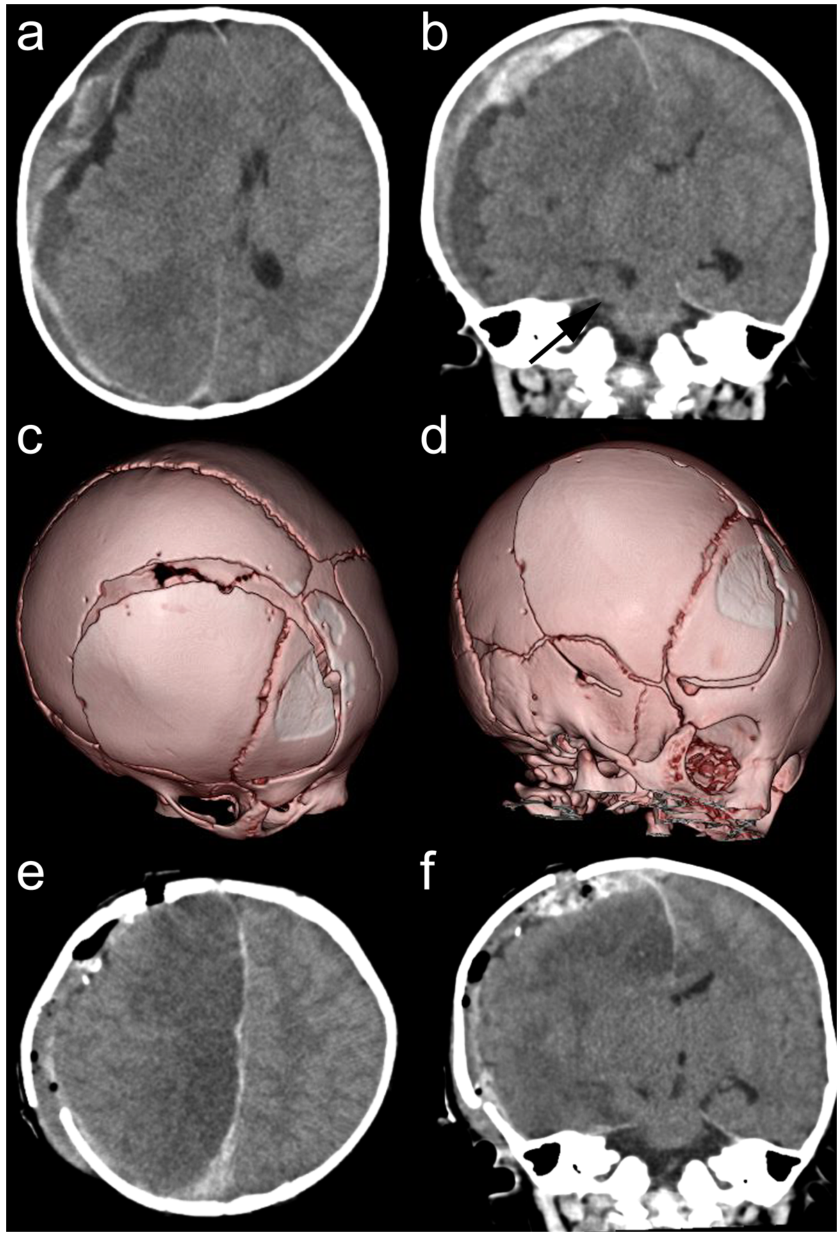

Fig. 1 Head CT images showing heterogenous density of the ASDH (**a**, **b**). A severe midline shift with an uncal herniation is shown (**b**, arrow). The elevated bone flap can be seen on three-dimensional CT images obtained following surgery (**c**, **d**). Midline shift was improved despite diffuse hemispheric brain swelling (**e**, **f**)

temporary closure of the scalp in an unusual pediatric case of extreme brain swelling encountered during a DC procedure [42]. DC can be performed on a prophylactic basis, depending on intraoperative findings and individual experience, because the extent of subsequent brain swelling is unpredictable. Hinge-craniotomy techniques are considered to have advantages for cases without brain swelling despite DC, which might otherwise require a cranioplasty. As a technical variant of a hinge-craniotomy without bone removal, we have found that the advantages of a greenstick fracture-hinge decompressive craniotomy include ease with obtaining a hinge and the ability to obtain adequate decompression without bony removal, because of the unique characteristics of a greenstick fracture, along with open fontanelles and sutures, findings specific to infant cases.

