



Clinical Study

Craniectomy-Associated Progressive Extra-Axial Collections with Treated Hydrocephalus (CAPECTH): Redefining a common complication of decompressive craniectomy

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ABSTRACT

Extra-axial fluid collections following decompressive craniectomy have been observed in a variety of patient populations. These collections have traditionally been thought to represent extra-axial signs of hydrocephalus, but they often occur even in settings where hydrocephalus has been optimally treated. This study aims to elucidate the phenomenon of extra-axial fluid collections after decompressive craniectomy in patients with treated hydrocephalus, in order to improve identification, classification, prevention and treatment. We retrospectively reviewed all patients at a single institution undergoing decompressive craniectomy for refractory intracranial pressure elevations from June 2007 through December 2009. We identified 39 patients by reviewing clinical reports and imaging. Any patient who died on or prior to the third post-operative day (POD) was excluded. The analysis focused on patients with extra-axial collections and treated hydrocephalus. Twenty-one of 34 (62%) patients developed extra-axial collections and 18 of these developed collections despite ventricular drainage. Subgroup analysis revealed that seven of seven patients (100%) with subarachnoid hemorrhage, and 11 of 14 (79%) with traumatic brain injury developed collections. Extra-axial collections may develop after decompressive craniectomy despite aggressive treatment of communicating hydrocephalus. In these patients, the term “external hydrocephalus” does not appropriately capture the relevant pathophysiology. Instead, we define a new phenomenon, “Craniectomy-associated Progressive Extra-Axial Collections with Treated Hydrocephalus” (CAPECTH), as progressive collections despite aggressive cerebral spinal fluid (CSF) drainage. Our data indicate that early cranioplasty can help prevent the formation and worsening of this condition, presumably by returning normal CSF dynamics.

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1. Introduction

Decompressive hemicraniectomy (DC) has become a common operative strategy in the management of conditions causing elevated intracranial pressure (ICP) and refractory cerebral edema. Despite early studies that did not definitively supportive its effectiveness,^{1–4} and even with a recent study questioning the benefit of DC in traumatic brain injury (TBI),⁵ the use of this surgery for ICP management continues to increase. This increase in utilization has been driven mainly by data supporting its efficacy in stroke patients with malignant cerebral edema.^{6–10} Support for this procedure has also come from studies demonstrating benefit in patients with subarachnoid hemorrhage (SAH) from ruptured aneurysms^{11,12} and in those with cerebral edema from TBI.^{13,14} DC is not without complication; including epidural hematomas,

intra- and extra-axial hemorrhages, cerebral contusions, infections, seizures, sunken flap syndrome, and extra-axial cerebrospinal fluid (CSF) collections.^{15,16}

The recent DECRA trial¹⁷ has renewed interest in this controversial surgery. The trial demonstrated that after DC, patients had decreased ICP and the length of stay in the Intensive Care Unit but increased unfavorable outcomes. We believe the surgery remains a valuable option in appropriately identified patients; however, the DECRA trial pointed out the importance of complications in shaping the outcomes we provide to our patients. In order to improve outcomes, we as neurosurgeons must be aware of and capable of managing these complications. We present our experience with a common complication of DC and offer possible pathophysiologic mechanisms of its etiology as well as treatment algorithms. As reported, we have observed the phenomenon of continued accumulation of non-hemorrhagic extra-axial fluid collections^{18–21} and reviewed a series of 39 consecutive patients who underwent DC and identified those who developed these collections.

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2. Methods

We retrospectively identified all patients who underwent a DC over a 30-month period between 1 July 2007 and 31 December 2009. The study was performed under the supervision of the Partners Healthcare and Brigham and Women's Internal Review Board. We reviewed the operative reports, clinical data, and imaging for these patients. All patients were admitted to the Brigham and Women's Hospital Neuroscience Intensive Care Unit. Thirty-nine patients with SAH, TBI, stroke, and tumor who underwent DC were identified and included.

Although the procedures were performed by different surgeons, all patients underwent a frontotemporal-parietal DC and an expansive radial durotomy to allow for brain swelling. An anterior temporal lobectomy was not performed in any patient. The dura was not closed in a watertight fashion; instead, dural substitutes were used to cover the brain.

