
Original Article

To Study the effect of Cranioplasty on cerebral blood flow with clinical outcome in a patient who underwent decompressive craniectomy

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Abstract:

TITLE:- To Study the effect of Cranioplasty on cerebral blood flow with clinical outcome in a patient who underwent decompressive craniectomy

Aims: This study was done to evaluate the effect of cranioplasty on CBF with computed tomography perfusion (CTP). It also aimed to determine the correlation between postcranioplasty CBF and clinical outcome.

Settings and Design: Prospective observational study.

Subjects and Methods: All patients had CTP done to determine precranioplasty CBF. CTP was repeated at 6 weeks postcranioplasty and clinical assessment at 6 and 24 weeks postcranioplasty.

Results: The median value of ipsilateral CBF was 52. 9 and 64.10 ml/min/100 g at precranioplasty and postcranioplasty.contralateral CBF also showed improvement from 67.4 to 74. 7 ml/min/100 g at precranioplasty and postcranioplasty.contralateral. Median value for mini mental state examination showed a significant difference with value of 22, 25, and 25.5 at precranioplasty, 6 and 24 weeks postcranioplasty ($P = 0.001$ and $P < 0.001$). Median value for frontal assessment battery was 12, 14.5, and 15 ($P = 0.002$ and $P = 0.001$).

Conclusions: Cranioplasty can improve cortical perfusion for both ipsilateral and contralateral hemisphere. Cranioplasty was observed to have a therapeutic role in terms of clinical outcome improvement.ce

Key words: Cerebral blood flow, clinical outcome, computed tomography perfusion, cranioplasty.

Introduction:-

Cushing in the early 20th century describe the method of decompressive craniectomy procedure for relief of ICP . Decompressive craniectomy (DC) procedure has recently experienced a renewed interest among neurosurgeons . Since then surgical decompressive has been advocated as a treatment for severe brain edema associated with brain injury and infarction.^[2] There was no clearly defined indication for or optimal timing of the procedure. The good outcomes are thought to be due to improved collateral circulation, reduction in tissue edema and improvement in oxygenation and energy metabolism in injured tissues.^[3]

Currently, cosmetic reconstruction and cerebral protection are the main indication for cranioplasty. Cranioplasty is usually performed several months after DC with the lack of specific guidelines on the timing of surgery. Unexpected improvements in patients neurological status have been observed in many centers.^[4,5] Until date, the mechanism of

improvement remains unclear. The atmospheric pressure is transmitted to the cranial cavity through the cranial defect, causing inward rotation of the scalp.^[6] This pressure on the cranial defect can thus cause the neurological deficit. The unprotected brain compression through the cranial defect by the atmospheric pressure can be normalized by cranioplasty.^[7]

Cerebral perfusion improvement after cranioplasty has also been shown by several other studies using transcranial Doppler.^[7,9,10] More recently, the use of CT perfusion imaging to measure CBF has been gaining popularity. This modality is generally easier to be performed and less operator dependent compared to transcranial Doppler and ¹³³Xe CT. Excellent cooperation from the patient is also needed if the technique of measuring CBF is by using ¹³³Xe CT. Besides that, CBF measurement using CT perfusion (CTP) gained much attention partly due to the improved helical scanning, CT scan machine, and advances in the software used to analyze the data which

aid in the accuracy and ease of performing.^[11] The procedure is also minimally invasive with the only intravenous administration of iodinated contrast material. More importantly, CTP has been validated and proven to have excellent correlation with ¹³³Xe CT in the measurement of CBF.^[12]

This study was done with the aim to further establish the hypothesis that cranioplasty not only provides cerebral protection and cosmesis but also improve CBF and clinical outcome.

METHOD :-

Study design:

This was a prospective observational study on patients who have underwent DC for intracranial hypertension requiring reconstructive cranioplasty at from the period of 1 JANUVARY 2016 to 1 MARCH 2017.

Study population

All patients aged over 18 and up to 80 years who underwent DC for intracranial hypertension and requiring reconstructive cranioplasty at Hospital from 1 JANUVARY 2015 to 1 MARCH 2017. They or guardians must also consent to be part of this study. Patient with previous bilateral DC, allergy to contrast, pregnant, or nursing woman will be excluded.

