Clinical Article

Comparative Study of Outcomes between Shunting after Cranioplasty and in Cranioplasty after Shunting in Large Concave Flaccid Cranial Defect with Hydrocephalus

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Objective : The cranioplasty and ventriculoperitoneal (VP) shunt operation have been used to treat a large cranial defect with posttraumatic hydrocephalus (PTH). The aim of this study was to evlauate the difference of outcomes between in the shunting after the cranioplasty (group 1) and the cranioplasty after the shunting (group 2) in a large flaccid cranial defect with PTH.

Methods : In this study, a retrospective review was done on 23 patients undergoing the cranioplasty and VP shunt operation after the decompressive craniectomy for a refractory intracranial hypertension from 2002 to 2005. All of 23 cases had a large flaccid concave cranial defect and PTH. Ten cases belong to group 1 and 13 cases to group 2. The outcomes after operations were compared in two groups 6 months later.

Results : The improvement of Glasgow outcome scale (GOS) was seen in 8 cases (80.0%) of total 10 cases in group 1, and 6 cases (46.2%) of 13 cases in group 2. Three (75.0%) of 4 cases with hemiparesis in group 1 and 3 of 6 cases (50.0%) in group 2 were improved. All cases (2 cases) with decrease of visual acuity were improved in each group. Dysphasia was improved in 3 of 5 cases (60%) in group 1 and 4 of 6 cases (66.6%) in group 2.

Conclusion : These results suggest that outcomes in group 1 may be better than in group 2 for a large flaccid concave cranial defect with PTH.

KEY WORDS : Large flaccid concave cranial defect · Cranioplasty · Shunt .

INTRODUCTION

Refractory intracranial hypertension (RICH) resulting from a severe brain lesion by a trauma or subarachnoid hemorrhage (SAH) or cerebral infarction, which is one of the most frequent reasons for the death of patients, has been a great challenge for the neurosurgeon. Many studies had addressed the efficacy of the wide decompressive craniectomy for the decreasing of intracranial pressure (ICP) and the improving early prognosis in these patients. However, large skull defects were frequently unappealing cosmetically and hazard to the subjacent brain.

A large cranial defect could lead to the turbulences of cerebrospinal fluid (CSF), circulation hydrodynamic, and cerebral blood perfusion by the atmospheric pressure

followed by hydrocephalus[3,9,10,15,21,31]. Some of these patients may develop the persistent bulging of the brain or even the herniation through the craniectomy site, particularly when associated with development of communicating hydrocephalus[26].

The purpose of this study was to find whether there was the difference between in the outcomes of ventriculoperitoneal (VP) shunt operation after cranioplasty and cranioplasty after VP shunts operation in patients with a flaccid concave or mild convex large cranial defect and hydrocephalus. Because shunt operation performed before cranioplasty in patients with a large cranial defect and hydrocephalus could result in excessive sinking at the craniectomy site due to the atmospheric gradient, we hypothesized that the outcomes in shunt operation after cranioplasty may be better than cranioplasty after shunt operation in these patients.

MATERIALS AND METHODS

Medical records were retrospectively reviewed in patients

with large cranial defects with hydrocephalus resulting from decompressive craniectomy performed for RICH after the brain injury or vascular lesions from 2002 to 2005. The cranial defect was classified into three types (Fig. 1). Type I consisted with a flaccid concave cranial defect. Type II was composed of a flaccid and slightly convex cranial defect. Type III was consisted with a tense convex cranial defect with the brain parenchymal herniation. In this study, type III was excluded because the shunt operation was first option in little doubt. A total of 23 cases underwent second operations (shunt operation after cranioplasty or cranioplasty after shunt operation); 10 cases received the shunt operation after the cranioplasty (M : F=6 : 4, Group 1) and 13 cases underwent cranioplasty after shunt operation (M : F=8 : 5, Group 2). The size of the cranial defect after craniectomy was at least 8 cm × 10 cm.

The criteria of Kishore et al.[15] to establish hydrocephalus were used in this study : 1) a distended appearance of the anterior horns of the lateral ventricles; 2) enlargement of the temporal horns and the 3rd ventricle; 3) normal or absent sulci; 4) if present enlargement of the basal cisterns

and the 4th ventricle; and 5) periventricuar decreased density. In this study, the operation indications for hydrocephalus were included 1) Kishore's criteria[15], 2) hydrocephalic index (HI)[4,18] >40, 3) clinical features, and 4) progressively increase in ventricular size in computed tomographic (CT) scan. The bones were stored at -40°C in our bone bank. The patient's own frozen skull bone was used for cranioplasty in all of patients. The mass lesions or brain swelling was ruled out with the repeated CT scan before the re-implantation of the skull bone was planned.

