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Original article

Outcome of Decompressive Craniectomy for Severe Traumatic Brain Injury Patients with persistently elevated Intracranial Pressure on Medical Treatment

(A Prospective Study Controlled by Intra-parenchymal Pressure Monitoring)

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Abstract

Back ground: Traumatic brain injury (TBI) can result in cerebral edema and vascular changes resulting in an increase in intracranial pressure (ICP), which can lead to further secondary damage.Monitoring of ICP is the standard of care for patients with TBI . **Objectives:** To evaluate outcome of decompressive craniotomy (DC) for management of severe traumatic brain injury (STBI) with persistently elevated intracranial pressure (ICP) on medical treatment and to determine feasibility, safety and accuracy of intraparenchymal ICP monitoring (IPM). **Patients and Methods:** Forty-one patients admitted to ICU with STBI underwent clinical evaluation. CT scanning was performed for lesions' description and grading with measurement of midline shift (MLS). IPM was inserted and initial ICP was recorded. Patients failed to respond to medical treatment underwent DC. Study outcome included frequency of postoperative (PO) complications and functional outcome judged by Extended Glasgow Outcome Scale (GOSE) 3, 6 and 12-m after hospital discharge. **Results:** Twenty-seven patients underwent early DC, while 14 patients had late DC. Unilateral craniectomy was performed in 38 patients and bifrontal craniectomy in 3 patients with diffuse cerebral edema and no MLS. During 48-hr PO, arterial pressure measures gradually increased, while ICP gradually decreased and CPP was progressively increased. Mean duration of ICP monitoring was 4±2.4 days, mean duration of ICU stay was 6.8±3.4 days and mean total hospital stay was 11.4±5 days. Five patients developed surgery-related PO complications and 12 patients died, but there was no surgery related mortality. At end of 12-m follow-up; 9 patients had good recovery, 9 patients had moderate disability and 3 had severe disability, while 3 patients were in vegetative state. **Conclusion:** Short-term trial of medical treatment judged by ICP monitoring of STBI patients allows early surgical

decision making. Decompressive craniectomy for patients with persistently elevated ICP provided rapid control of ICP with subsequent improvement of CPP and little PO surgery-related morbidity and no mortality. DC provided acceptable functional outcome with good recovery rate of 37.5%. ICP monitoring using intraparenchymal sensor provided satisfactory perioperative ICP monitoring.

Keywords: Severe traumatic brain injury, Intraparenchymal ICP monitoring, Decompressive craniectomy

Introduction

Traumatic brain injury (TBI) can result in cerebral edema and vascular changes resulting in an increase in intracranial pressure (ICP), which can lead to further secondary damage [(1)]. Traumatic brain injury may be classified by etiology as blunt closed, penetrating and blast TBI or by severity into mild, moderate and severe. TBI induced a Glasgow Coma Score (GCS) of 13-15 is considered mild, 9-12 moderate, and GCS of ≤8 severe TBI [(2)]. TBI can also be classified as focal injury which constitutes extra-axial (subdural and epidural) or intraparenchymal hematomas, and hemorrhagic contusions or diffuse injury involving widespread damage to axons, diffuse microvascular injury, hypoxic ischemic injury, and brain swelling [(3)].

Moderate/severe TBI management involves minimizing cerebral edema to maintain brain oxygen delivery. Medical therapy consisting of diuresis, hyperosmolar therapy, ventriculostomy, and barbiturate coma is the standard of care. However, decompressive craniectomy (DC) for refractory intracranial hypertension (ICH) has gained renewed interest [(4)].

Decompressive craniectomy is surgical procedure that involves removal of part of the skull to accommodate brain swelling [(5)]. DC was used as an auxiliary neurosurgical invasive procedure for treatment of severe TBI with brain edema and/or ICH [(6)]. DC can be divided into categories, according to the timing and rationale for performing the procedure: primary DC when done at the time of mass lesion evacuation and secondary DC when done to treat refractory ICP [(7)].

Monitoring of ICP is the standard of care for patients with TBI [(8)]. ICP monitoring is indicated in comatose TBI patients with cerebral contusions in whom interruption of sedation to check neurological status is dangerous or when the clinical examination is not completely reliable, while in comatose TBI patients with normal computed tomography (CT) scan, there is no indication for ICP monitoring [(9)]. Device selection for ICP monitoring provides prognostic discrimination

[8]. However, there is significant practice variation associated with ICP monitoring and management [10].

