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Original Article

Is basal cisternostomy in traumatic brain injury a need of hour or white elephant – A randomized trial to answer

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ABSTRACT

Background: Basal cisternostomy (BC) recently emerged as an adjuvant/alternative procedure to decompressive craniectomy (DC) in traumatic brain injuries (TBIs) with its potential to effectively reduce both intracranial pressure (ICP) and brain edema. However, its role in TBI is not yet established in the true sense and with clarity. The objective of the present study was to evaluate the effect of adjuvant BC on ICP, mortality, and clinicoradiological outcome.

Methods: A single-center randomized control trial was conducted. Fifty patients were assigned to each DC-group and DC+BC-group. Randomization was done using the sealed envelope method. Both groups were followed in the postoperative period to compare the impact of surgery on ICP, radiological changes, and clinical outcome (mortality, days on ventilator/in intensive care unit (ICU), and Glasgow outcome scale-extended (GOS-E) at 12 weeks).

Results: Both groups were comparable in terms of preoperative clinicoradiological characteristics. On postoperative days 1, 2, and 3, mean ICP was significantly low in the DC+BC-group ($P < 0.0001$). The decline in ICP in the DC+BC-group was significant in both moderate and severe TBI patients. In comparison, DC+BC-group has a shorter duration of mechanical ventilation/ICU stay and significantly better GOS-E score at 12 weeks ($P < 0.0001^*$). The mortality rate was less in the DC+BC-group (48%) as compared to the DC-group (64%). Among radiological features, mean midline shift and mean outward brain herniation were significantly less in the DC+BC group. Bone-flap replacement was possible in ten patients of DC+BC-group at the time of primary surgery.

Conclusion: Results of our study indicated that BC is beneficial in reducing both ICP and brain edema, which translates into favorable clinicoradiological outcomes.

Keywords: Basal cisternostomy, Intracranial pressure, Traumatic brain injury

INTRODUCTION

Traumatic brain injury (TBI) is one of the leading causes of morbidity and mortality, especially in the younger age group,[11] leading to a substantial burden on the healthcare system. The pathogenesis of traumatic brain injury consists of two parts – primary and secondary. The goal of treatment of TBI is the prevention of secondary brain injury, which develops in response to a rise in intracranial pressure (ICP) and brain edema.[12] The current best surgical procedure for TBI is decompressive craniectomy (DC), but it's only proven effect is that it decreases ICP with no effect on brain edema. In reality, it provides an outlet for the edematous brain to expand, causing axonal stretch and irreversible damage, which manifests as a vegetative state and disabilities.[2-4]

In addition, DC is associated with many complications and requires a second surgery in the form of cranioplasty. In view of the above, basal cisternostomy (BC) was introduced by Cherian *et al.*[2,4] for TBI. It is hypothesized that BC has the potential to reduce both ICP and cerebral edema. However, the role and efficacy of BC have not been clearly established in the context of TBI patients. Limited studies have been done to evaluate the efficacy of BC, and the study design in most of the studies was retrospective.[5,7,10,13] Only published randomized controlled study was done by Chandra *et al.*[1] which included 50 patients, where 25 patients were assigned in each group and where randomization was done preoperatively. Therefore, we conducted a randomized controlled study to evaluate the contribution of cisternal drainage on surgical outcomes in TBI patients.

MATERIALS AND METHODS

This was a single-center randomized controlled study conducted at the Department of Neurosurgery, King George's Medical University, Lucknow, Uttar Pradesh, India, from February 2022 to April 2023. The study was approved by the Institutional Ethical Committee (Registration no: ECR/262/Inst/UP/2013/RR-19). The study was also registered with the Central Trial Registry of India (CTRI reference no: CTRI/2022/04/042144).

Inclusion criteria

Following were the inclusion criteria.

Patients of age ≥18 years presenting with TBI who were planned for DC (as per institutional protocol) and whose brain was bulging even after evacuation of the traumatic lesion (hematoma and contused brain).

We considered it a brain bulge when the brain surface remained above the level of the inner table of the skull bone of the craniectomy site after eliminating the effect of gravity [Figure 1].

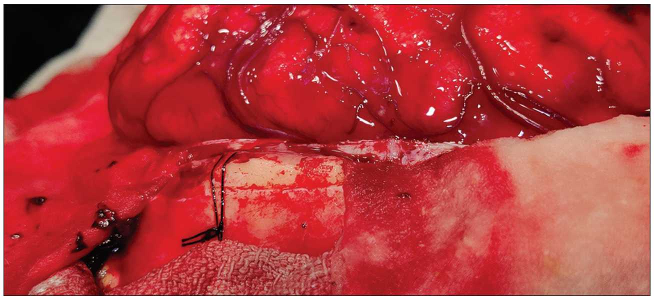

Figure 1: Brain bulge (brain parenchyma is above the level of the inner table of the skull).

Our institutional clinicoradiological criteria for planning DC in TBI were the followings:

1. Acute subdural hematoma (SDH) with a maximum thickness of ≥ 10 mm or mass effect and midline shift >5 mm in computed tomography (CT) head irrespective of Glasgow coma scale (GCS) score.
2. Patients with GCS ≤ 9 having acute SDH thickness <10 mm and midline shift of <5 mm whose GCS score decreased by two or more points after hospital admission.
3. Patients with GCS score of 6–8 and frontal and/or temporal contusions of >20 cc in volume with mass effect and midline shift > 5 mm or cisternal compression on CT head.
4. Patients with any supratentorial contusion >50 cc in volume on CT head irrespective of GCS score.