All patients with suspected hydrocephalus received frontal ventriculostomies for treatment. CSF drainage was titrated to a goal of approximately 360 cm³ per 24 hours. CT scans were obtained at regular intervals, averaging one imaging study every two days. All patients were followed until replacement of their cranial bone flaps or placement of a synthetic cranioplasty. No patient was lost to follow-up.

We determined the presence and resolution of extra-axial collections after review of CT scans. There is no established guideline to define the minimum thickness or volume of these extra-axial collections, so we therefore defined them as fluid collections exerting mass effect, greater than 5 mm in thickness.²² The appearance of these collections on CT scans had densities consistent with CSF, in order to exclude post-operative hematomas. Resolution of the collections was defined as the time to the first CT scan showing disappearance of the fluid.

Any patient who did not survive past the third POD was excluded from further analysis, as in our experience it takes at least three days for collections to occur. It is possible that these collections do not appear within the first three POD because we generally place subgaleal drains for two to three days following DC. There were five deaths (four TBI and one stroke) in our cohort prior to or on the third postoperative day, yielding a total of 34 patients for further analysis.

3. Results

Our results help illustrate the previously undefined entity which we have chosen to identify as Craniectomy-associated Progressive Extra-Axial Collections with Treated Hydrocephalus (CAPECTH). This name describes a clinical entity where extra-axial CSF collections occur in the presence of hydrocephalus treated actively with external ventricular drainage (EVD). Furthermore, the extra-axial CSF collections present with a clinically aggressive course and the development of mass effect on underlying brain structures.

Of the 34 patients who underwent DC, their diagnoses were: TBI in 14 patients, malignant middle cerebral artery infarction in 11 patients, aneurysmal SAH in seven patients, and tumor-associated cerebral edema in two patients. Analysis of the entire cohort demonstrated that 21/34 (62%) patients developed extra-axial collections after DC, but only 18 of the 21 had an EVD in place and would fit the criteria for CAPECTH (Table 1). These patients averaged approximately 10 to 15 cm³ of CSF drainage per hour. ICP control was not a significant issue in any of the patients with the combination of a DC and aggressive CSF drainage. There were transient ICP spikes above 20 mmHg in five patients, but no episode was sustained for over 10 minutes. This raises the issue of the

Table 1

Incidence of Craniectomy-Associated Progressive Extra-axial Collections with Treated Hydrocephalus (CAPECTH)

Diagnosis	No. of patients	Incidence of CAPECTH (%)
TBI	14	11/14 (79)
SAH	7	7/7 (100)
Ischemic stroke	11	0/11 (0)
Tumor	2	0/2 (0)

SAH = subarachnoid hemorrhage from aneurysm or arteriovenous malformation, TBI = traumatic brain injury, including subdural hematoma

meaning of ICP readings for patients with DC, but given these limitations, none of our patients had problems with ICP control. Since the patients with strokes and tumors did not have evidence of hydrocephalus, they were not included in the final analysis. Seven of seven patients (100%) with SAH, and 11 of 14 (79%) with TBI developed these collections despite ventricular drainage. When combined, 18/21 (86%) patients with either SAH or TBI developed extra-axial collections. A detailed list of characteristics, cause, progression and resolution of those 18 patients is presented in Table 2.

3.1. Traumatic brain injury

The average age of patients in the TBI group was 41 years (range 16–79 years) with 79% male and 21% female patients. Of the 14 patients who presented with TBI, six underwent immediate surgery for removal of a subdural hematoma and the bone flap was left off to allow for brain swelling. The remaining eight patients with TBI presented with generalized cerebral edema without a mass lesion, and did not undergo immediate surgery. They received a ventriculostomy for CSF drainage and ICP monitoring as well as aggressive medical management for ICP control. Medical therapy included placing the head of the bed at 30° to maximize venous outflow from the cranium, temperature control below 36.7 °C (98 °F), sedation and use of hyperosmotic therapy (20% mannitol and/or 23.4% sodium chloride). Failure of medical therapy was considered when all of these measures were exhausted with maximal CSF drainage, mild hypothermia, maximal sedation, serum osmolality >320 mOsm/kg, sodium of >160 meq/L, and persistently elevated ICP above 25 mmHg. The decision to operate was made by the neurosurgeon in conjunction with the critical care team. CAPECTH was observed in 11 of these 14 patients (78.5%) post-operatively.