Parenchymal catheter tip pressure transducer devices are advantageous when ventricular ICP cannot be obtained or if there is an obstruction in the fluid couple, though they have the potential for significant measurement differences and drift due to the inability to recalibrate [11]. **Some studies.** [12] favored intraparenchymal than subdural placement of telemetric ICP measurement devices for long-term ICP follow-up. On contrary, **Other stusies.** [8] recommended routine placement of external ventricular drain in patients with TBI, unless only parenchymal-type monitoring is available.

The current study was designed to evaluate the outcome of decompressive craniotomy (DC) for management of patients had severe traumatic brain injury (STBI) with persistently elevated ICP on medical treatment and to determine feasibility, safety and accuracy of Codman intraparenchymal ICP monitoring.

Patients and Methods

The current prospective study was conducted at Neurosurgery Departments in governmental hospitals of Ministry of Health Saudi Arabia since Jan 2012 till Aug 2015 so as to allow a minimum follow-up period of 1 year for clinical follow up and outcome. The study protocol was approved by the Local Ethical Committee. One of the nearest relatives to enrolled patients signed fully informed written consent prior to inclusion. This study intended to include only patients with STBI and persistently elevated ICP despite of intensive medical therapy.

All STBI patients were admitted immediately to ICU for evaluation, tracheal intubation and were maintained supine with elevation of head-of-bed by 20-30^{o}. At ICU admission blood pressure measures systolic, diastolic and mean arterial pressure (SAP, DAP, MAP) were determined. Then, patients underwent CT scanning that were reviewed for lesions' description, measurement of midline shift (MLS) and classification of lesions according to Marshall's classification [13].

Then, all patients underwent clinical evaluation for trauma severity using the Abbreviated Injury Scale (AIS) [14] and STBI was defined as head AIS of ≥3 [15] with Glasgow coma scale (GCS) of 3-8 [2, 16]. Invasive ICP monitoring of patients with STBI was indicated according to the Brain Trauma Foundation [16] in patients with an abnormal CT scan revealing hematomas, contusions, swelling, herniation, or compressed basal cisterns [17, 18] or patients with normal CT but aged ≥40 years, and had systolic blood pressure < 90 mmHg [17]. ICP was monitored

invasively according to guidelines of Brain Trauma Foundation [16] using an intraparenchymal monitor (IPM).

Technique for insertion of Codman Intraparenchymal monitors (IPM)

A codman icp monitoring system was used Figute 1,Figure 4 .A 0.5-cm linear skin incision was made at 1-cm anterior to the coronal suture at 3-cm away from the midline in a plane with the midpupillary line behind the hairline, usually on the right (nondominant) side of the brain, unless contraindicated. A twist drill hole was made though the outer and inner tables of the skull, then dura was incised by blade. Calibration was done by putting of catheter in container with saline and reference zero point was registered. The catheter was tunneled subcutanously attached to the **monitor** and then it was extended for 1 to 2 cm **into** the brain parenchyma. Pressure waveform was checked and initial ICP was recorded

Medical Treatment

Until surgical decision taking, medical treatment was started Figure 1 Figure 3. The target of medical treatment was to maintain ICP at <20 mmHg with cerebral perfusion pressure (CPP=MAP - ICP) [19] at ≥70 mmHg. Fluid therapy was adjusted to maintain CPP at ≥70 mmHg but without over-hydration. Hyponatremia was avoided or treated if present. If ICP was >20 mmHg or exceeded 20 mmHg during medical treatment, mannitol infusion in dose of 0.5–1 gm/kg with continuous monitoring of serum osmolarity and serum sodium levels. Deep sedation was induced on failure if these measures failed to keep ICP <25 mmHg otherwise surgery was conducted.

Surgical Management

Some Studies[20] Defined Early DCas DC conducted within 12 hr and was applied for STBI patients younger than 50 years, with time since trauma inflection of <12 hr and had non-penetrating head injury, and GCS <9 after emergency room resuscitation with CT findings compatible with diffuse injury or had mass lesion to be evacuated. Patients with STBI and not fulfilling criteria for early DC and their CT findings showed no indication for immediate surgical interference but still had ICP ≥25 mmHg despite of intensive medical therapy for 12 hr underwent late DC.