Exclusion criteria

Exclusion criteria were the following: (1) Hemodynamic instability, (2) pregnant females, (3) coagulopathy, (4) brain stem dysfunction and signs of irreversible brain damage (B/L fixed dilated pupils), (5) GCS score 3, (6) acute infarcts with mass effect, (7) extradural hemorrhage/chronic SDH/posterior fossa bleed, (8) penetrating brain injuries/brain matter leak, (9) non-traumatic subarachnoid hemorrhage (SAH)/intraparenchymal bleeds, and (10) patients for whom consent could not be obtained.

At admission, patients received treatment as per institutional protocol, and data related to trauma was collected. GCS and pupillary reaction were examined at admission and just before surgery. Non-contrast computed tomography (NCCT) head was done. The following details were noted: (1) Side and site of contusion/hematoma, (2) presence or absence of traumatic SAH and intracerebral hemorrhage (IVH), (3) status of cisternal space, (4) midline shift, and (5) presence of ischemia/infarct. Rotterdam scoring was calculated. Patients were divided into three classes – severe, moderate, and mild TBI.

Randomization

The randomization sequence was generated before the start of the study by a computer-generated set of random numbers. Treatment allocation was done by the opaque sealed envelope method opened by the operation theater (OT) nurse in charge [Figure 2].

Two groups

A total of 100 patients were included in the study. Fifty patients were assigned to the DC group alone and 50 patients to the DC+BC group. Written informed consent from family members of each patient included in the study was taken.

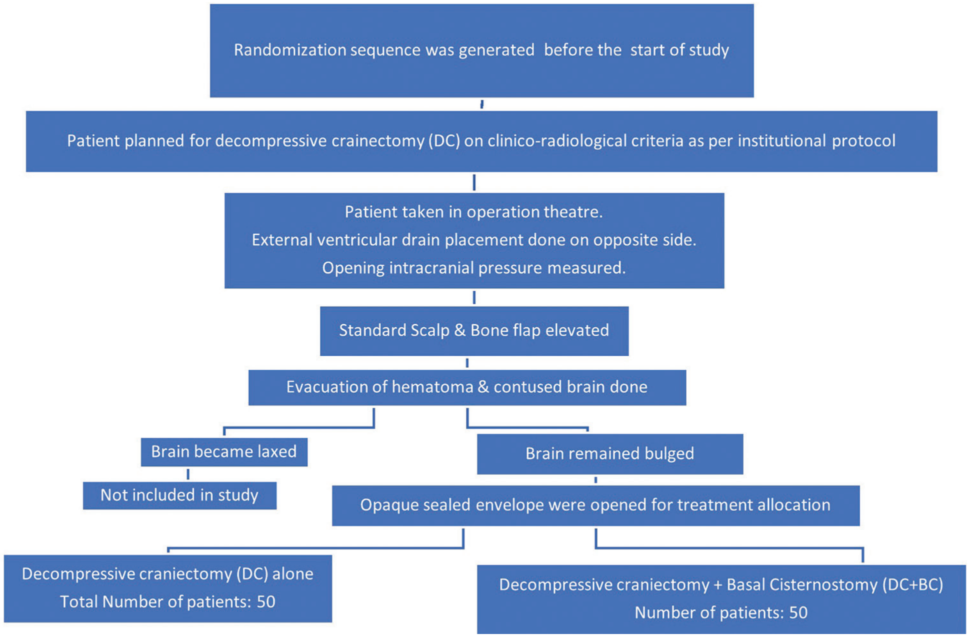

Figure 2: Flow chart showing the method of randomization.

Surgical steps for DC Group

Surgeries were performed under general anesthesia. External ventricular drain (EVD) placement was done on the opposite side of the surgical site for measuring ICP (Not used for draining cerebrospinal fluid (CSF) in either group).

The patient was positioned supine with the head rotated approximately 20–30° toward the opposite side. A standard question mark or reverse question mark bone-deep incision was used. The scalp flap, along with the periosteum, was elevated off the skull and reflected anteriorly. Temporalis muscle was reflected anteroinferiorly. A standard craniotomy of 15 cm × 12 cm was obtained. The temporal bone is nibbled to obtain a craniotomy that is flush with the middle fossa. The sphenoid ridge was cut to the lateral edge of the superior orbital fissure using Kerrison rongeur to visualize the orbitomeningeal fold and artery. The orbitomeningeal band was cut to unfurl the frontal and temporal dura. After that, the dura was opened in a C-shaped manner, and hematoma (Acute SDH/contusion) evacuation was done. After that, standard lax duraplasty was done with autologous pericranium. Temporalis muscle was sutured, followed by skin closure, which was done in two layers (galea and skin). The bone flap was placed in a subcutaneous pouch made in the anterior abdominal wall.

Surgical steps for DC+BC group

All steps till the evacuation of hematoma were similar to the DC group. After the evacuation of the hematoma, a lateral subfrontal approach was used to reach basal cisterns. The frontal lobe was retracted gently, and the olfactory tract was identified. We used dynamic retraction with the help of a suction cannula of small caliber and bayonet-shaped long micro forceps in place of a fixed retraction system. Inter-optic, optico-carotid, and lateral carotid cisterns were identified and opened. Liliequist membrane was perforated through the optico-carotid window or the lateral carotid window to open interpeduncular and prepontine cisterns, and the basilar artery is visualized [Figure 3]. Thorough irrigation of all cisterns was done to clear out the subarachnoid blood or clots blocking the cisterns. No cisternal drain was put in to avoid any bias during the comparison of ICP in both groups. The surgical incision was closed in a manner similar to the DC group.

