Does Size and Site Matter in Therapeutic Decompressive Craniectomy? A Laboratory-Based Experimental Study

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BACKGROUND: **Therapeutic decompressive craniectomy (TDC) controls increased intracranial pressure (ICP). Its role was controversial until its successful introduction to treat malignant middle cerebral artery ischemia. However, standardization of size and site of TDC remains controversial. This study was designed to evaluate whether size and site matter in TDC.**

METHODS: **A replica skull of a patient with refractory increased ICP and successful TDC was used. ICP was increased using an intracranial balloon modified to monitor ICP and permit progressive incremental increases in ICP. When a desired increased ICP was reached, segments of TDC were removed sequentially to increase its size until the ICP normalized. We also measured the volume of air required to raise the ICP back to the increased ICP value.**

RESULTS: **The most effective TDC size to lower increased ICP was 8.3 cm in diameter ($P < 0.001$). However, a 7.5-cm TDC was sufficient to control increased ICP of 25–30 mm Hg ($P < 0.01$). There was strong correlation between TDC size and potential volume created to accommodate brain swelling postoperatively (Pearson correlation coefficient = 0.95928). The location of TDC did not matter when size was ≤3.5 cm or ≥7.5 cm; location mattered when size was 4.5 cm or 5.5 cm, where anteriorly located flaps were more effective in lowering increased ICP and increasing cranial volume ($P < 0.05$).**

CONCLUSIONS: **The size of a TDC is very important in reducing increased ICP. The size should be tailored to the level of increased ICP and the likelihood of further brain swelling postoperatively. A smaller TDC should be located more anteriorly to control increased ICP. Although location is not as important when increased ICP is >30 mm Hg and TDC size ≥8.3 cm is required.**

INTRODUCTION

Increased intracranial pressure (ICP) resulting from traumatic brain injury (TBI) or malignant middle cerebral artery ischemia (MMCAI) is associated with very high morbidity and mortality.[1-4] A meta-analysis of the outcome of patients who had increased ICP secondary to TBI found a mortality rate of 55.6% in patients with increased ICP >40 mm Hg compared with 18.4% in patients with increased ICP <20 mm Hg, along with a 3-fold to 4-fold increase in the chances of death or poor neurologic outcome in patients with increased ICP.[5] Therapeutic decompressive craniectomy (TDC) is a neurosurgical procedure that involves the removal of a large part of the skull and opening the dura mater to overcome the rigid noncompliant nature of the skull, provide room for the swollen brain, reduce ICP, and decrease mortality and morbidity.[6,7] Although TDC is not a new procedure, its optimal indications, timing, size, and location remain uncertain leading to its underuse worldwide. A Cochrane review called for standardization in the surgical technique of TDC and the investigation of timing of TDC, size of TDC, and patient selection.[8] Because it is extremely unlikely that a clinical randomized controlled trial investigating the size and location of TDC would be carried out, owing to logistical and ethical reasons, the following laboratory-based experiments were designed to study the influence of size and location of TDC on control of increased ICP.

Key words
- Decompressive craniectomy
- Intracranial hypertension
- Middle cerebral artery ischemia
- Traumatic brain injury

Abbreviations and Acronyms
ICP: Intracranial pressure
MMCAI: Malignant middle cerebral artery ischemia
TBI: Traumatic brain injury
TDC: Therapeutic decompressive craniectomy

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MATERIALS AND METHODS

Using a three-dimensional printer, a replica human skull was created from reconstructed computed tomography images of a patient who had had refractory increased ICP resulting from TBI. In this patient, a TDC on the left frontoparietotemporo-occipital region controlled the increased ICP, and the patient had good recovery without postoperative complications. The TDC bone defect in the replica skull was repaired using a cranioplasty plate fixed rigidly to the skull. The cranioplasty plate was divided into frontal, occipital, parietal, and temporal segments, which were fixed to each other and to the skull rigidly. The frontal, occipital, parietal, and temporal segments can be removed and reattached sequentially to change the size and location of the TDC with ease. The replica skull was filled with a thick blood pressure balloon that was used to increase the ICP in increments. The balloon had 2 ports that exited the skull through the foramen magnum; the first port was used to continuously measure and monitor the ICP using a Codman ICP transducer (Codman Neuro, Raynham, Massachusetts, USA), and the second port was used to inflate the balloon to increase the ICP by adding air into the balloon using a syringe or a pressure pump (Figure 1).