3.2. Subarachnoid hemorrhage

In the group of patients with SAH, the average age was 52 years (range 33–65 years), with a female predominance (71%). DC was performed immediately in conjunction with aneurysm clipping in three patients. The decision to perform the DC at the same time as the aneurysm clipping was made based on the neurosurgeon's observation of the degree of cerebral edema. Four of the seven patients with SAH had the DC in a delayed fashion relative to the aneurysm clipping (on POD 4, 5, 5 and 6) secondary to intractable edema. All the patients were treated with an EVD prior to aneurysm clipping. Full medical management of elevated ICP was performed as previously described. No patient who had a DC at the time of original aneurysm clipping required further decompression. CAPECTH was observed in seven of the seven patients (100%) post-operatively.

3.3. Stroke

A total of 11 patients underwent DC for ischemic stroke (eight women and three men with an average age of 56 years [range 42–72 years]). The mean time from stroke to DC was three days

Table 2
Patients and characteristics of Craniectomy-Associated Progressive Extra-axial Collections with Treated Hydrocephalus (CAPECTH)

Patient No.	Diagnosis	Age (years)	Gender	External collection	EVD	Location of collection ^A	Appearance of collection (days) ^B	Shunt (POD)	Cranioplasty (POD)	Resolution of collection
1	SAH	54	F	Yes	Yes	IL	3	No	103	Sunken flap syndrome at time of cranioplasty
2	SAH	65	M	Yes	Yes	IL	4	84	21	After cranioplasty before shunt
3	SAH	33	F	Yes	Yes	IL	5	12	12	After cranioplasty-shunt
4	SAH	56	F	Yes	Yes	IL	2	12	12	After cranioplasty-shunt
5	SAH	42	F	Yes	Yes	IL	9	10	10	After cranioplasty-shunt
6	SAH	61	M	Yes	Yes	IL/IH	3 IL 3 IH	9	30	Sunken flap syndrome at time of cranioplasty
7	SAH	55	F	Yes	Yes	IL	40	14	43	After cranioplasty NOT with shunt
8	TBI	16	F	Yes	Yes	IL	5	17	85	Sunken flap syndrome at time of cranioplasty
9	TBI	27	M	Yes	Yes	IL/IL/IH ^C	6 IH 13 IL	18	57,61 ^D	Sunken flap syndrome at time of cranioplasty
10	TBI	24	M	Yes	Yes	IL	18	24	52	Sunken flap syndrome at time of cranioplasty
11	TBI	18	M	Yes	Yes	IL	6	No	120	Sunken flap syndrome at time of cranioplasty
12	TBI	43	F	Yes	Yes	IL	14	No	24	After cranioplasty
13	TBI	17	M	Yes	Yes	IL/CL/IH	14 IL 14 CL 14 IH	No	X	Persisted ^E
14	TBI	52	M	Yes	No	IL/CL	1	159	X	After shunt, prior to removal 2 weeks later ^F
15	TBI	50	M	Yes	Yes	IL	2	16,25,35,48	20	After cranioplasty ^G then recurred
16	TBI	62	M	Yes	Yes	IL/CL	11	No	40	After cranioplasty
17	TBI	50	M	Yes	Yes	IL	4	No	X	Persisted ^H
18	TBI	51	M	Yes	Yes	IL	1	22	18	After cranioplasty

^A Location of collections in relation to craniectomy: CL = contralateral, IH = interhemispheric, IL = ipsilateral.

^B When collections occurred in multiple compartments, appearance at each site is denoted separately.

^C Patient 9 had bilateral craniectomies and developed extra-axial collections on both sides as well as in interhemispheric space.

^D Patient 9 had cranioplasties for bilateral cranial defects at separate surgeries.

^E Patient 13 expired 22 days after craniectomy and never underwent shunt or cranioplasty.

^F Patient 14 had a delayed shunt on post-operative day (POD) 159 which was removed after becoming infected. He later died of PE.

^G Patient 15 had a complicated course described in detail in the results section.