Shunt implantation (Codman-medos programmable VP shunt, Medos, SA, Le Loche, Switzerland or Medtronic VP shunt, Medtronic, Inc, Mineapolis, USA) was performed for hydrocephalus. The outcomes were evaluated 6 months after the procedures, including the changes in the Glasgow Coma scale (GCS)[29], the Glasgow outcome scale (GOS)[14], hemiparesis with modified muscle strength grading scale[32], dysphasia with our simple new classification (Table 1), the visual acuity, and the complications. Comparisons between the outcomes in two groups were done using paired student's test. The difference was considered as the statistical significance with p value less than 0.05 ($p<0.05$).

Table 1. New grading scale for dysphasia in Inha University Hospital

Grade	Description
0	We don' t understand what patient said, unable to speak simple word
1	We don' t understand what patient said, speaking simple word
2	We understand partially what patient said
3	We understand sufficiently what he said, speaking interruptedly
4	We understand sufficiently what he said, speaking fluently

Table 2. Neurological conditions (Glasgow Coma Scale)

GCS	At craniectomy		At second operation*		6 months later†	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
5-6	5	7	0	0	0	0
7-8	4	5	2	3	0	1
9-10	1	1	2	3	2	3
11-12	0	0	6	7	6	7
13-15	0	0	0	0	2	2

*second operation : shunt after cranioplasty or cranioplasty after shunt, †6 months later means months after the second operation. GCS : Glasgow Coma Scale
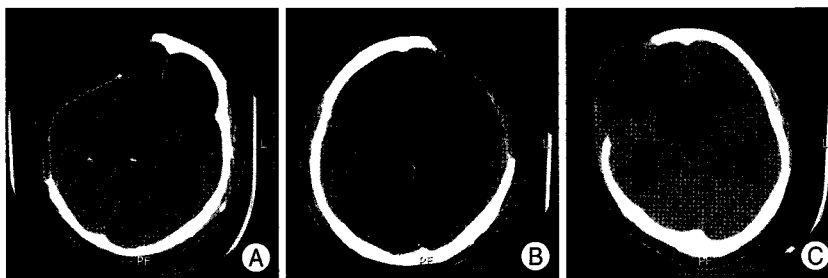

Fig. 1. Computed tomographic images after decompressive craniectomy for refractory intracranial hypertension showing three types of cranial defect based on the degree of brain swelling. Type I (A) : flaccid concave cranial defect, Type II (B) : mild convex cranial defect, Type (C) : tense convex cranial defect (herniation of brain through craniectomy site).

RESULTS

The age of these cases were ranged from 25 to 65 years old, and the average age was 41 years old (14 male and 9 female).

The etiology of the CSF disorder included : 16 cases had decompressive craniectomy after traumatic ICP elevation, 3 cases for a complicated clinical course after SAH and 4 cases after ischemic brain insults.

In group 1, the neurological conditions at craniectomy for RICH were as follows; 5 cases involved in GCS 5-6, 4 cases in GCS 7-8, and 1 case in GCS 9-10, but at the second operation, absent in GCS 5-6, 2 cases in GCS 7-8, 2 cases in GCS 9-10, and 6 cases in GCS 11-12. In group 2, 7 cases involved in GCS 5-6, 5 cases in GCS 7-8, and 1 case in GCS 9-10, but at second operation, absent in GCS 5-6, 3 cases in GCS 7-8, 3 cases in GCS 9-10, and 7 cases in GCS 11-12 (Table 2). These findings indicate the

good effects of large craniectomy for RICH.

Six months later, the neurological conditions in group 1 were as follows; absent in GCS 5-6 and GCS 7-8, 2 cases in GCS 9-10, 6 case in GCS 11-12, and 2 cases in GCS 13-15. But, in group 2, absent in GCS 5-6, 1 case in GCS 7-8, 3 cases in GCS 9-10, 7 cases in GCS 11-12, and 2 cases in GCS 13-15. Neurological conditions were improved in 6 cases (60.0%) in group 1 and 6 cases (46.2%) in group 2, 6 months after the second operation (Table 2). There were no statistically significant difference between two groups ($p>0.05$), but the neurological conditions had a tendency to be improving in group 1 compared to group 2.

