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ORIGINAL ARTICLE

Intracranial Pressure Monitoring Alone: Not an Absolutely Reliable Tool after Decompressive Craniectomy for Traumatic Acute Subdural Hematoma

Sing Soon Sam[1], Che-Kuang Lin[1], Kin-Sang Iao[1], Lin-Hsue Yang[1]

[1]*Department of Surgery, Division of Neurosurgery, Far Eastern Memorial Hospital, Banqiao, New Taipei City 220, Taiwan, Republic of China*

Introduction: The monitoring of intracranial pressure (ICP) in traumatic brain injury (TBI) is important for postoperative care. In our clinical practice, we have found that neurological deterioration because of contralateral epidural hematoma (EDH) occurs despite normal ICP in patients who have undergone decompressive craniectomy (DC). This study was performed to elucidate the dilemmas associated with ICP monitoring after DC and the possible complementary role of intraoperative and immediate postoperative imaging studies. **Methods:** Patients who had received DC due to TBI during a 7-year period were retrospectively identified from our database and evaluated. Logistic regression analyses were used to evaluate the associations between patients. **Results:** Twenty patients had contralateral skull fractures. Five patients (5 of 10, 50%) who developed EDH on the ipsilateral side of the skull fracture underwent operations for EDH evacuation due to the deterioration of their clinical condition. The ICP was significantly lower ($P = 0.016$) in these patients compared with patients who did not undergo secondary surgery due to EDH. **Conclusions:** ICP monitoring alone cannot absolutely ensure early detection of contralateral space-occupying lesion after DC due to improvement in cerebral compliance. Imaging studies using brain computed tomography is beneficial for early detection of delayed EDH after DC in a high-risk skull fracture with contralateral acute subdural hematoma patients.

Key words: Intracranial pressure monitoring, decompressive craniectomy, traumatic acute subdural hematoma

INTRODUCTION

In recent years, decompressive craniectomy (DC) has been widely used to control increased intracranial pressure (IICP) resulting from traumatic brain injury (TBI). However, contralateral acute epidural hematoma (EDH) in a patient who has undergone DC for delayed subdural hematoma (SDH) has been reported with an incidence of 6%–30%.[1] Intracranial pressure (ICP) monitoring in TBI is important for the early detection of delayed hemorrhage and the management of intracranial hypertension. Unfortunately, although it is rare, delayed hemorrhage can be masked by lower-than-expected ICP values resulting from DC.

The monitoring of ICP is recommended in the Brain Trauma Foundation Guidelines for comatose patients who have sustained severe head injury.[2] In this group of patients, several evidence-based studies have shown that ICP monitoring is associated with significantly lower mortality compared with patients who do not receive ICP monitoring.[3,4] In our clinical practice, we have observed that neurological deterioration can occur despite normal ICP. We present several cases featuring deterioration of the neurological status or poor postoperative neurological recovery despite having ICP that was maintained within the normal range. In spite of normal ICP values, imaging may reveal a contralateral hemorrhage with mass effect and even uncal herniation.

The relationship between ICP and delayed EDH after DC will be discussed. The goal of this study is to elucidate the dilemmas associated with ICP monitoring in the management of acute SDH after DC and the possible complementary role of intraoperative and immediate postoperative imaging studies.

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Corresponding Author: Dr. Lin-Hsue Yang, Department of Surgery, Division of Neurosurgery, Far Eastern Memorial Hospital, No. 21, Section 2, Nanya South Road, Banqiao, New Taipei City 220, Taiwan, Republic of China. Tel: +886960587896; Fax: +886-2-77281317. E-mail: yang68744@gmail.com

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METHODS

This study protocol was approved by the Institutional Review Board, and because of the retrospective nature, the requirement of informed patient consent was waived. From 2008 to 2013, all patients suffered from TBI and underwent DC were retrospectively identified from our database. This information was obtained by a review of the medical records and the radiographs. We arranged DC for patients who suffered from traumatic SDH accompanied with midline shift for more than 0.5 cm or uncal herniation with brainstem compression. The dimensions of DC in our cases were approximately 12 cm in the anteroposterior and 9 cm in the superoinferior direction. After the procedure, fentanyl and midazolam were prescribed with infusion pump continuously for all patients. We kept the patient in deep sedation status according to the Richmond Agitation-Sedation Scale. Mannitol was also given for ICP control routinely.

Patients who meet the selection criteria for DC and underwent postoperative computed tomography (CT) during hospitalization were included in this study. Postoperative CT was not performed routinely for all patients, including those with good recovery after the operation. These patients were excluded from this study. Patients with severe brain injury who were not suitable for DC due to their poor condition were not in our study.