Illustrative case

A 4-month-old male infant was referred to us with consciousness disturbance, with a Glasgow Coma Scale score of E1V1M1 upon arrival. Anisocoria with a dilated pupil on the right side was noted and the anterior fontanelle was hard. The patient was intubated because of generalized convulsions, hypoxia, and bradycardia. Head computed tomography (CT) revealed an ASDH on the right hemisphere, with a severe

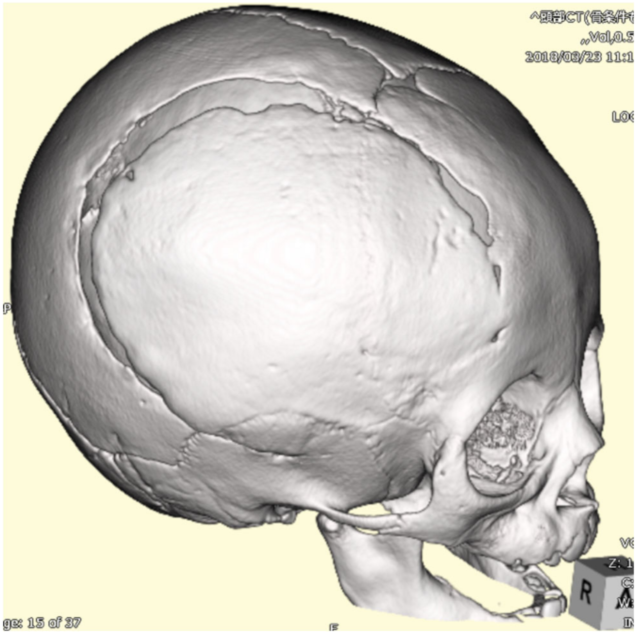

Fig. 2 Three-dimensional CT image obtained 3 months after surgery demonstrating partial ossification of the skull defect with acceptable cosmetic results

midline shift and uncal herniation (Fig. 1a, b). Examinations of the optic fundi revealed papilledema and retinal hemorrhaging in the dilated right pupil. We performed an emergency craniotomy, with removal of the ASDH, a duraplasty, and placement of an ICP sensor. Following a large question mark scalp incision, a periosteal flap was obtained on the frontal bone with temporal muscle tissue left attached to the temporal bone, then several burr holes were placed and the skull was cut toward the temporal base side. A hinge-craniotomy was done with a greenstick fracture made at the temporal base. Dural tenting sutures were used for preventing epidural bleeding. The ASDH was removed with a gradual dural opening and a hinge-bone flap was placed in situ without fixation after an expansive duraplasty with a periosteal flap.

Pupillary abnormalities disappeared soon after surgery. Head CT revealed reversal of the uncal herniation with adequate decompression under the raised bone flap (Fig. 1c–f). The basal cisterns were well visualized. The patient was kept under mild hypothermia at 34 °C with his head elevated to 30° and given barbiturate coma therapy for 5 days. ICP was maintained below 20 mmHg, while cerebral perfusion pressure was controlled at around 60–65 mmHg using vasopressors. Extensive postoperative brain swelling was tolerable and no additional neurosurgical surgical procedures were required. At a postoperative 3-month follow-up examination, the infant had recovered well, without cosmetic or wound problems. Head CT demonstrated hemispheric encephalomalacia with ossification around the bone flap (Fig. 2). The patient was transferred to another hospital for continuous care as a suspected victim of abusive head trauma.

Conclusion

There is a significantly high rate of complications associated with a DC and subsequent cranioplasty when performed in children, thus a decompressive craniotomy with use of a hinge technique may be useful, especially for infant cases. Additional studies are required to clarify whether a decompressive hinge-craniotomy technique without bone removal can contribute to a good clinical outcome along with a reduction in complications.

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to declare in regard to this study.

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