^H Patient 17 expired on POD 7 due to cardiac event and had a persistent collection at that time.

(range 1–8 days). The etiology causing the medically intractable cerebral edema was a middle cerebral artery (MCA) territory infarction in all, with three of these patients having an associated anterior cerebral artery (ACA) territory infarction (27%). Although 11 patients underwent DC for stroke, only one received an EVD for post-operative ICP control. This patient did not develop any extra-axial collection and hence no patients in the stroke subgroup analysis fulfilled the criteria for CAPECTH.

3.4. Tumor

Two patients with brain tumors presented with rapid clinical deterioration and evidence of brainstem dysfunction from severe cerebral edema. Both patients were females, one 38 and the second 58 years of age. Both were taken emergently to the operating room for tumor resection, DC and ventriculostomy placement. Neither patient had elevated ICP post-operatively. CAPECTH was not observed in these patients.

3.5. Illustrative patients

3.5.1. Patient 15, with TBI

A 50-year-old male was struck by a car and presented with a Glasgow Coma Scale (GCS) score of 3. A CT scan of the head demonstrated numerous calvarial fractures extending through the skull base, with associated pneumocephalus, cortical SAH, a small left frontal intraparenchymal hemorrhage, minimal midline shift, and generalized cerebral edema with blurring of the gray–white junction. Treatment consisted of maximal medical management for ICP control including EVD placement, in the absence of an operative mass lesion. Despite these aggressive measures, the patient declined on hospital day 4, at which point he was taken to the operating room for a left decompressive craniectomy.

On POD 4 an extra-axial fluid collection was noted on a CT scan performed to evaluate a decline in the neurologic status (Fig. 1A).

At this time, the patient had a functioning EVD draining 380 cm³ of CSF daily. Shortly after this image, the patient developed a dilated, non-reactive left pupil. After mannitol administration and emergent percutaneous bedside drainage of the extra-axial collection, the patient's pupil became reactive.

Two days later, the patient's scalp flap was noted to be tense and once again the left pupil was fixed and dilated (Fig. 1B). At this point a ventricular catheter was placed into the subgaleal space and attached to a CSF drainage kit. The flap gradually became sunken with visible bone margins. Over the following 10 days several attempts at weaning the subgaleal drain resulted in increasing size of the extra-axial collection, tensing of the flap, and a decline of the neurologic condition. The patient required operative placement of a ventriculoperitoneal shunt (VPS) and cranioplasty (Fig. 1C).

This patient exemplified the aggressive nature of post-craniectomy extra-axial collections, which developed despite conventional treatment of hydrocephalus. This collection was progressive and clinically significant by indirectly causing brainstem compression. Ultimately, a combination of drainage, cranioplasty, and VPS was curative. Presumably, replacement of the bone flap served to restore normal cerebral pressure dynamics, thereafter enabling treatment of his altered CSF dynamics with a VPS.

3.5.2. Patient 2, with SAH

A 65-year-old female presented with a GCS score of 7T after collapsing at home. A CT angiogram demonstrated diffuse SAH, a right temporal hematoma and a 7 mm right posterior communicating aneurysm. An EVD was emergently placed and the patient underwent angiography with successful coiling of the aneurysm.

Despite aggressive ICP control for five days, the patient had a neurologic decline with a CT scan showing an enlarging hematoma and edema. She was taken to the operating room for a DC and evacuation of the right temporal hematoma. The craniectomy scalp flap became tense on POD 4 with the CT scan demonstrating