Two kinds of ICP monitor were used for ICP monitoring during DC routinely. A Camino® or Codman® ICP monitor was used for the direct measurement of ICP in the brain parenchyma or the subdural space. All the monitors placed ipsilateral to DC.

The Mann–Whitney U-test and Chi-square test were used to compare characteristics of patients treated with or without a second operation for contralateral delayed EDH. Logistic regression analyses of the total sample were used to evaluate the associations between ages, gender, presence of EDH before the operation, changes in ICP after the operation, and score on the Glasgow Outcome Scale (GOS) 1 year after injury. The GOS is assigned on a scale of 1–5: 1 (death), 2 (persistent vegetative state), 3 (severe disability), 4 (moderate disability), and 5 (good recovery).[5] All statistical tests with $P < 0.05$ were considered statistically significant. Analyses were performed using IBM Statistical Package for the Social Sciences Statistics version 20 software.

RESULTS

A total of 790 patients who received DC because of TBI were review retrospectively. Twenty-one of them underwent postoperative CT during hospitalization were included for logistic regression analyses. Almost all of them (20 of 21, 95.24%) had a contralateral skull fracture. Ten patients (47.62%) initially developed EDH on the ipsilateral side of the skull fracture initially. Five of them (50%) underwent operations for EDH evacuation due to progressive enlargement of the EDH with mass effect [Figure 1]. Patients' characteristics, ICP after craniectomy, and outcome results are summarized in Table 1. Patients were divided into two groups: Delayed contralateral EDH occurred in eleven patients (11 of 21, 52.38%), and the others (10 of 21, 47.62%) showed no evidence of EDH on the first brain CT. The mean age was 38.38 ± 19.64 years (range 19–78 years), and

Table 1: Clinical characteristics and outcome after decompressive craniectomy

Characteristics	No contralateral EDH	Contralateral EDH	*P*
Number of patients	11	10	
Skull fracture	10	10	0.329
Sex (male/female)	5/6	5/5	0.835
Age			
Mean±SD	44.73±18.89	52.4±20.64	0.436
Range	19-78	23-76	
Initial GCS			
Mean±SD	8.91±3.39	8.8±3.99	0.988
Range	3-14	3-13	
ICI (h)			
Mean±SD	7.05±15.67	0.98±0.56	0.822
Range	0.42-52	0.42-2.5	
ICP			
Mean±SD	9.6±9.48	13.1±5.92	0.109
Range	1-34	6-22	
GOS (*n*)*			
5	3	3	0.385
4	3	2	
3	0	2	
2	2	2	
1	2	0	
Second operation (*n*)	0	5	

*Loss data for some patients. ICP = The exact value of ICP when wound closure after DC; ICI = The interval from injury to CT completion; GOS = 1 year after injury - 1 = Death; 2 = Persistent vegetative state; 3 = Severe disability; 4 = Moderate disability; and 5 = Good recovery; second operation, a patient who received operation for EDH evacuation. EDH = Epidural hematoma; SD = Standard deviation; ICP = Intracranial pressure; GCS = Glasgow Coma Scale; DC = Decompressive craniectomy; GOS = Glasgow Outcome Scale; CT = Computed tomography

only 38.1% were age ≥60 years. No statistically significant differences in age, gender, or GOS 1 year after injury were observed between these groups. Seventeen patients (80.95%) were sent to our emergency department and received brain CT within 1 h after injury. The patients were evaluated using the Glasgow Coma Scale (GCS) and the results were recorded. No significant difference was observed in the initial GCS score between EDH and without-EDH groups. The postoperative ICPs of patients who suffered from blunt head injury with acute SDH and received DC are also recorded in Table 1. No significant difference (P = 0.109) in ICP were found.

Postoperative brain CT was not routinely performed for patients with good recovery after DC and was reserved for patients suffering from persistently IICP, poor consciousness recovery, seizure, or pupil dilatation. Table 2 demonstrates the patient characteristics, serial change in ICP after craniectomy, the timing of brain CT, and the outcomes of the EDH group. Fifty percent of patient who suffered from EDH progression with mass effect and uncal herniation required an operation for EDH evacuation. The serial change in ICP was recorded [Table 3]. No significant ICP elevation was observed despite clinical deterioration. Paradoxically, the ICP was significantly lower (P = 0.016) in the patients suffering from clinical deterioration and needing a secondary operation for contralateral EDH removal. The mean ICP of patients with EDH but without secondary surgery was 30.50 ± 12.40 mmHg (range 20–46 mmHg). The IICP of these groups of patients were not related with EDH but an edematous change of the side of DC because of brain contusion. The mean ICP of patients with EDH but needing a second operation for EDH evacuation was 13.60 ± 4.56 mmHg (range 7–18 mmHg). Three postoperative brain CTs were performed after DC due to