Postoperative neurocritical care, ICP monitoring, and outcome assessment

Patients of both groups were shifted to the intensive care unit (ICU) after the surgery for standard neurocritical care management. ICP monitoring was done for 72 h in the postoperative period with the help of EVD. The EVD was kept *in situ* for 72 h and used exclusively for measuring ICP. CSF drainage through EVD was not done in either group to avoid its lowering effect on ICP and its confounding effect on the result. All patients were sedated and mechanically ventilated, aiming to keep PaO_2 and $PaCO_2$ between 90 and 100 mmHg and 36 and 40 mmHg, respectively. Cerebral perfusion pressure was maintained between 60 and 70 mmHg with the use of isotonic fluids and vasopressors. Metabolic control included the maintenance of normoglycemia and normothermia. In our study, we did not

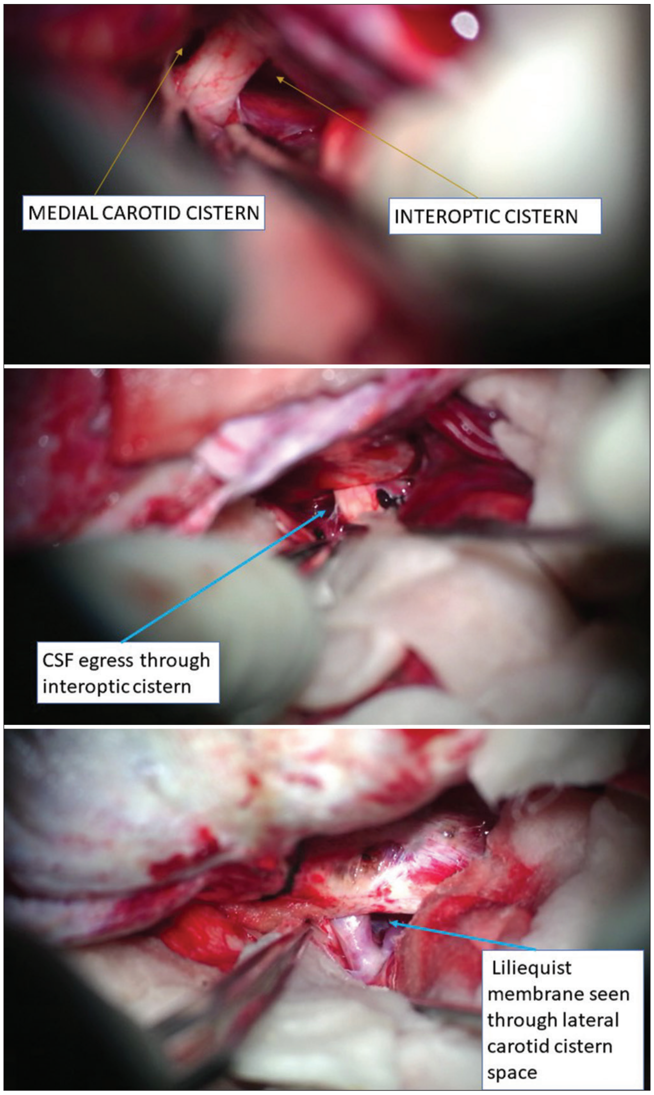

Figure 3: Surgical exposure of basal cisterns during basal cisternostomy.

place PbtO2 probes due to constraints of resources. If the ICP reading remained superior to 20 mmHg for more than 5 min, osmotherapy consisting of intravenous bolus (over 20 min) of 20% mannitol (0.5 g/kg) was administered. The numbers of osmotherapy bolus required in both groups were calculated separately for comparison. Two groups were compared for the total number of days in ICU/on mechanical ventilation, the in-hospital mortality rate (related to TBI sequelae), GCS, and GOS-E at 12 weeks follow-up. Postoperative CT scans were done on postoperative days 0, 3, and 7 or as and when required. Midline shift and brain outward herniation were noted. Postoperative complication (clinical/radiological) was also noted down.

Statistical analysis

Collected data with proper headings were entered in a Microsoft Excel 2019 (Microsoft Corporation, Redmond, Washington, USA) datasheet. Data were expressed as mean ± standard deviation for continuous variables. Data were represented as counts and percentages for categorical variables. Student *t*-test was used to make a comparison of means between 2 groups, in case data were normally distributed; else, the Mann–Whitney U-test was used. The chi-square test was used to compare categorical variables. For statistical analysis, IBM SPSS Version 21.0 (IBM, Corporation, Armonk, New York, USA) was used.

RESULTS

A total of 100 patients who fulfilled the inclusion criteria were included in the study. Most of the patients in both groups were in low GCS (4–8) at the time of admission. In the DC group, 37 patients, and in the DC+BC-group, 43 patients had severe TBI. A total of 13 patients in the DC group and seven patients in the DC+ BC-group had moderate TBI. No patient in either group had mild TBI. On data analysis, the two groups were homogenous for preoperative clinicoradiological characteristics (age and sex, duration between trauma and admission, GCS at admission, type and size/volume of hemorrhage, Midline shift, status of cisternal space, presence of ischemia/infarct in vascular territories, and Rotterdam score in preoperative NCCT head) [Table 1].

Duration of surgical procedures

The mean duration of surgery was 189 min in the DC group and 206.6 min in the DC+BC group ($P < 0.0001^*$). Hence, on average, the extra time needed to perform cisternostomy was approximately 15–20 min. The bone flap was replaced at the craniotomy site during primary surgery in ten patients out of 50 patients randomized in the DC+BC group.