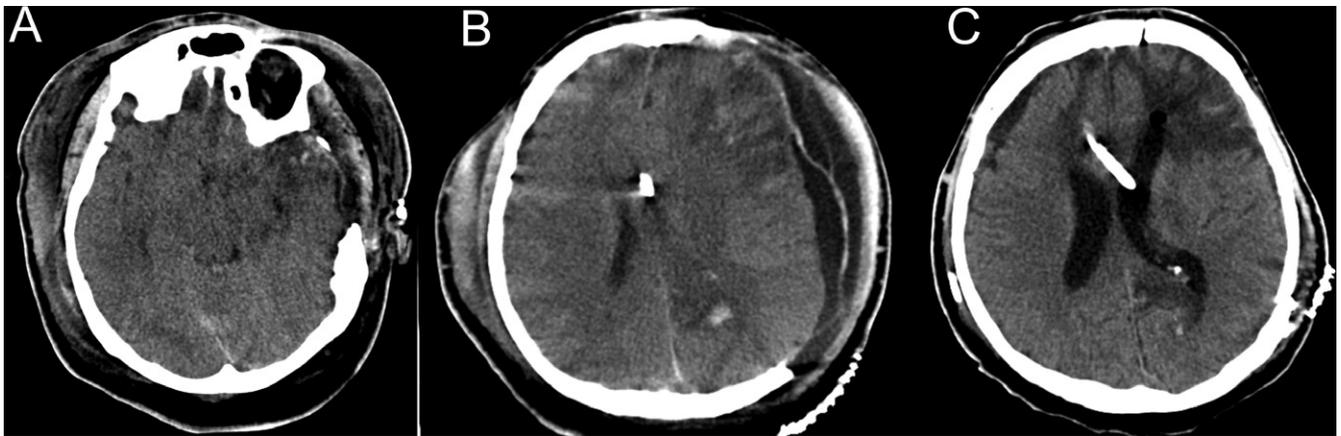


Fig. 1. Patient 15: a 50-year-old male with severe traumatic brain injury and hemorrhage who developed an extra-axial collection ipsilateral to the craniectomy. (A–C) Axial non-contrast head CT scans showing: (A) brainstem compression from mass effect; (B) a large collection slightly denser than cerebrospinal fluid with significant mass effect; and (C) the collection resolved after cranioplasty and ventriculoperitoneal shunt placement.

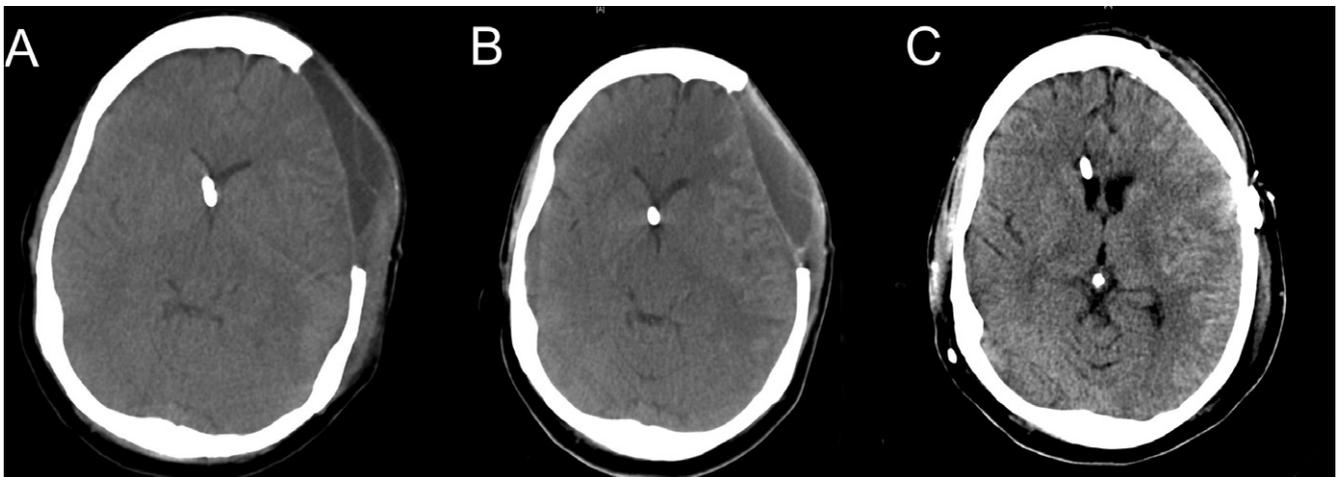


Fig. 2. Patient 3: a 33-year-old female with a ruptured left middle cerebral artery aneurysm who underwent subsequent hemicraniectomy for refractory elevated intracranial pressure and edema. (A–C) Axial non-contrast head CT scans showing: (A) an extra-axial collection ipsilateral to the craniectomy with minimal mass effect; (B) on post-operative day (POD) 8, continued progression of the collection with increased mass effect; and (C) the collection resolved on POD 12 after early intervention with cranioplasty and ventriculoperitoneal shunt placement.

development of an extra-axial CSF fluid collection. The patient was treated with aggressive ventricular drainage without resolution of her collection. On POD 21 from DC the patient was taken to the operating room for drainage of her collection and a cranioplasty.