Decompressive craniectomy was conducted as described previously by Some studies[21]. Figures 2,5. For patients with unilateral hemispheric swelling, unilateral fronto-temporo-parietal (UFTP) craniectomy (hemicraniectomy) with at least diameter of 12 cm bone flap was performed; hemicraniotomy was extended into the temporal lobe base to

release compression on the basilar cisterns. For patients with diffuse brain swelling affecting both hemispheres on imaging studies, bifrontal (BF) craniectomy extending from the floor of the anterior cranial fossa to the coronal suture to the pterion. Augmentative duraplasty was performed in all DC patients; after opening of the dura mater and evacuation of hematoma if present; a dural patch was placed over the cerebral cortex and the opened dura was repositioned over the substitute, but the bone flap was not replaced. The previously inserted intraparenchymal ICP monitor was safeguarded during DC and a subgaleal drain was routinely placed. Collected operative data included frequency of patients required UFPT and BF procedure, bone flap areas and largest bone flap diameter for each patient were calculated from an immediate postoperative (PO) thin-slice CT scan and frequency of intraoperative complications.

Study Outcome

A) Surgical Outcome included the following items

- Frequency of PO hemorrhagic complications including

1. Subdural (SDH) hemorrhage of ≥10 mm thickness within the field of DC in the immediate PO CT scan
2. Increase in the thickness of SDH within the field of DC in the CT scan within or on day-7 PO compared with thickness determined on immediate PO CT scan
3. Progression of preexisting contusion or ICH relating to the edge of the DC or within the field of DC in the CT scans.
4. Appearance of new areas of hemorrhagic contusion or ICH relating to the edge of the DC or within the field of DC in the CT scans.

- PO complications including infection, development of brain herniation, hydrocephalous, seizures, or mortality

B) ICP follow-up outcome included 6-hourly recording of ICP and MAP with calculation of CPP during 1st PO 24-hr and then 12-hourly until stabilization of ICP at <20 mmHg.

C) Duration of ICP monitoring, ICU stay total hospital length of stay (LOS) and mortality rate.

D) Extended Glasgow Outcome Scale (GOSE) was evaluated at 3, 6 and 12-m after hospital discharge. The Glasgow Outcome Scale (GOS) rates patient status into one of five categories: Dead, Vegetative State, Severe Disability, Moderate Disability or Good Recovery. The Extended GOS (GOSE) subdivided the categories of severe disability, moderate disability and good recovery into a lower and upper category [22, 23].

Statistical analysis

Obtained data were presented as mean ± SD, ranges, numbers and ratios. Statistical analysis was conducted using the SPSS (Version 15, 2006) for Windows statistical package. P value <0.05 was considered statistically significant.

Results

Throughout the study period 51 STBI patients; 25 males and 26 females with mean age of 40±12.6; range: 23-67 years. Mean GCS at time of enrolment was 4.8±1.4; range: 3-8 and mean head AIS score of 3.9±0.7; range: 3-5. Details of enrolment data.

All patients had low blood pressure measures at time of enrolment with a mean MAP of 65.9±4.5 mmHg and 32 patients had MAP of ≤70 mmHg. Mean ICP estimated at time of insertion of IPM was 26.7±1.1 mmHg and mean calculated CPP was 39.2±4.2 mmHg. Initial CT showed varied pathological lesions with frequency of lesions/patient of 1.34. Only three patients showed diffuse brain edema without midline shift, while 38 patients had lesions causing midline shift for a mean distance of 7.4±4.1 mm. According to Marshall Classification 15 patients had lesions to be evacuated, 10 patients had diffuse injury with shift (Grade IV), 7 patients had non-evacuated mass lesion and 9 patients had diffuse injuries of varied grade. Details of TBI-related data.

Twenty-seven patients underwent early DC, 10 of them underwent surgery within 6 hours after trauma inflection and 17 had DC after 6-12 hr after trauma inflection. The remaining 14 patients had late DC after failure of medical treatment to reduce ICP within 24-hr after trauma inflection. Unilateral **craniectomy** was performed in 38 patients and bifrontal craniectomy was performed in 3 patients with diffuse cerebral edema and no midline shift. All surgeries were conducted uneventfully within a mean operative time of 201.5±42.3; range: 125-300 min. Immediate PO CT showed that mean length of largest diameter of bone flap was 12.6±1.7 cm and mean bone flap area was 101.5±17.7 cm^2. Details of operative data.

Arterial pressure measures showed gradual increase during 48-hr PO with significant difference at each estimate compared to previous one and to baseline measure. On the other hand, mean recorded ICP showed gradual progressive significant decrease throughout 48-hr PO and consequently, CPP was progressively increased.