Intracranial pressure

The mean opening intracranial pressure was 26.52 ± 1.18 mm of Hg in the DC group and 27.46 ± 1.13 mm of Hg in the DC-BC group ($P = 0.773$, which was insignificant). Mean ICP was significantly low in DC+BC group on postoperative day-1, day-2, and day-3 as compared to DC group having $P < 0.0001^*$, $P < 0.0001^*$, and $P < 0.049^*$, respectively on day-1, day-2, and day-3 [Table 2]. On subgroup analysis based on the severity of TBI (moderate and severe TBI), we observed that mean ICP control was better in both moderate and severe TBI patients in the DC+BC group as compared to the DC group [Figure 4].

We further analyzed the mean ICP trends in two subsets in the DC+BC group, a first subset of ten patients who underwent bone flap replacement intraoperatively due to sufficient brain laxity after BC and a second subset of 40 patients in whom bone flap could not be replaced. We found no statistical difference in mean ICP in these two subsets on day one and day 2 ($P = 0.638$ and 0.734,

Table 1: Comparison of preoperative clinicoradiologic baseline characteristics.

Preoperative characteristics	DC	DC+BC	*P*-value
Mean age in years (SD)	40.42±12.86	40.06±12.59	0.787
Male: Female	37:13	34:16	0.508
Mean GCS at admission	6.76	6.70	0.133
Mean Rotterdam score	3.9	3.7	0.458
Midline shift in mm (SD)	9.21±2.35	8.49±1.77	0.569
Hemorrhagic lesions			
SDH	13 (26%)	10 (20%)	
ICH	14 (28%)	15 (30%)	0.775
SDH+ICH	23 (46%)	25 (50%)	
Mean thickness of SDH in mm	13.02±0.84	14.20±0.75	0.98
Mean volume of ICH in cm^3 (SD)	37.89±(2.95)	42.52±(3.67)	0.304
Infarct in vascular territories	9 (18%)	11 (22%)	0.887
The mean time gap between admission to the start of surgery (in hours)	16.34±(1.89)	17.04±(1.98)	0.774

DC: Decompressive craniectomy, BC: Basal cisternostomy, SD: Standard deviation, SDH: Subdural hematoma, ICH: Intracerebral hemorrhage, GCS: Glasgow coma scale

Table 2: Comparison for intracranial pressure in postoperative period days 1, 2, and 3.

ICP in mmHg on postoperative day	Study group	*N*	Mean	Std. deviation	Std. error mean	*P*-value
Day: 1	DC	50	17.4820	1.04074	0.14718	<0.0001*
	DC+BC	50	11.8300	1.44211	0.20395	
Day: 2	DC	42	17.4143	1.06142	0.16378	<0.0001*
	DC+BC	46	11.7500	1.48365	0.21875	
Day: 3	DC	34	16.9441	1.10979	0.19033	0.049*
	DC+BC	38	11.2421	1.37027	0.22229	

DC: Decompressive craniectomy, BC: Basal cisternostomy, ICP: Intracranial pressure, *: Significant *P*-value

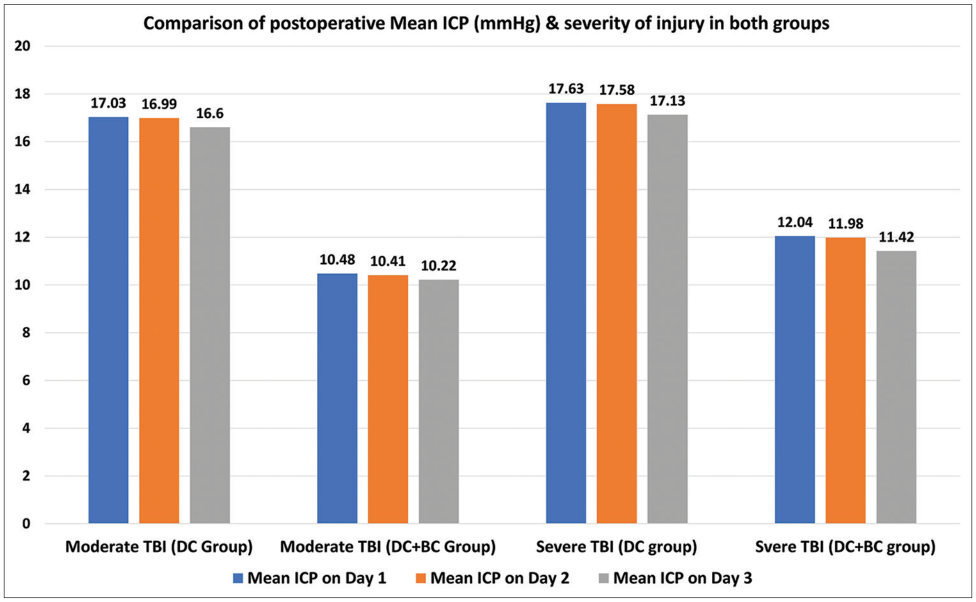

Figure 4: Comparison of postoperative intracranial pressure (ICP) trends in subgroups based on severity of traumatic brain injury (TBI) who underwent decompressive craniectomy (DC) and decompressive craniectomy (DC) + Basal cisternostomy (BC).

respectively). Still, it was significantly low on day 3 in the first subset of ten patients as compared to a second subset of the DC+BC group (P = 0.045*) [Figure 5].

Osmotherapy requirement

In the postoperative period, patients in the DC group required osmotherapy boluses more frequently. The total number of times boluses of i/v 20% Mannitol needed in the DC group was 266 as compared to 112 times in the DC+BC group. Consequently, bolus osmotherapy was delivered in the DC group at a rate of 5.3 per patient, compared to 2.2 in the DC+BC group (P = 0.02*).