To validate our model, we performed several experiments to increase ICP using the balloon and the pressure pump with the TDC defect closed and opened. Once we established that the model worked and the results were reproducible, we carried out our investigation of TDC size and location. A normal ICP in these experiments was defined as an ICP of $\leq$15 mm Hg, and an effective TDC was defined as a TDC that normalized the increased ICP to $\leq$15 mm Hg.

When the ICP was increased to the desired level, segments of TDC were removed consecutively to increase the size of the craniotomy until the ICP was normalized. The segments of TDC were also removed in different combinations to investigate the influence of location of the TDC. We also measured the volume of air required to increase the ICP >15 mm Hg, if possible after each TDC that normalized ICP. The volume of air added to increase the ICP >15 mm Hg was used as an indirect measure of the volume created by the TDC to accommodate postoperative brain swelling. The experiments were conducted at increased ICP levels of 20 mm Hg, 25 mm Hg, 30 mm Hg, and 35 mm Hg. Table 1 summarizes the locations, diameters, and surface areas of the TDC tested.

SAS version 9.2 (SAS Institute Inc, Cary, North Carolina, USA) was used to analyze the data sets. To investigate the influence of size on reducing increased ICP, frontal (3.5 cm in diameter, 10.5 cm^2), temporal (4.5 cm in diameter, 16.5 cm^2), frontotemporal (5.5 cm in diameter, 27 cm^2), frontoparieto-occipital (6.5 cm in diameter, 34 cm^2), frontoparietotemporal (7.5 cm in diameter, 43.5 cm^2), and frontoparietotemporo-occipital (8.3 cm in diameter, 54 cm^2) segments were compared. To investigate the influence of location of the TDC, bone flaps of equal sizes in different locations were compared: frontal versus occipital (3.5 cm in diameter, 10.5 cm^2), parietal versus temporal (4.5 cm in diameter, 16.5 cm^2), frontotemporal versus parieto-occipital (5.5 cm in diameter, 27 cm^2), frontoparietal versus temporo-occipital (5.5 cm in diameter, 27 cm^2), and frontoparietotemporal versus occipitoparietotemporal (7.5 cm in diameter, 43.5 cm^2). The mean ICP reductions at different TDC sizes and different locations were compared using Student t test. The mean differences in volume capacity of different TDC sizes and different locations were also compared using Student t test. Differences between groups were considered significant if P was < 0.05.

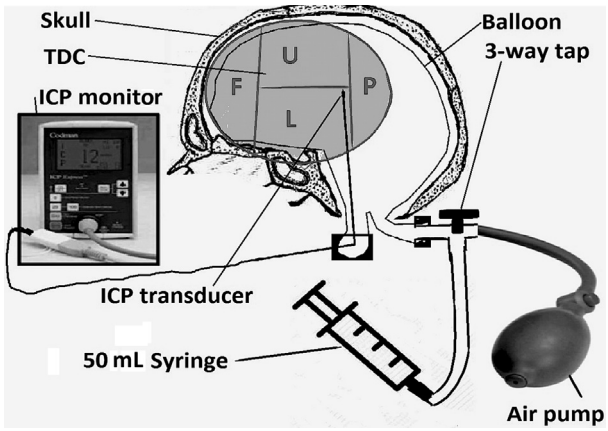

Figure 1. Schematic diagram of experiment setup. ICP, intracranial pressure; TDC, therapeutic decompressive craniectomy; F, frontal TDC segment; L, temporal TDC segment; U, parietal TDC segment; P, occipital TDC segment.

RESULTS

Effect of TDC Size on Increased ICP

The most effective TDC size that controlled increased ICP was a flap size of 8.3 cm in diameter (54 cm^2) ($P < 0.001$). However, a

Table 1. Therapeutic Decompressive Craniectomy Sizes and Locations

Location	Abbreviation*	Flap Diameter (cm)	Flap Surface Area (cm^2)
Frontal	F	3.5	10.5
Occipital	P	3.5	10.5
Temporal	L	4.5	16.5
Parietal	U	4.5	16.5
Frontotemporal	FL	5.5	27.0
Frontoparietal	FU	5.5	27.0
Temporo-occipital	LP	5.5	27.0
Parieto-occipital	UP	5.5	27.0
Temporoparietal	LU	6.5	34.0
Frontoparietotemporal	FUL	7.5	43.5
Occipitoparietotemporal	PUL	7.5	43.5
Frontoparieto-occipitotemporal	FUPL	8.3	54.0

*Corresponding abbreviation in Figure 1.