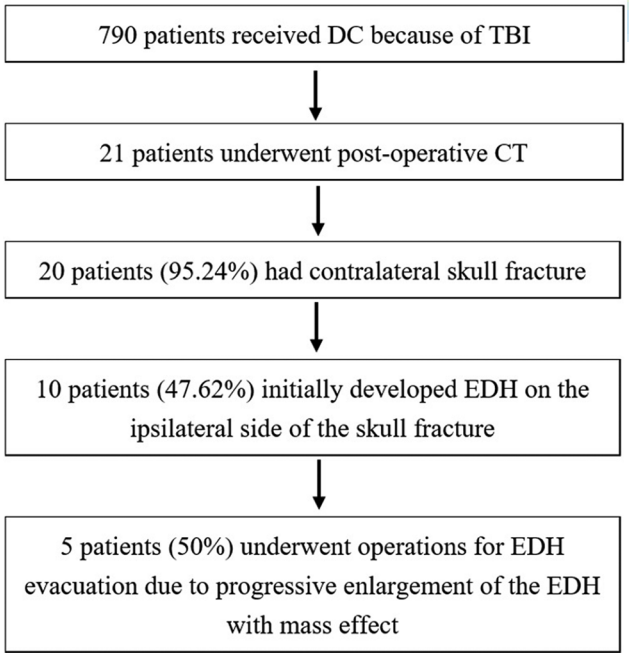

Figure 1: Flow diagram showing patient selection process

Table 2: Clinical characteristics of the patients with or without the secondary surgery for contralateral epidural hematoma

Characteristics	Patients without secondary surgery	Patients with secondary surgery	*P*
Number of patients	5	5	
Sex (male/female)	4/1	1/4	0.058
Age			
Mean±SD	54.6±17.97	50.2±24.97	0.738
Range	36-76	23-71	
Initial GCS			
Mean±SD	7.4±5.13	10.2±2.17	0.508
Range	3-13	7-13	
ICP1 (mmHg)			
Mean±SD	14.4±7.77	11.8±3.77	0.786
Range	6-22	8-18	
ICP2 (mmHg)			
Mean±SD	30.5±12.4	13.6±4.56	0.016
Range	20-46	7-18	
GOS (*n*)*			
5	2	1	0.522
4	1	1	
3	1	1	
2	0	2	
1	0	0	
ICI (h)			
Mean±SD	0.9±0.11	1.05±0.83	0.373
Range	0.75-1	0.42-2.5	
CCI (h)			
Mean±SD	83±126.5	51.7±67.11	0.389
Range	7-307	0.5-137.5	

*Loss data for some patients. ICP1 = The exact value of the ICP when wound closure after DC; ICP2 = Value of ICP when receiving the second CT; GOS = 1 year after injury - 1 = Death; 2 = Persistent vegetative state; 3 = Severe disability; 4 = Moderate disability; and 5 = Good recovery; ICI = The interval from injury to CT completion; CCI = Craniectomy to second CT interval. SD = Standard deviation; ICP = Intracranial pressure; GCS = Glasgow Coma Scale; DC = Decompressive craniectomy; GOS = Glasgow Outcome Scale

Table 3: Intracranial pressure change of the patient who received the second operation for epidural hematoma

Case	Sex	Age	ICP1 (mmHg)	ICP2 (mmHg)	ICP3 (mmHg)	CCI (h)	Reason for CT
1	Female	70	8	17	12	4.5	PD
2	Male	23	18	18	20	0.5	PD
3	Female	64	10	11	2	4.5	PD
4	Female	23	11	15	5	111.5	Consciousness
5	Female	71	12	7	1	137.5	Consciousness

ICP1 = ICP after decompressive craniectomy; ICP2 = ICP during the second CT; ICP3 = ICP after the second operation for EDH; CCI = Craniectomy to second CT interval; Consciousness = Poor recovery of consciousness. CT = Computed tomography; ICP = Intracerbral pressure; EDH = Epidural hematoma; PD = Pupil dilatation; CCI = Controlled cortical impact

pupil dilatation. The other two patients were found to have a contralateral EDH with mass effect during 111.5 h and 137.5 h after DC, respectively. No pupil dilatation was observed, but poor recovery of consciousness was noted at that time. There were no statistically significant different in age, gender, or GOS 1 year after injury in these EDH groups. The ICP (range 1–20 mmHg) after the second operation for EDH removal was also record in Table 3.