Clinical and radiological outcome

In our study, the in-hospital mortality rate in the DC group was 64 %, and the DC+BC group was 48%. Although there is a difference in percentages, this difference was not clinically significant (P = 0.708). Overall, in-hospital mortality in our study was 56%. The duration of mechanical ventilation required in the DC group was 9.83 ± 6.6 days, and in the DC+BC group was 4.34 ± 3.48 days (P < 0.0001*). The number of days required in ICU was 12.83 ± 8.16 days in the DC group and 5.6 ± 4.24 days in the DC+BC group (P < 0.0001*). The calculated mean GCS at 12 weeks was 13.03 ± 0.94 for the DC group and 14.3 ± 0.66 for the DC+BC group (P = 0.196). Mean GOS-E at 12 weeks was 3.11 ± 1.11 for the DC group and 4.23 ± 1.73 for the DC+BC group (P < 0.0001*). On further subgroup analysis based on severity of head injury at the time of admission, we observed that GOS-E at 12 weeks was 3.5 ± 1.23 in moderate TBI-DC subgroup and 2.8 ± 1.01 in the severe TBI-DC subgroup, whereas it was 4.57 ± 1.78 in moderate TBI DC+BC subgroup and 4.10 ± 1.67 in severe TBI DC+BC subgroup. No patient in the DC group attained a favorable outcome at six weeks, whereas 11 (22%) patients in the DC+BC group were in the favorable outcome category. All these 11 patients belonged to lower moderate disability (GOS-E-5).

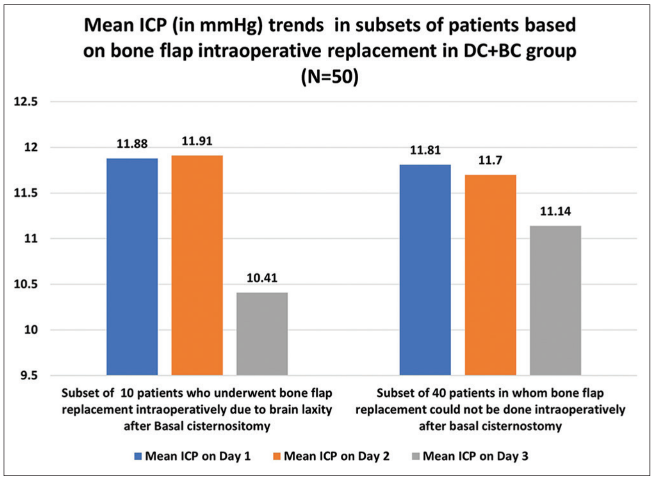

Figure 5: Mean intracranial pressure (ICP) trends in two subsets, who underwent bone flap replacement and in whom bone flap was not replaced intraoperatively in decompressive craniectomy (DC) + basal cisternostomy (BC) group.

The mean midline shift on postoperative days and 3 in the DC+BC group were significantly less as compared to the DC group, while mean brain outward herniation on postoperative day 3 and 7 in the DC group was statically more as compared to the DC+BC group and in DC+BC group [Table 3].

Complications

Newer infarcts (venous and arterial) in the brain developed in eight patients of the DC group and two patients of the DC+BC group. IVH developed in three patients in the DC group and two patients in the DC+BC group. SDH developed in one patient in each group. In the DC group, one patient developed subdural hygroma, and one patient developed epidural hematoma (EDH). Three patients in the DC group developed posttraumatic hydrocephalus in a follow-up period of 3 months.

DISCUSSION

The current standard surgical treatment for TBI is decompressive craniectomy. The decompressive craniectomy

Table 3: Comparison of midline shift and brain outward herniation in CT head done on postoperative period days 0, 3 and 7.

Variables	DC	DC+BC	*P*-value
Midline shift in mm (mean)			
Day: 0	7.48±1.85	4.93±2.66	0.005*
Day: 3	5.75±1.42	3.73±2.40	0.012*
Day: 7	3.70±1.19	2.00±1.39	0.561
Mean brain outward herniation in mm (mean)			
Day: 0	9.45±1.47	4.48±0.97	0.186
Day: 3	9.01±1.57	4.19±0.88	0.049*
Day: 7	8.53±1.68	3.42±0.96	0.024*

DC: Decompressive craniectomy, BC: Basal cisternostomy, ICU: Intensive care unit, CT: Computed tomography, *: Significant *P*-value procedure has proven its role in decreasing ICP and mortality. Whether this translates into a favorable or unfavorable outcome is still under debate. Decompressive craniectomy procedure has its own set of complications, such as external cerebral herniation, blooming of contusions, subdural/EDH or hygroma, strangulation of cerebral tissue at edge of bone flap causing infarction, hydrocephalus, and syndrome of trephine. The pathophysiological basis for these complications is based on the fact that DC helps in reducing ICP but not intracerebral pressure, causing alterations in compliance, cerebral blood flow, autoregulation, and disruption of the subarachnoid CSF pathways and circulation.

Cisternostomy has been recently proposed as an alternative or adjunctive technique that has the potential to reduce ICP as well as brain edema. It is based on the concept of reversal of "CSF shift edema," the rationale of which lies in recognition of paravascular Virchow Robin spaces that constitute glymphatic pathways and have an important contribution to CSF circulation.[2,4]

It is postulated that in TBI, this glymphatic system gets impaired due to traumatic SAH that clogs natural CSF pathways, causing a rise in cisternal pressure, leading to a decrease in interstitial fluid drainage and, hence, brain edema.[8] By opening basal cisterns, cisternal pressure is decreased, reversing the shift of fluid from the intraparenchymal region to the cisternal compartment, thus alleviating brain swelling. Based on this, we enrolled 100 patients, and 50 patients were assigned to each DC group and DC+BC group. These groups were studied for the clinical and radiological outcomes of these two procedures.