The patient presented two months after discharge with complaint of a headache and a CT scan revealed significantly enlarged ventricles, for which a VPS was placed. Follow up imaging displayed stable ventricular volume and no extra-axial collections.

This patient demonstrates the benefits of early cranioplasty for the resolution of extra-axial collections. Ultimately, a VPS was required after restoration of normal CSF flow and pressure dynamics, unrelated to the collection itself. Fig. 2 demonstrates the progressive nature and mass effect of these collections in a similar patient (patient 3) with SAH from a ruptured aneurysm.

4. Discussion

In the past decade there has been a significant increase in the utilization of DC for increased ICP for a variety of etiologies. While some studies have shown no benefit,¹⁷ others have demonstrated improved outcomes for selected patients with SAH, TBI, and cerebral infarction.^{6–16} It is possible that the conclusions in the recently

completed DECRA trial are a reflection of the negative outcomes resulting from associated complications and a lack of a clear treatment paradigm for patients requiring surgical treatment for increased ICP. Multiple reports detail what are now well-recognized complications of the procedure including intraoperative blood loss, intra- and extra-axial hemorrhages, cerebral contusions, infections, seizures, sunken flap syndrome, and extra-axial CSF collections.^{15,16} Given the extra-axial nature of the CSF collections, this specific complication does not necessarily attract the appropriate level of concern. Since there is inherent heterogeneity of decompressive craniectomies, more studies are needed to better determine its utility for specific patient populations.

An issue of specific interest to our group has been the development of extra-axial collections following DC. Several different terms have been utilized to describe them, including subdural hygromas, external brain tamponade or external hydrocephalus.^{15,16,22–25} None of these terms appropriately represent the physiologic changes that underlie the development of these collections.

In our study 21/34 (62%) of the patients developed some extra-axial collections after DC, 18 of these 21 patients developing progressive collections despite ventricular drainage. The patients who developed progressive collections despite ventricular