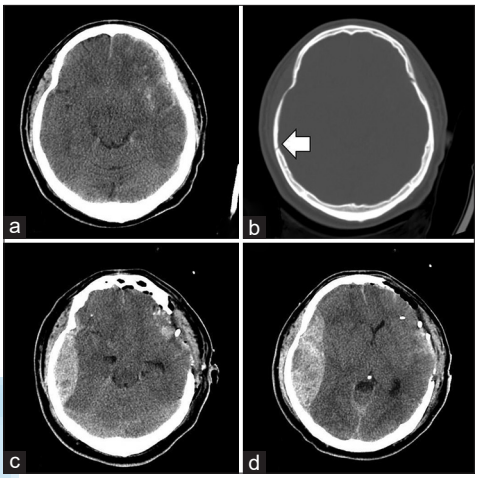

Figure 2: A 23-year-old man suffered from head injury after fall from 3 meters. (a) Axial noncontrast computed tomography illustrates left frontotemporal contusion subdural hematoma, subarachnoid hemorrhage and left to right midline shift with uncal herniation. (b) Right, temporal skull fracture (white arrow) without epidural hematoma was observed at initial computed tomography. (c and d) After decompressive craniectomy for left-sided, brain computed tomography was arranged due to right pupil dilatation. Right frontotemporal epidural hematoma with midline shift to left develop without significant changes of intracranial pressure

DISCUSSION

For severe TBI, DC is an effective and life-saving procedure for lowering ICP, reducing the mortality rate and improving neurological outcomes. [6,7] In the case series of Su *et al*.,[8] younger patients had a higher incidence of contralateral EDH after decompressive surgery for acute SDH. This is explained by the increased adherence of the dura to the inner skull table in elderly. [8,9] Decompressive surgery is a predisposing factor for the development of contralateral EDH.[9-11] Besides this, delayed EDH may be caused by a loss of the tamponade effect, meningeal artery injury with hemorrhagic expansion, venous injury with low tension bleeding, or skull fracture.[9,12,13] In this study, young age was not a risk factor for contralateral EDH. Half of patients with EDH on initial brain CT were older than 60 years.

In patients with severe head injury, IICP has been recognized as one of the most important factors affecting morbidity and mortality rates. Aggressive ICP monitoring and treatment of patients with severe TBI is associated with a statistically significant improvement in outcome.[14] In recent years, several different types of fiberoptic monitoring systems have become available. The transducer can be positioned in the epidural space, subdural space, brain parenchyma, or ventricle. [15-19] In this study, ICP monitor was placed in the brain parenchyma or the subdural space for measurement. According to the study of Gray *et al*., ICP had no effect on the differential performance of the microsensors in the parenchymal or subdural compartments. [20] The aims of ICP monitoring are to allow early detection of secondary hemorrhage, to guide anti-IICP therapies, and optimize cerebral perfusion. [21] Although early detection of delayed contralateral EDH and treatment promptly may improve the outcome, the clinical findings associated with these patients should be evaluated carefully. [8,9] In our clinical practice, we have found that ICP monitoring cannot detect the contralateral EDH early. The ICP remained lower than 20 mmHg and even decreased paradoxically in spite of contralateral EDH progression. DC enlarges the intracranial space so that the swollen cerebral hemisphere can expand beyond its cranial limits, avoiding the progression of brain herniation. [22] The advantages of DC are that it increases the total intracranial volume and compliance to accommodate posttraumatic brain edema on the ipsilateral side. However, it is precisely this advantage that results in a blind spot, allowing a new contralateral mass lesion to occur and progress to uncal herniation without a significant ICP change. ICP monitoring is

a reliable tool in an intact skull, but it loses its sensitivity after DC. Most patients have lower ICP after the second operation for EDH removal, but some of them have not. Figure 2 illustrated a 23-year-old man who suffered from head injury after fall from 3 meters. Right frontotemporal EDH with uncal herniation developed without significant changes of ICP after DC. No obvious ICP change of this patient was observed even after EDH removal.