Study design and timing of randomization

Our study was a randomized controlled study, and we decided to do randomization intraoperatively. As we know, in some patients who are being planned for decompressive craniectomy (DECRA), on the basis of clinicoradiological criteria, the brain gets lax after the evacuation of hematoma/contusion. Therefore, they no longer need DECRA. In studies related to BC available in literature till now, patients were selected for BC procedure preoperatively based on only clinicoradiological criteria for DECRA. In these studies, the status of the brain (lax/bulge) was also not clearly defined before performing the cisternostomy procedure. Selection of cases in such a way without considering the effect of hematoma evacuation on brain laxity may lead to a false-positive effect of BC. That's why we have randomized the patient during the intraoperative period to evaluate the real effect of this procedure.

Surgical technique

Performing BC does require a surgeon skilled in skull base and micro neurosurgery. It becomes even trickier in an edematous brain in the setting of traumatic brain injury. It also needs an OT equipped with an operative microscope**.** The basal cisternostomy procedure in our study was performed by a single surgeon (corresponding author) experienced in skull base and aneurysm surgery. In studies conducted by Cherian *et al.*,[2,6] Parthiban *et al.*,[10] Thapa *et al.*,[13] Giammattie *et al.*,[7] Chandra *et al.*,[1] and Kumar *et al.*,[9] anterior clinoid process drilling was done. Some difficult cases also needed posterior clinoid process drilling. Drilling of the anterior clinoid process in the edematous brain has added risk of injuring the internal carotid artery in inexperienced hands. In these studies, static retraction with a brain spatula was used to retract the brain, that might lead to further injury in a traumatized edematous brain. These limitations hinder its practice in trauma cases, which are generally taken care of by neurosurgery residents. In our experience, we were able to reach the basal cisterns using a lateral subfrontal approach without requiring anterior clinoid process drilling. We used dynamic retraction with suitable working instruments (narrow caliber suction cannula and long bayonet micro forceps) and an operating microscope to reach the basal cisterns. The patient's head positioning is one of the key factors for the utilization of gravity to minimize the use of static retraction and to take a safe trajectory to these cisterns. With this simplification, adequate training is needed for residents under skilled neurosurgeons as it requires a period of learning curve to be able to perform this procedure in a neurotrauma setting.

Timing of opening of cisterns

In studies conducted by Cherian *et al.*,[2,6] Thapa *et al.*,[13] Giametti *et al.*,[7] and Kumar *et al.*,[9] the authors, after removing the bone flap performed durotomy and then opened the cisterns first. Contusion or hematoma evacuation was done after performing the BC procedure. In studies conducted by Parthiban *et al.*[10] and Chandra *et al.*[1] after opening the dura, firstly, evacuation of hematoma and contusion was done, and then BC was performed. In both the above conditions, the laxity of the brain after completion of surgery cannot be definitively and specifically attributed to the BC procedure alone. In our study, only those cases in which the brain remains bulged even after evacuation of hematoma were randomized in either group. In patients who fall after randomization in the DC+BC group and in whom the brain gets lax after adjuvant BC, we can safely and definitively conclude that it occurred in response to the BC procedure.

No placement of a cisternal drain

In studies conducted by Cherian *et al.*[2,6] and Parthiban *et al.*,[10] authors analyzed the role of cisternostomy, and there were no control groups. The authors placed a drain in cisternal space after completing the BC to allow continuous CSF drainage, which was kept for five days on average. As we know, this continuous CSF drainage may lead to laxity of the brain and decreased ICP. In studies conducted by Thapa *et al.*,[13] Giammattie *et al.*,[7] Chandra *et al.*,[1] and Kumar *et al.*,[9] authors analyzed the utility of BC with DECRA as the control group. In these studies, a cisternal drain was placed in all patients who were in the BC group as opposed to the DC group. During the BC procedure, fenestration of lamina terminalis was also done in these studies; therefore, drain in cisternal space drained CSF from both cisternal and ventricular compartments. This drain was kept for approximately five days, and continuous CSF drainage resulted in a laxed brain and decreased ICP in BC group patients. As no provision of such CSF drainage was there in the DC group, these two groups remained no more comparable. To overcome this bias, in our study, no cisternal drain was placed to maintain the comparability of the two groups in the true sense.

Replacement of bone flap at craniotomy site

Another important aspect of the studies mentioned above was that the brain became lax enough after completing the surgical procedure, so authors were able to replace bone flaps at the craniotomy site in primary surgery in a significant number of cases. There is a possibility that the brain became lax due to evacuation of hematoma/contusion, and whether these candidates were real candidates for DECRA was not clearly mentioned. In our study, in all 50 patients of the DC+BC group, brain bulges decreased to some extent. Still, we were able to observe satisfactory brain laxity in only ten patients in whom the bone flap was replaced at the craniotomy site during primary surgery.

Duration of surgical procedures

Cherian *et al.*[2] and Thapa *et al.*[13] observed that on an average of 10-20 min, extra was needed to perform BC in experienced hands. In studies by Giammattie *et al.*[7] and Chandra *et al.*,[1] found that on an average of 20–30 min, extra were needed to perform BC. In our study, the mean duration of surgery was 189 min in the DC group and 206.6 min in the DC+BC group ($P < 0.0001^*$). Hence, on average, the extra time needed to perform cisternostomy was approximately 15–20 min.