The recorded ICP during the 1^{st} 48-hr after DC showed progressive decrease and the frequency of patients had ICP ≤20 mmHg

started at 18-hr PO and increased progressively and by 48-hr all patients had ICP of ≤20 mmHg. Mean duration of ICP monitoring was 4±2.4; range: 2-9 days, but IPM was removed within 2-3 days in 24 patients (58.5%) and 8 patients had continuous ICP recording for ≥7 days. Details of ICP monitoring data.

Surgery-related PO complications were encountered in 5 patients for a rate of 12.2%. Three patients developed wound infection that responded to extensive antibiotic therapy in two, but the 3rd patient required surgical revision. Two patients developed wound hematomas; one extradural and one subdural hematoma. Mean duration of ICU stay was 6.8±3.4; range: 3-17 days and mean total hospital stay was 11.4±5; range: 3-22 days. Throughout hospital stay, 12 patients died for a total mortality rate of 29.3%. Seven patients died after early DC and 5 patients after late DC with non-significantly ($p>0.05$) higher mortality rate with late than early (35.7% vs. 25.9%). Four patients died during ICU stay after a mean duration of ICU stay 9.5±4.4; range: 3-12 days; while 8 patients died during their hospital stay after ICU discharge after a mean duration of hospital stay of 12.1±3.8; range: 7-17 days. Six patients died secondary to associated trauma, four patients died secondary to associated medical diseases and two patients were not fit for early DC and failed to respond to medical treatment and had late DC, but unfortunately still comatosed despite of decreased ICP and died 3 and 4 days after trauma.

Throughout 12-m follow-up period, 5 patients died for a follow-up mortality rate of 17.2%. At time of discharge there were 5 patients (12.2%) were in vegetative state; two of them died and three remained without any progress. Eleven patients (26.7%) were discharged with severe disability; three of them died and 5 were improved to moderate disability, but three were still severely disable. Seven patients were discharged with moderate disability; three were improved to lower good recovery grade, 2 improved to upper moderate disability and one remained at lower moderate disability grade. Three patients were discharged with lower good recover; one had improved to upper good recovery and the other two were stationary at lower good recovery grade. Totally, at end of 12-m follow-up; 9 patients had good recovery, another 9 patients had moderate disability and 3 had severe disability, while 3 patients were in vegetative state.

Table (1): Patients' clinical data of STBI patients developed persistently high ICP

Data		Findings
Age (years)	<30	7 (17.1%)
	31-40	16 (39%)
	41-50	9 (22%)
	51-60	4 (9.8%)
	>60	5 (12.2%)
	Mean	40±12.6
Gender	Males	25 (61%)
	Females	16 (39%)
Mechanism of injury	Motor vehicle accident	16 (39%)
	Fall from height	11 (26.9%)
	Pedestrian auto-accident	8 (19.5%)
	Others	6 (14.6%)
Associated medical diseases	No	30 (73.2%)
	Liver disease	3 (7.3%)
	Respiratory disorders	2 (4.9%)
	Cardiac diseases	4 (9.7%)
	Renal impairment	2 (4.9%)
Associated other body trauma	Yes	35 (85.4%)
	No	6 (14.6%)
Head AIS score	=3	11 (26.9%)
	=4	23 (56%)
	=5	7 (17.1%)
	Mean	3.9±0.7
Total AIS score		11.5±0.9
GCS	=3	8 (19.5%)
	=4	11 (26.9%)
	=5	9 (22%)
	=6	8 (19.5%)

	=7	3 (7.3%)
	=8	2 (4.9%)
	Mean	4.8±1.4
Pupil response	Normal	28 (68.3%)
	Unilateral unreactive	9 (22%)
	Bilateral unreactive	4 (9.7%)

Data are presented as numbers & mean ± SD; percentages are in parenthesis; AIS: Abbreviated Injury Scale; GCS: Glasgow coma scale