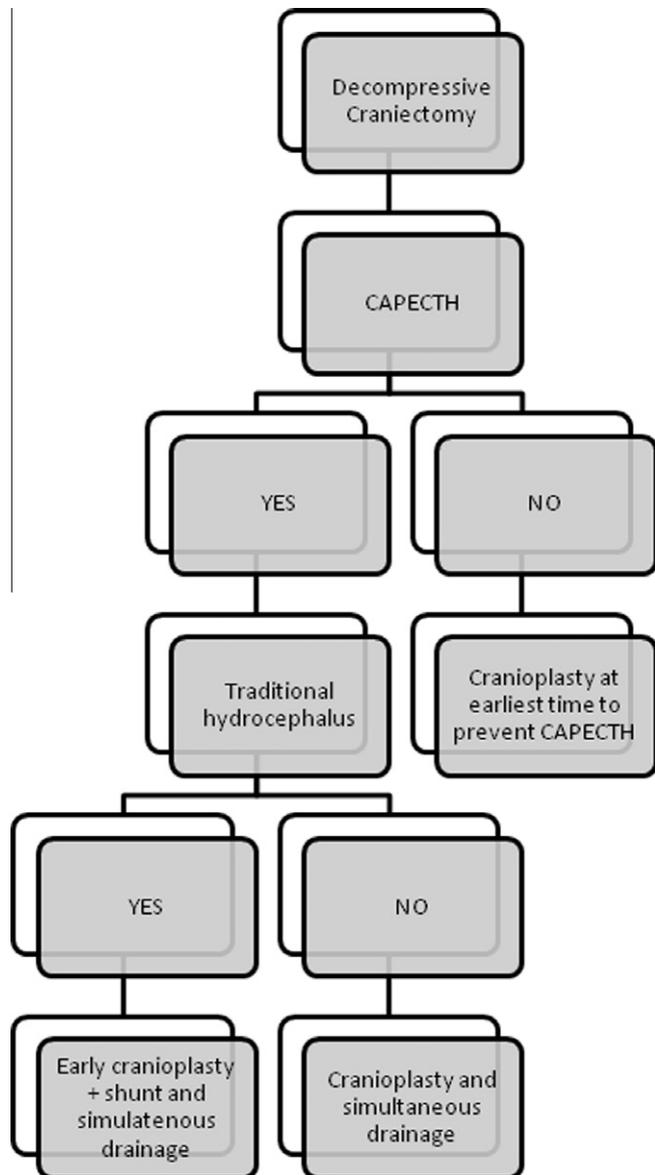


Fig. 3. A treatment algorithm for patients with Craniectomy-Associated Progressive Extra-Axial Collections with Treated Hydrocephalus (CAPECTH).

drainage were those with either SAH (seven patients), or TBI (11 patients). Of these 18 patients, six (33%) had clinical deterioration directly attributed to the collection. In all the remaining patients the collections had a clear effect on the continued poor clinical status of the patients, and were a clear impediment to recovery. We defined CAPECTH as progressively enlarging extra-axial CSF collections in the face of high output ventricular drainage (>300 cm³/day) and with no ventricular enlargement on imaging. The term specifically refers to these collections in the setting of treated hydrocephalus.

Other explanations have been put forth to explain the appearance of extra-axial collections after this operation.^{26–28} It has been theorized that decompressive surgery and durotomy perturb homeostatic pulsative CSF dynamics and allow egress of spinal fluid into the extra-axial compartments as an external manifestation of hydrocephalus. Our data, however, do not support this concept. It is clear that the patients who developed these progressive collections in our series did so despite treatment of hydrocephalus. We propose that the well-known subarachnoid inflammatory response triggered in SAH and TBI may create a partial disconnection

between the ventricular system and the subarachnoid space, causing CSF to be diverted into the extra-axial space rather than the ventricles. The creation of small arachnoid rents either by the underlying processes or the surgery itself may form a type of ball-valve mechanism that makes these collections enlarge progressively without spontaneous resolution. CSF that is formed in the fourth ventricle may be more likely to enter the extra-axial space than be drained through a patent ventriculostomy located in the lateral ventricle. This process perpetuates the further enlargement of these collections which can eventually produce mass effect with resultant clinical deterioration, as demonstrated in our illustrative patients.

In our experience, once CAPECTH develops, it can be resolved only with early bone flap replacement, as depicted in Fig. 3. It would appear that by re-establishing normal ICP dynamics, the usual flow of CSF is restored leading to resolution of the perturbation. Patients who demonstrate evidence of “traditional” hydrocephalus in addition to CAPECTH may require permanent ventricular CSF diversion. This observation is supported by the anecdotal lack of extra-axial collections in patients who undergo craniotomy as opposed to craniectomy. Cranioplasty is associated with its own well-described complications^{29–31}; however, we believe that prompt restitution of normal ICP dynamics is necessary in patients who have undergone craniectomy. The surgeon must decide on the proper timing of this corrective procedure in each individual, taking into consideration that it is imperative to resolve the intracranial hypertension that prompted the hemicraniectomy. In our experience, this can usually be accomplished in four to six weeks after the initial injury.

Our study attempts to define the pathophysiology and treatment paradigm for this important complication of a common procedure, but the results are limited by a small sample size and its retrospective nature. We recognize these limitations but believe that the conclusions have strong and applicable potential.

5. Conclusion

Complications following DC are well described^{15,16} and the development of extra-axial fluid collections has been one of the most vexing. These collections develop not as an external manifestation of communicating hydrocephalus, as has been hypothesized, but rather represent a unique phenomenon; CAPECTH. In our treatment algorithm, early cranioplasty can help prevent the formation and worsening of this condition, presumably by normalizing CSF dynamics. Patients with underlying hydrocephalus may still require permanent CSF diversion together with bone flap replacement. In order for neurosurgeons to continue to utilize this procedure we must not only better define the indications for DC but also recognize and manage the complications that may result from this important procedure.

Disclosure and Conflict of Interest

The authors have no disclosures or personal, financial or institutional interest in any of the drugs, materials, or devices described in this article.

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