Effect on ICP

In a study conducted by Giammattie *et al.*,[7] postoperative monitoring of ICP was done for 72 h. A decreasing trend in ICP was observed in both adjuvant cisternostomy (AC) and DC groups. This decrease in ICP was more in the AC group as compared to the DC group. This trend can be due to the fact that the cisternal drain was placed in the cisternostomy group that was used for continuous CSF drainage for approximately five days in the postoperative period. On the contrary, in a study conducted by Kumar *et al.*,[9] they failed to observe any significant decrease in ICP after the AC procedure. Rather, it was more in the AC group than the DC alone group. They measured opening and closing ICP intraoperatively in both AC (in all nine patients) and DC group (16 out of 31 patients). They found that closing pressure was significantly less for the patients undergoing DC alone (5.3 ± 3.5) compared to those undergoing DC with BC (11.3 ± 5.9) ($P = 0.003$). Moreover, the mean drop in ICP was greater for the DC group (18.9 ± 12.4) compared to the DC+BC group (14.4 ± 11.5). They also measured ICP in the postoperative period for 72 h heterogeneously. In the AC group, it was done for 24 h in seven patients, 48 h in six patients, and 72 h in three patients. Postoperative ICP monitoring was done for 24 h in ten patients, 48 h in seven patients, and 72 h in six patients. They observed that mean intracranial pressure over the initial 72 h was higher in the adjuvant cisternostomy group (11.9 ± 2.1) as compared to the DC group (11.7 ± 1.5) ($P = 0.549$). In a study by Chandra *et al.*, [1] intraoperative ICP was monitored. Mean ICP after 1st burr hole and after craniotomy was measured. They found that the mean decrease in ICP from 1st burr hole to craniotomy was lower in BC as compared to the DC group.

In our present study, opening pressure was measured intraoperatively and was found to be comparable in two groups. ICP was measured in the postoperative period for 72 h, and the mean postoperative ICP on day 1, day 2, and day three was found to be decreased in both groups. This decline in ICP was more in the DC+BC group as compared to the DC group, and the difference was statistically significant. This result is consistent with the rest of the studies. However, in contrast to other studies, in our study, this significant decrease in ICP in the DC+BC group is not due to CSF drainage through the cisternal drain. Therefore, this decrease in ICP in our study can be attributed to the addition of BC procedure. On subgroup analysis, we observed that adding BC to DC leads to a further decline in ICP in both moderate and severe TBI patients as compared to the DC alone, proving its efficacy in both categories of patients.

On subset analysis, we observed that mean ICP trends were a little higher on day one and day two and lower on day 3 in ten patients who underwent bone flap replacement intraoperatively in the DC+BC group as compared to the rest of the 40 patients' subset. A possible explanation for slightly higher (but statistically insignificant) mean ICP on day one and day two would be the added bone flap volume, which was replaced at the operative site in these ten patients. Decreasing mean ICP trends on day 3 in this ten patient's subset might be due to the early establishment of normal physiological CSF flow circulation at brain convexity and its

Table 4: Summary of recently performed studies for comparison of results with the present study.

Study	Number of patients	Extra time needed for BC**	Mortality rate	Mechanical ventilation in days (mean)	ICU*** stay in Days (mean)	Mean brain outward herniation in cm in postoperative CT head	Midline shift in mm in postoperative CT head (mean)	GOS****/ GOS-E*****
Chandra *et al.*[1] (Randomized controlled trial)	DC*=25 BC**=25	DC=2.90±0.38 hours BC=3.28±0.52 hours *P*=0.005	DC=44% BC=32%	DC=7.60±4.93 BC=5.683±3.80 (*P*=0.130)	DC=7.12±3.93 BC=5.48±4.85 (*P*=0.190)	Not mentioned	Not mentioned	(GOS at three months) DC=2.68±1.65 BC=3.12±1.64
Cherian *et al.*[2] (Prospective nonrandomized study)	DC=284 DC+BC=272 BC=476	10–20 min	DC=34.8% DC+BC=26.4% BC=15.6%	DC=6.3 DC+BC=3.2 BC=2.4	Not mentioned	Not mentioned	Not mentioned	(GOS at six weeks) DC=2.8 DC+BC=3.7 BC=3.9
Thapa *et al.*[13] (Retrospective cohort study)	DC=73 DC+BC=77	10–20 min	DC=43.8% DC+BC=28.6% (*P*=0.052)	Not mentioned	Not mentioned	Not mentioned	Not mentioned	(GOS at six months) (*P*=0.323) DC=3.03 DC+BC=3.4
Giammattei *et al.*[7] (Retrospective cohort study)	DC=22 DC+BC=18	DC=178±30.5 min BC=204±43 min	DC=27.3% DC+BC=22%	DC=12.9±6.7 DC+CS=8.5±5.6 (*P*=0.03)	DC=16.9±7.6 DC+BC=11.9±7.3 (*P*=0.04)	DC=0.86±0.67 DC+BC=0.37±0.85 (*P*=0.05)	Not mentioned	(GOS-E at six months) DC=3.6±2.1 DC+BC=4.8±2.5 (*P*=0.1)
Kumar *et al.*[9] (Prospective nonrandomized study)	DC=31 DC+BC=9	Not mentioned	DC=32.2% DC+BC=66.6%	Not mentioned	DC=10.6±9.3 DC+BC=7.0±6.1	Not mentioned	Not mentioned	(GOS-E>5 at 1 month) DC=9.7% DC+BC=11.1% (*P*=0.999)
Present study (Randomized control trial)	DC=50 DC+BC=50	DC=189 min DC+BC=206.6 (*P*=0.001)	DC=64% DC+BC=48% (*P*=0.708)	DC=9.83±6.6 DC+BC=4.34±3.48 (*P*=0.0001)	DC=12.83±8.16 DC+BC=5.6±4.24 (*P*=0.0001)	DC=0.90±0.15 DC+BC=0.41±0.08 (*P*=0.049)	DC=5.75±1.42 DC+BC= 3.73±2.40 (*P*=0.012)	(GOS-E at three months) DC=3.11±1.11 DC+BC=4.23±1.73 (*P*=0.0001)

DC*: Decompressive craniectomy, BC**: Basal cisternostomy, ICU***: Intensive care unit, GOS****: Glasgow outcome scale, GOS-E*****: Glasgow outcome scale-extended, CT: Computed tomography further flow for absorption at arachnoid granulation located in superior sagittal sinus with the help of replaced bone flap of at operative site. As these two subsets are not balanced in terms of patient number, we need further study in the future focusing on these two subsets only to validate our findings.