Table (2): TBI-related data of enrolled patients

Data			**Findings**
Blood pressure measures (mmHg)		SAP	82.3±6.9
		DAP	57.7±5.1
		MAP <65	20 (48.8%)
		65-70	12 (29.3%)
		>70	9 (21.9%)
		Mean	65.9±4.5
ICP (mmHg)		25	7 (17.1%)
		26	11 (26.9%)
		27	12 (29.1%)
		28	9 (22%)
		29	2 (4.9%)
		Mean	26.7±1.1
CPP (mmHg)		<35	8 (19.5%)
		35-40	17 (41.5%)
		>40-45	11 (26.8%)
		>45	5 (12.2%)
		Mean	39.2±4.2
Initial CT findings	Pathological lesion	Subdural hematoma and multiple brain contusions	16 (39%)
		Brain contusions	7 (17.1%)
		Subdural hematoma	3 (7.3%)
		Subarachnoid and intraventricular	9 (22%)

	hemorrhage	
	Diffuse edema	6(14.6%)
	Frequency of lesions/patient	1.36
Midline shift	0	3 (7.3%)
	<5	9 (22%)
	5-<10	23 (56.1%)
	≥10	6 (14.6%)
	Mean	7.4±4.1
Analysis of lesions according to Marshall classification	Diffuse injury I	2 (4.9%)
	Diffuse injury II	3 (7.3%)
	Diffuse injury III (swelling)	4 (9.7%)
	Diffuse injury IV (shift)	10 (24.4%)
	Evacuated mass lesion	15 (36.6%)
	Non-evacuated mass lesion	7 (17.1%)

Table (3): Operative data of enrolled patients

Data			**Findings**
Timing in relation to time of trauma inflection (hr)	**Early**	**<6**	10 (24.4%)
		6-12	17 (41.5%)
	Late >12		14 (34.1%)
Type of craniectomy	**Unilateral FTP**		38 (92.7%)
	Bi-frontal bilateral		3 (7.3%)
Duration of surgery (min)	**<180**		13 (31.7%)
	>180-240		21 (51.2%)
	>240		7 (17.1%)
	Mean		201.5±42.3
Bone flap data	**Largest diameter (cm)**		12.6±1.7
	Area (cm^2)		101.5±17.7

Data are presented as numbers & mean±SD; percentages are in parenthesis; FTP: Fronto-tempro-parietal

Table (4): Mean estimates of arterial pressure and ICP measures and calculated cerebral perfusion pressure determined throughout 48-hr after DC

Time	SAP (mmHg)	DAP (mmHg)	MAP (mmHg)	CPP (mmHg)	ICP (mmHg)
Baseline	82.3±6.9	57.7±5.1	65.9±4.5	39.2±4.2	26.7±1.1
6-hr	87.6±6.1	64.2±4.5	72±3.8	47.7±3.8	24.4±1.2
12-hr	88.5±55	65±3.7	72.8±3.3	48.8±3.3	24±1.1
18-hr	89.6±4.8	65.3±3.4	73.4±3	51.1±3.5	22.3±1.4
24-hr	90.9±3.7	66±2.8	74.3±2.5	54.9±3.4	19.4±2
36-hr	91.6±3.2	67.3±2.3	75.4±2.1	57.9±2.5	17.5±1.8
48-hr	92±3.1	67.5±2.1	75.7±2	58.8±2.2	16.9±1.1

Data are presented as mean±SD; SAP: Systolic arterial pressure; DAP: Diastolic arterial pressure; MAP: Mean arterial pressure; CPP: Cerebral perfusion pressure; ICP: Intracranial pressure

Table (5): ICP monitoring measures and duration of monitoring

	ICP pressure recorded during 1st 48 hr PO				**Duration of ICP monitoring**	
Time	>25	21-25	18-20	<18	Duration	Data
Baseline	41 (100%)	0	0	0	2-d	15 (36.6%)
6-hr	7 (17.1%)	34 (82.9%)	0	0	3-d	9 (22%)
12-hr	4 (9.8%)	37 (90.2%)	0	0	4-d	6 (14.6%)
18-hr	0	34 (82.9%)	7 (17.1%)	0	5-d	3 (7.3%)
24-hr	0	15 (36.6%)	4 (9.8%)	0	6-d	0
36-hr	0	4 (9.8%)	14 (36.1%)	23 (56.1%)	≥7	8 (19.5%)
48-hr	0	0	11 (26.8%)	30 (73.2%)	Mean	4±2.4

Data are presented as numbers & mean±SD; percentages are in parenthesis; ICP: Intracranial pressure: PO: Postoperative

Table (6): Functional outcome of studied patients as judged by GOSE throughout 12-m follow-up period