Study schedule

During admission for cranioplasty, CBF, and clinical outcome assessment mini mental state examination (MMSE), Glasgow Outcome Score (GOS), and frontal assessment battery (FAB) were done. Postcranioplasty 6 weeks, a repeat of CBF and clinical outcome assessment was repeated. Subsequently, on 24 weeks postcranioplasty clinical outcome assessment was repeated.

Study procedure and evaluations

CTP analysis was performed using 40-slice CT scanner (SIEMENS, SOMATOM Sensation Open) using a 40-slice long continuous (cine) scan. One hundred and twenty axial images were constructed with three 9.6 mm thick sections which covered a total of 28.8 mm from the level of foramen of Monro to the lateral ventricle. The CT scanner protocols were 80 kV, 209 mA, 1 s per rotation and at 0° gantry. The CTP scan was started with a 4 s delay after the injection of 40 ml of nonionic contrast agent Iopamidol (BRACCO, Iopamiro 370) at a rate of 6 ml/s with an infuser pump (STELLANT, medrad). All CTP scans were analyzed with a software package using an imaging workstation (SIEMENS, Syngo multimodality workplace 2010A). CBF map was generated for each patient and was expressed in ml/min/100 g. CBF were measured in three circular regions of interest at a size of 1 cm², manually drawn on the plain CT brain and averaged CTP images in the ipsilateral hemisphere and then automatically reflected onto the contralateral hemisphere in the midline. In each patient, the CBF was averaged to generate a single value for each hemisphere.

Sample size calculation

Prior data indicate that the standard deviation of preoperation hemispheric CBF was 3.4 and standard deviation for postoperation hemispheric CBF was 3.9.^[8] If the mean difference between pre- and post- hemispheric CBF was 2.6, by using Power and Sample Size Calculation software version 3.0.12 (IBM, United States),^[14] with reference to specific objective 1, we will need to study 18 patients to be able to reject the null hypothesis that this response difference is zero with probability (power) 0.8.

The Type 1 error probability associated with this test of this null hypothesis is 0.05. However, after taken into account of 20% dropout rate, the total sample size required were 22 patients.

RESULT:-

A total of 22 patients were recruited in this study from the period of 1 JANUVARY 2016 to 1 MARCH 2017.in the Neurosurgery Department. From the total of 22 patients, 15 patients (68.20%) were male and 8 patients (31.80%) were female. The patients were aged 19–55 years old with a mean age of 38.73 years old [Table 1].

CBF median value measured in the ipsilateral hemisphere was significantly higher at 6 weeks postcranioplasty (64.10 ml/min/100 g) compared to precranioplasty (52.90 ml/min/100 g) ($P < 0.001$). Similarly, the CBF mean value of the contralateral hemisphere also showed a significant improvement 6 weeks postcranioplasty (74.84 ml/min/100 g) from precranioplasty

(67.45 ml/min/100 g) ($P < 0.001$) [Table 2].

The median value for GOS at precranioplasty, 6 weeks and 24 weeks postcranioplasty was four [Figure 1]. There was no difference in the median value at precranioplasty compared to 6 weeks and 24 weeks postcranioplasty ($P = 0.046$ and $P = 0.014$).The median value for MMSE at precranioplasty, 6 weeks and 24 weeks postcranioplasty was 22, 25 and 25.5, respectively.

It was a statistically significant difference in the median value of MMSE at precranioplasty (22, IQR 12.74) and 6 weeks postcranioplasty (25, IQR 12.50) ($P = 0.001$). At 24 weeks postcranioplasty median value of MMSE (25.5, IQR 13.00), further improved ($P < 0.001$). The median value of MMSE at 6 weeks postcranioplasty (25, IQR 12.50) and 24 weeks postcranioplasty was also significantly different with $P = 0.012$ [Figure 2].