Effect on radiological outcome

In a study conducted by Giammattei *et al.,*[7] mean brain outward herniation (in cm) was 0.86 ± 0.67 in the DC (DC) group and 0.37 ± 0.85 in the AC group ($P = 0.05$). No other study in the literature has commented on radiological outcomes. In our study, we calculated the mean midline shift as well as the mean brain outward herniation on POD 0, 3, and 7. We found that mean midline shift and mean brain outward herniation were significantly less in the DC+BC group as compared to the DC group. A possible explanation can be that BC leads to a decrease in brain edema. The mechanism for this decreased brain edema can be extensive washout and clearing of blood clots and debris from cisternal spaces while performing BC procedure, which in response made glymphatic pathway and normal CSF circulation pathways functional again.

Effect on clinical outcome

In studies conducted by Cherian *et al.*,[2] Giammattei *et al.,*[7] and Thapa *et al.*,[13] they observed that the mortality rate was lower in the adjuvant BC (DC+BC) group as compared to DC alone group. One randomized control study by Chandra *et al.*[1] comparing BC alone with DC has found the mortality rate to be lower in the cisternostomy group (32%) as compared to the DC group (44%). However, in a study conducted by Kumar *et al.,*[9] the mortality rate was higher in the AC group (66.6%) as compared to the DC group (32.2%). In our study, the mortality rate in the DC group was 64 %, and the DC+BC group was 48%. The high mortality rate in our study can be attributed to factors like delayed presentation after trauma due to the considerable distance between the referring center and our center (which is a tertiary care high-volume referral center), poor GCS, and severe Rotterdam score at the time of presentation, delay in surgery after admission due to unavoidable circumstances, multiple associated injuries leading to added morbidity and comorbid conditions.

In studies conducted by Cherian *et al.*,[2] Giammattei *et al.*,[7] Thapa *et al.*,[13] and Kumar *et al.,*[9] they observed that the duration of ICU stays and ventilatory support was lower in the AC group. Similar results were observed in a study conducted by Chandra *et al.*[1] In our study, the DC+BC group has a significantly shorter duration of ventilatory support and ICU stay.

Cherian *et al.*[2] calculated the Glasgow outcome scale (GOS) at six weeks, whereas Thapa *et al.*[13] calculated mean GOS at six months and observed better mean GOS in the AC group as compared to the DC group. Similarly, in a study by Chandra *et al.,*[1] better mean GOS at three months was observed in the cisternostomy group as compared to the DC group. Parthiban *et al.*[10] retrospectively studied 40 head injury patients who underwent BC. They observed satisfactory results with BC in severe head injury patients with a favorable outcome of 77.8% in the BC alone group (BC alone) and 72.7% in the DC+BC group (DC with BC) with an overall mortality of 6.8% in the severe traumatic brain injury group. However, they did not compare their results with patients undergoing DC alone procedure.

In studies conducted by Giammattei *et al.*[7] and Kumar *et al.,*[9] mean GOS-E was calculated at six months and one month, respectively, and was better in the AC group in contrast to the DC group. Our study showed similar results, and we observed better GCS and GOS-E scores at 12 weeks in the DC+BC group as compared to the DC group. Again, with subgroup analysis based on the severity of TBI at the time of admission, we observed that GOS-E at 12 weeks in the DC+BC-group was better than the DC group. GOS-E at 12 weeks was 3.5 ± 1.23 in the moderate TBI-DC subgroup and 2.8 ± 1.01 in the severe TBI-DC subgroup, whereas it was 4.57 ± 1.78 in moderate TBI DC+BC subgroup and 4.10 ± 1.67 in severe TBI DC+BC subgroup. Seizures developed in 8 patients (16%) in the DC group and four patients (8%) in the DC+BC group. This better clinical outcome can be explained by the fact that adding BC reduced both intracranial pressure and cerebral edema and, hence, slowed down ongoing secondary brain injury. We have summarized the results of our present study as well as other recently performed studies (randomized controlled trials [RCT], retrospective studies, and prospective cohort studies) related to BC in tabulated form for better understanding and comparison [Table 4].[1,2,7,9,13]

Limitations

Our study has certain limitations. It was a single-center study. Patients less than 18 years old and pregnant females were not included in the study. Patients were followed up for three months due to paucity of study time.

CONCLUSION

Adding BC is effective in reducing both ICP as well as brain edema, which translates into clinically relevant patient outcomes. This procedure also has the potential for replacement of bone flap during primary surgery and, hence, can avoid complications of DC and second surgery in the form of cranioplasty. In our study, we also observed that it is a safe and feasible procedure to be performed in a trauma setting as it can be performed without the need for clinoid drilling. With all these, it seems like a promising procedure. Still, the key roadblock is the mandate of surgeons skilled in skull base and micro neurosurgery and the requirement of the operative microscope in neurotrauma setup. The results of our single-center RCT are encouraging, and we recommend that more multi-center trials should be conducted to establish the role of this procedure in trauma settings.

Ethical approval

The author(s) declare that they have taken the ethical approval from IEC (Registration no: ECR/262/ Inst/UP/2013/RR-19).

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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