GOSE	Discharge	3-m FU	6-m FU	12-m FU
1 (Death)	12 (29.3%)	1 (3.4%)	2 (7.1%)	2 (7.7%)
2 (Vegetative state)	5 (12.2%)	5 (17.2%)	4 (14.3%)	3 (11.5%)
3 (Lower severe disability)	4 (9.8%)	3 (10.3%)	2 (7.1%)	1 (3.8%)
4 (Upper severe disability)	7 (17.1%)	6 (20.7%)	4 (14.3%)	2 (7.7%)
5 (Lower moderate disability)	4 (9.8%)	5 (17.2%)	5 (17.9%)	4 (15.4%)
6 (Upper moderate disability)	3 (7.3%)	3 (10.3%)	4 (14.3%)	5 (19.2%)
7 (Lower good recovery)	3 (7.3%)	3 (10.3%)	4 (14.3%)	5 (19.2%)
8 (Upper good recovery)	3 (7.3%)	3 (10.3%)	3 (10.7%)	4 (15.4%)
	41 (100%)	29 (100%)	28 (100%)	26 (100%)

Data are presented as numbers; percentages are in parenthesis; GOSE: Glasgow Outcome Score- Extended; FU: Follow-up

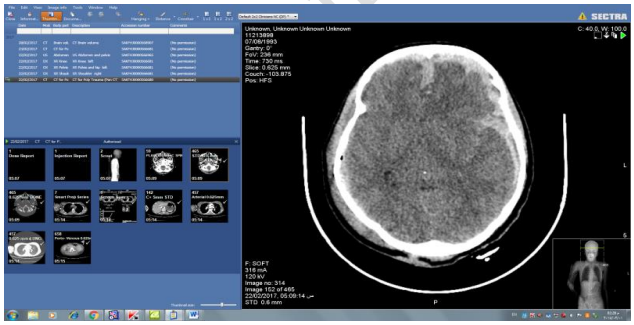

Fig. 1: CT brain showes left subdural hematoma with multiple contusions. Width (Px): 1920, Height (Px): 1080 Color Depth: 24 bit(True color)

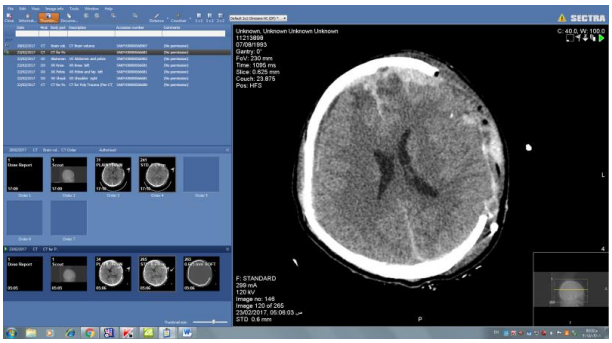

Fig 2: same patient after icp insertion with persistant elevation of icp and decompressive craniectomy. Width (Px): 1920, Height (Px): 1080 Color Depth: 24 bit(True color)

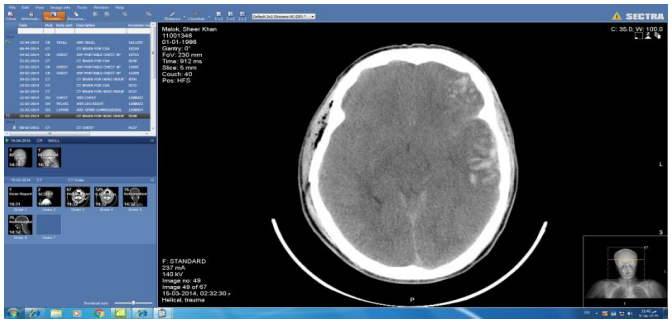

Fig. 3: CT brain showes multiple brain contusions. Width (Px): 1920, Height (Px): 1080 Color Depth: 24 bit (True color)

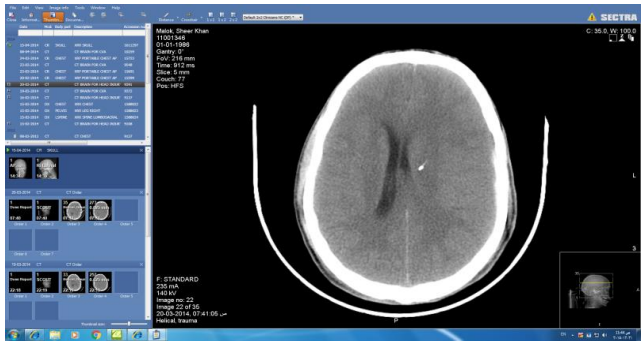

Fig. 4 : Same patient after icp insertion with persistent elevation of ICP Width (Px): 1920, Height (Px): 1080 Color Depth: 24 bit(True color)