The median value for FAB at precranioplasty, 6 weeks and 24 weeks postcranioplasty was 12, 14.5 and 15, respectively. Median value for FAB precranioplasty showed improvement compared to 6 weeks postcranioplasty from 12 (IQR 10.75) to 14 (IQR 11.35) ($P = 0.002$). At 24 weeks postcranioplasty follow-up, median value for FAB was 15 (11.25) ($P = 0.001$) [Figure 3].

There was no significant correlation between CBF and clinical correlation [Table 3].

Table 1: Demographic analysis

Characteristics	Number of patients (%)
Number of patients	22
Male	15(68.20%)
Female	7(31.80%)
Mean age (years)	38.7
Laterality of craniectomy Right	13(59%)
Left	9(41%)
Cranioplasty material Autologous	10(45.5%)
Titanium	12(54.5%)
Indication for decompressive craniectomy Trauma	17 (77.27)
Ischemic stroke	1 (4.55)
Hemorrhagic stroke	3 (13.64)
Bleeding vascular lesion (AVM)	1 (4.55)
Mean number of weeks between craniectomy and cranioplasty	67.27±66.33

Table 2: Nonparametric Wilcoxon signed -rank

(median value of CBF for ipsilateral and contralateral hemisphere at precranioplasty and 6 weeks postcranioplasty)

Cerebral hemisphere	Median (IQR) CBF precranioplasty (mL/min/100 g)	Median (IQR) CBF 6 weeks postcranioplasty (mL/min/100 g)	Z statistic ^a	P test
Ipsilateral	52.90(28.20)	64.10(33.56)	-4.207	<0.001
Contralateral	67.45(24.30)	74.84(31.24)	-4.207	<0.001

^aWilcoxon signed- rank test. CBF – Cerebral blood flow; IQR – Interquartile range

Table 3: Nonparametric Spearman’s correlation test (CBF and clinical outcome) at 6 weeks postcranioplasty

	Spearman’s correlations	
	CBF ipsilateral 6 weeks postcranioplasty	CBF contralateral 6 weeks postcranioplasty
GOS 6 weeks postcranioplasty Correlation coefficient	0.018	0.005
Significant (two- tailed)	0.935	0.981
<i>n</i>	22	22
FAB 6 weeks postcranioplasty Correlation coefficient	0.076	0.178
Significant (two- tailed)	0.737	0.428
<i>n</i>	22	22
MMSE 6weeks postcranioplasty Correlation coefficient	-0.66	0.120
Significant (two- tailed)	0.770	0.595
<i>n</i>	22	22

Discussion

DC has been widely used for more than a century for the treatment of medically refractory intracranial hypertension for multiple reasons. This procedure is efficient, not complicated and straight forward. DC managed to effectively reduce ICP in 85% of patients who have intracranial hypertension refractory to conventional medical treatment.^[15,16] Long-term results (3 years) and good clinical outcome are also seen in up to 40% of patients who were otherwise most likely to die.^[17]

In the past, the majority of patients after DC will undergo reconstructive cranioplasty for cosmesis or protective reasons. Exceptions are to those who are very old, vegetative, and with poor outcome. However, the results of cranioplasty were beyond cosmetic and protective effect. The reconstructive cranioplasty procedure provides important support and restores normal cerebrospinal fluid flow dynamics and protecting vital structures. Some clinicians actually documented clinical improvement in them; therefore in these recent years, the influence of cranioplasty on clinical outcome has garnered much interest. Patient with sinking skin flap after DC showed unquestionable clinical improvement after cranioplasty.^[20] Globally many researches have concluded from their studies that cranioplasty not only serve as cerebral protection and cosmesis but also for the final patient clinical outcome. Due to the above reason, this study was conducted to evaluate the clinical outcome improvement after cranioplasty,

alongside with CBF improved perfusion. These improvements seen were not limited only to a patient with traumatic brain injury, which was a population of interest in most of the previous studies. In fact, clinical improvement was also seen in the nontraumatic cause for DC.^[11] Our sample population therefore not only limited to traumatic brain injury cases that underwent DC but also included cases of DC for other reasons, as we believe these improvements can also be seen in such cases.