Adequate decompression after craniectomy, age-associated cerebral atrophy, or other reasons that can result in increasing intracranial compliance can relieve the tamponade effect on a contralateral expanding mass lesion and cause false negatives in ICP monitoring. To improve the early detection rate of contralateral EDH progression, intra- or post-operative high-resolution ultrasonography or brain CT should be performed regularly for the high-risk patient [Figure 3]. In this study, acute EDH was found in a patient who received DC and had ICP readings lower than 20 mmHg. A relatively low ICP may be a risk factor for delayed EDH after DC. In our clinical practice, three patients were to have pupil dilatation due to uncal herniation within 4.5 h. According to the result, we suggested postoperative high-resolution ultrasonography 4 h after DC, and brain CT if a contralateral EDH is found using ultrasonography. Important clinical findings included intraoperative brain swelling, pupil dilatation, postoperative neurological deterioration, seizure, and intractable IICP should be proposed as warning signs that should alert suspicion.[8,13,23-25] Brain CT should be arranged promptly for these patients.

Our study has several limitations, including its retrospective study design. The small sample size and loss of data for some patients prevented more detailed statistical analysis. Some older-age patients did not undergo craniectomy due to their poor medical condition, introducing a selection bias to this study.

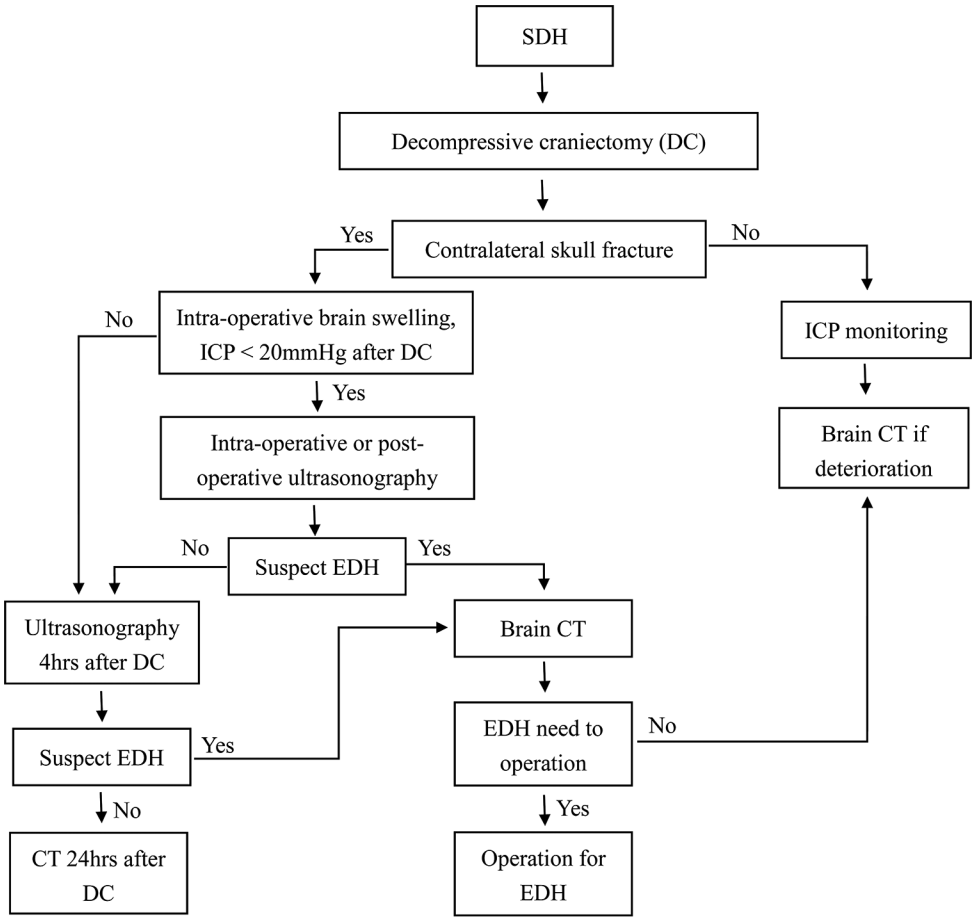

Figure 3: Intra- or post-operative high-resolution ultrasonography should be performed regularly for high-risk patient. Brain computed tomography could be arranged if contralateral epidural hemorrhage was found under ultrasonography. SDH: Subdural hematoma; ICP: Intracranial pressure

CONCLUSIONS

ICP monitoring alone cannot absolutely ensure early detection of the contralateral space-occupying lesion after DC due to improvement in cerebral compliance. The Early imaging study is beneficial for diagnosis of delayed EDH in traumatic acute SDH concomitant with contralateral skull fracture underwent DC and ICP monitoring.

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Conflicts of interest

There are no conflicts of interest.

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