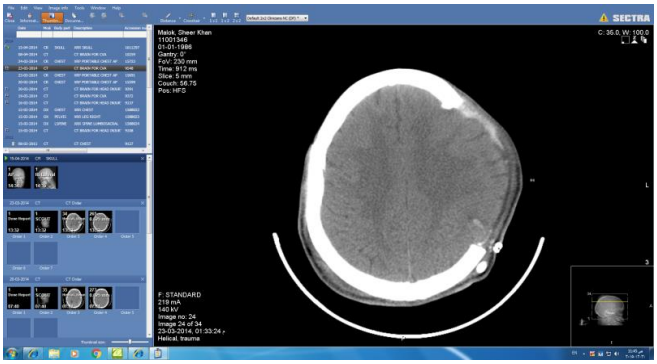

Fig. 5: Same patient after decompressive craniectomy. Width (Px): 1920, Height (Px): 1080 Color Depth: 24 bit(True color)

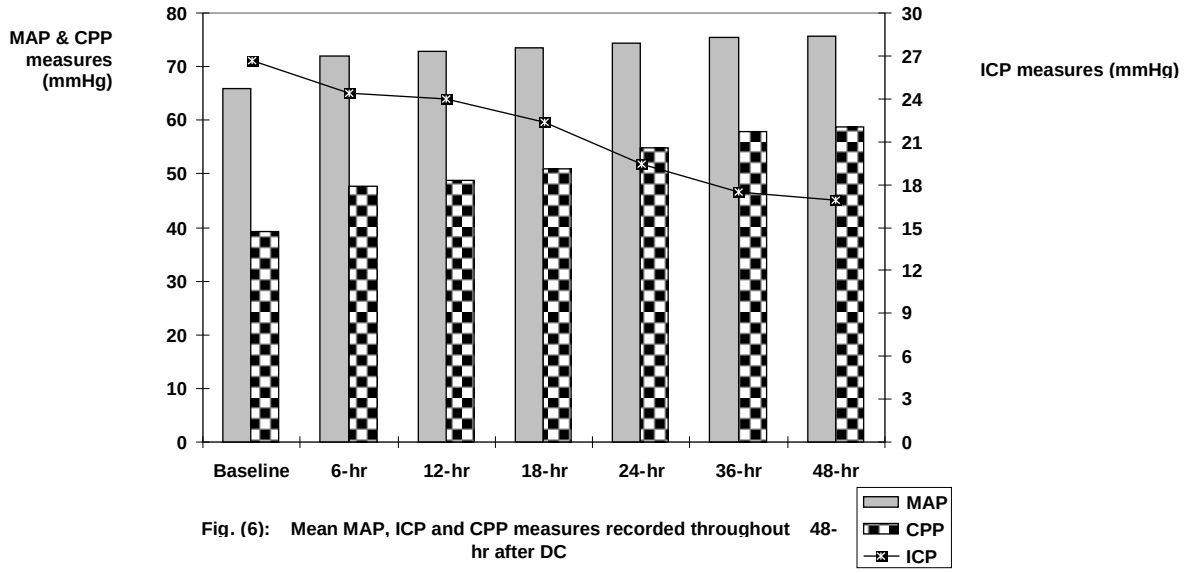

Fig. (6): Mean MAP, ICP and CPP measures recorded throughout 48-hr after DC

Discussion

All studied STBI patients with persistently elevated ICP responded well to decompressive craniectomy (DC) that was conducted as early procedure in 27 patients and late DC in 14 patients. All patients, irrespective of timing of DC, showed significantly lower ICP compared to baseline ICP and had ICP of <20 mmHg by 48-hr PO. Patients had early DC showed rapid improvement of ICP than those had late DC, despite the non-significant difference.

In line with these findings, **Some studies.** [6] documented better control of ICP especially in patients in which a DC surface was made >40 cm^3.**Others also** [24] reported that DC can effectively decrease ICP and increase CPP in patients with TBI and refractory elevated ICP. **Some studies.** [25] found that after DC, there was significant improvement in the overall stability in ICU with stability of blood pressure, CPP, pulse rates and oxygen saturation, and postoperative ICP monitoring in the immediate within 24 hours and within 24-48 hours period showed significant decrease. Recently, **some studies.** [1] reported a mean decrease of mean preoperative ICP by 7.7 mmHg and concluded that DC decreased ICP postoperatively and **Others also.** [26] found DC might effectively reduce ICP and shorten hospital stay in patients with TBI.