Patients commonly after DC exhibit collapsed hemispheric over the side of the cranial defect. A collection of neurological symptoms is attributed to the collapsed hemispheric such as the neurological deficit, headache, dizziness, fatigue, and psychiatric changes. Syndrome of the sinking skin flap is defined as a presence of neurological deficit with depressed skin at the site of the cranial defect after a large DC.^[6] A similar condition, on the other hand, is characterized by subjective symptoms such as a headache, dizziness, vague discomfort, irritability, and lethargy which is known as a syndrome of trephined.^[19] Both of these conditions most likely were due to a similar mechanism of onset as the symptoms caused by these conditions improve rapidly following cranioplasty.^[11] The pathophysiology of both these syndromes may involve many confounding factors such as CBF, cerebrospinal fluid, and atmospheric pressure.^[6,20,21] Atmospheric pressure acting on the unprotected brain at the bone defect site is said to be the main contributing factor. This will then lead to compression

of the dura with irritation of the underlying cortical tissue and eventually gliosis, therefore, causing neurological deficits. Cranioplasty is said to normalize this situation, by preventing atmospheric pressure acting on the unprotected brain.^[21] A more thorough explanation is published by Segal *et al.*, which attributed the abnormal symptoms to the impediment of venous return and presence of cortical scar tissue.^[22] He suggested that scar tissue produced by injury would increase pressure on the cortex and subarachnoid space along with the compressive effect from the atmosphere. These cumulative effects then alter the cerebral hemodynamics with the resultant of increase in local external pressure on the vessels, which would then reduce the CBF in the area of the cranial defect. However, no concrete evidence to support his explanation until of recent years whereby many studies was done that shows improved perfusion with cranioplasty.^[4,8,11,23,24]

In this study, we sought to define the brain cortical CBF changes before and after cranioplasty for both ipsilateral and contralateral hemisphere. CBF assessment on the contralateral side of the lesion was also included. CBF measurement using Xenon CT was the technique of choice in the past. Recently, newer technologies have made a measurement of CBF more feasible in critically ill patients and less complicated. CTP is currently considered emerging imaging modalities for cerebral hemodynamics measurement.^[11,24] CTP imaging quantitative measurement of CBF gained much attention partly due to the improved helical scanning, CT scan machine and advances in the software used to analyze the data. Besides that, it is also less operator dependent compared to transcranial Doppler and less invasive which only involved intravenous administration of iodinated contrast material. Dynamics of CBF is also proven to be accurately map out by Xenon CT; however, this technique necessitates excellent collaboration from the patient.^[12] Most importantly, CBF measurement via CTP is reported to have good correlation with Xenon CT and, therefore, reliable.^[12]

The selection of candidates was based on convenience sampling mainly due to time and resource limitation in this study. Our patient underwent DC for intracranial hypertension due to multiple initial diagnoses. We did not limit our selection to only traumatic brain injury patient as the objective of our study is to evaluate the improvement of CBF between pre- and post-cranioplasty regardless of initial diagnosis for DC. More so, Sakamoto *et al.* in his case report had shown improvement in CBF in a patient who underwent bone flap removal during treatment of an epidural abscess due to wound infection after clipping of a ruptured aneurysm.^[11] Therefore, the improvement in CBF is not limited only to cases of traumatic brain injury which was the selection criteria for many previous studies.^[13,23]

In our series, among the 22 patients evaluated by CTP pre- and 6 weeks post- cranioplasty, a statistically significant improvement in CBF was noted for both ipsilateral and contralateral hemisphere. For the ipsilateral hemisphere, median cortical CBF was 52.90 (IQR 28.20) ml/min/100 g at

precranioplasty, improved to median cortical CBF of 64.10 (IQR 33.56) ml/min/100 g at 6 weeks postcranioplasty. Similarly, contralateral hemisphere also documented improvement in median cortical CBF with 67.45 (IQR 24.30) ml/min/100 g at precranioplasty to 74.84 (IQR 31.24) ml/min/100 g at 6 weeks postcranioplasty. Both of these findings were statistically significant with $P < 0.001$ (Wilcoxon signed-rank test). Our findings suggest that restorative cranioplasty not only improve on local cortical CBF, but also contralateral cortical CBF. This clinical data were supported by the findings of Sakamoto *et al.* and Sarubbo *et al.* in their studies using CTP and Chibbaro *et al.* by using transcranial Doppler.^[11,13,23] However, in the study of Sarubbo *et al.*, which involved six stable patients with traumatic brain injury after cranioplasty the increment of CBF was only observed between precranioplasty and 7 days postcranioplasty. Further follow-up at 3 months postcranioplasty, CBF actually showed a reduction in value. The explanation to his findings was that the gradual decline in cortical perfusion in the ipsilateral hemisphere over a 3 months period may be due to a restoration of flow compatible with prevailing metabolic demand rather than worsening of perfusion that could trigger ischemic injury as supported by no new clinical deterioration.^[13] For our patients, we believe that the restorative cranioplasty actually normalized the atmospheric pressure acting on the unprotected brain. Therefore, it improved on the ipsilateral and contralateral cerebral hemodynamics in the context of CBF postcranioplasty as suggested by Stula.^[21]

Clinical outcome in terms of GOS, MMSE, and FAB were compared precranioplasty, 6 and 24 weeks postcranioplasty in our series. Both median values of MMSE and FAB showed a significant improvement at precranioplasty compared to 6 and 24 weeks postcranioplasty. These clinical data were corresponding to the studies done by Chibbaro *et al.*, whereby remarkable neurological and cognitive improvement has been recorded at postcranioplasty.^[10,23] However, in their studies the sample populations were limited to those with severe head injury and undergoing early reconstructive cranioplasty. Therefore, cranioplasty was effective not only for cosmesis and cerebral protection but also for the improvement of CBF and neurological deficits (MMSE and FAB). On the other hand, the median value of GOS showed no difference between precranioplasty, 6 weeks and 24 weeks postcranioplasty with all giving a median value of 4. These findings were statistically significant. We believe that this finding may not be the actual scenario as GOS has been criticized for its lack of sensitivity to detect small but clinically significant changes in outcome.^[25] In fact, the extended GOS may potentially address this shortcoming.

Interestingly, in our study we noticed that there was no between CBF and clinical outcome (GOS, FAB, and MMSE) at 6 weeks postcranioplasty (Spearman's correlation test, $P > 0.05$). With these findings, it actually suggested that CBF alone may not be the only factor that determine clinical outcome. The selection of our candidates had a wide age range, different education level, different indication for DC

(trauma vs. nontrauma), time of cranioplasty

(early vs. late), laterality of DC (right vs. left), and choice of cranioplasty material (autologous vs. acrylic vs. titanium), which may have influence on the clinical outcome. Until today, the choice of cranioplasty material and time of cranioplasty (early vs. late) is still inconclusive whether these variables actually affect surgical outcome.^[26-30] But we believe that these variables play a significant role in the surgical outcome and thus affecting the final clinical outcome. Other than that, we also noticed that patient and patient's family member were more actively involved with physiotherapy and rehabilitation activity after cranioplasty. This may be due to the confidence that the patient and patient's family had after the reconstructive cranioplasty which provide cerebral protection. The role of rehabilitation and physiotherapy were undeniably an important factor in contributing to the better clinical outcome. The relationship of rehabilitation intervention and the good functional outcome was also seen in a stroke patient.^[31]

Conclusion

This study suggests that reconstructive cranioplasty after DC for intracranial hypertension can significantly improve cortical CBF not only in ipsilateral but also in the contralateral hemisphere. This is concluded based on higher median CBF value for precranioplasty as compared to 6 weeks postcranioplasty bilaterally. Significant improvement in clinical outcome (MMSE and FAB) was also noted to improve following cranioplasty.

However, there was no significant correlation between improve CBF and clinical outcome. This finding may be attributed to several other confounding factors that will affect the clinical outcome of cranioplasty. Skull defect after DC can severely impair cortical perfusion and clinical outcome. We propose that reconstructive cranioplasty should be done to all patients to improve cerebral perfusion and clinical outcome. Cranioplasty also provides cosmetic correction and cerebral protection which will further boast patient's and caregiver's psychosocial aspect to participate in a rehabilitation program which will then enhance future recovery.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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