Surgical outcome was favorable and PO complications were encountered in only 5 patients **(12.2%)** with no surgery related mortality, **d**espite of the total mortality rate of 29.3%. As regards functional outcome, at time of discharge 12 patients (29.3%) had good recovery, 7 patients (26.9%) had moderate

disability and 11 patients (42.3%) had severe disability, while at 12-m PO, out of 24 survivors; 9 patients (37.5%) had good recovery, another 9 patients (37.5%) had moderate disability and 3 (12.5%) had severe disability. These data indicated a favorable surgical and functional outcome for STBI patients after DC.

Unfortunately, the outcome of DC for management of STBI patients, where **some studies.** [4] documented that early DC does not seem to significantly improve mortality in patients with refractory ICH compared with medical treatment. Also, **other studies.** [7] found primary DC showed 45.5% good outcome and 40.9% mortality, while secondary DC showed 73.1% good outcome and 15.4% mortality.

On contrary, **Some studies.** [27] found craniectomized patients with TBI achieved good long-term outcome and **also others.** [28] documented that early DC in patients with higher GCS may result in better functional outcomes. **Some studies.** [29] suggests that DC in children is not only a life-saving procedure, but also leads to a good functional outcome after severe injury. Thereafter, **Some studies.** [6] reported a mortality rate of 18% vs. 54% of patients underwent early versus late DC and less follow-up CT scans were made when DC procedure, especially early DC was performed and **Other studies.** [26] in meta-analysis of randomized controlled trials of DC versus medical treatment reported that patients receiving DC seemed to have lower odds of death than patients receiving only medical management, despite of the non-significant difference. Recently, **Some studies.** [30] found early DC may be more helpful to improve long-term outcome of patients with refractory raised ICP after moderate and severe TBI and **also other studies.** [31] documented that the benefits of early DC were more impressive with lower rates of unfavorable outcome, in-hospital mortality and cerebral infarctions on follow-up CT scans

In trial to explore mechanisms underlying the beneficial effect of DC, **Some studies.** [32] documented that improvement in perfusion after DC implied an increase in perfusion pressure, likely linked to partial restoration of autoregulation and this increase in perfusion may partially be responsible for improved clinical outcome after DC.

Preoperative and PO monitoring of ICP using the intraparenchymal monitor (IPM) provided valuable help for selection for patients with persistently high ICP and to follow-up the effect of DC on ICP and was free of complications. In support of ICP monitoring

once patients' admission, **Some studies.** [33]**, (2016)** studied 18 studies involving 25229 patients with STBI in a meta-analysis and found overall mortality, hospital mortality, 2-week and 6-month mortality were reduced in ICP monitored patients and documented that patients with an increased ICP were more likely to require ICP monitoring.

In line with the selection and reliance on IPM, **Some studies.** [34] experimentally detected good agreement between minimally invasive and direct Codman intraparenchymal ICP monitoring in response to ICP increase. Clinically, **some studies.** [35] found the risk for hemorrhagic and infectious complications when using the Codman MicroSensor (CMS) ICP monitor is low and documented that to meet the need for ICP monitoring, an intraparenchymal ICP monitoring device should be preferred to the use of an external ventricular drainage (EVD). Recently, **some studies.** [36] retrospectively evaluated ICP measuring accomplished using a variety of monitors placed primarily either in the ventricles or brain parenchyma and found that when all time points were compared, the correlation between EVD and IPM was strong. In accordance of PO monitoring of ICP, **Some studies** [37] documented that ICP monitoring after primary DC for head-injured patients significantly decreases in-hospital mortality to 14.7% vs. 32.7% in patients without PO monitoring.

Conclusion

In patients with severe TBI short-term trial of medical treatment judged by ICP monitoring allows early surgical decision making. Decompressive craniectomy for patients with persistently elevated ICP provided rapid control of ICP with subsequent improvement of CPP and little PO surgery-related morbidity and no mortality. DC provided acceptable functional outcome with good recovery rate of 37.5%. ICP monitoring using intraparenchymal sensor provided satisfactory pre and post-operative monitoring of ICP.

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