Using GOS for evaluating outcomes 6 months later in group 1, 3 cases involved in GOS 5 (none in GOS 5 at second operation), 5 cases in GOS 4 (4 cases), 2 cases in GOS 3 (5 cases). But, in group 2, 3 cases involved in GOS 5 (1 case), 5 cases in GOS 4 (4 cases), 3 cases in GOS 3 (5 cases), and 2 cases in GOS 2 (3 cases). The improvement of GOS was seen in 8 cases (80.0%) of total 10 cases in group 1, but there were 6 cases (46.2%) of 13 cases in group 2 (Table 3).

Before the second operation, there were 4 cases with hemiparesis, 2 cases with decrease of the visual acuity, and 5 cases with dysphasia in group 1, and 6 cases with hemiparesis, 2 cases with the visual defect acuity, and 6 cases with dysphasia in group 2 (Table 4).

In group 1, 3 of 4 cases with hemiparesis, 6 months later after the second operation, the improvement or relief was shown as follows : absent in grade 2 (1 case at the second operation), 2 cases in grade 3 (1 case), and 2 cases in grade 4+ (1 case in grade 4-, 1 case in grade 4). In group 2, 3 of 6 cases with hemiparesis, the improvement or relief was shown as follows : absent in grade 2 (1 case at the second operation), 3 cases in grade 3 (2 cases), 1 case in grade 4 (3 cases), and 2 cases in grade 4+ (absent). The hemiparesis was improved in 3 cases (75.0%) in group 1 and 3 cases (50.0%) in group 2 (Table 4).

Out of the 5 cases with the dysphasia in group 1, 3 cases are improved or relieved symptom after the second operation as follows; there are 1 case in grade 1 (2 cases in grade 1 at the second operation), 2 cases in grade 2 (3 cases), 2 cases in grade 3 (absent). In group 2, the improvement or relief of symptoms was demonstrated in 4 of 6 cases with the dysphasia after the second operation as follows; there are 4 cases in grade 2 (2 cases in grade 1 and 4 cases in grade 2 at the second operation), 2 cases in grade 3 (absent). The dysphasia was improved in 3 of 5 cases (60.0%) in group 1 and 4 of 6 (66.6%) in group 2. The improvement or relief of visual acuity was observed in all of 2 cases in each groups (Table 4).

In group 1, 5 cases complained headache and nausea 3-5 days after shunt operation. CT scan revealed that there was a complication of epidural hematoma (EDH) in 1 case, subdural fluid collection (SDF) in 1 case, which were small amount and the conservative treatment was done (Fig. 2), and more dilation of the ventricle size in 1 case, which the shunt device was changed this conventional shunt with medium pressure to programmable shunt followed by the improvement of clinical features.

In group 2, 2 cases after the shunt operation complained

Table 3. Post-operative outcomes, 6 months later*

GOS	Group 1		Group 2	
	Pre-Op	Post-Op	Pre-Op	Post-Op
1	0	0	0	0
2	1	0	3	2
3	5	2	5	3
4	4	5	4	5
5	0	3	1	3

*6 month later : 6 months after the second operation. Pre-Op : pre-second operation. Post-Op : post-second operation. GOS : Glasgow Outcome Scale

Table 4. Neurological deficits after second operation*

Neurologic deficits	Group 1		Group 2	
	Pre-Op	Post-Op	Pre-Op	Post-Op
Hemiparesis				
Grade 2[†]	1	0	1	0
Grade 3	1	2	2	3
Grade 4-	1	0	0	0
Grade 4	1	0	3	1
Grade 4+	0	2	0	2
Visual acuity				
<1.0	2	0	2	0
>1.0	0	2	0	2
Dysphasia				
Grade 1[†]	2	1	2	0
Grade 2	3	2	4	4
Grade 3	0	2	0	2

*second operation : shunt after cranioplasty or cranioplasty after shunt, [†]grade : modified muscle strength grading scale. [†]grade : new grading scale for dysphasia in Inha university hospital. Pre-Op : pre-second operation, Post-Op : post-second operation
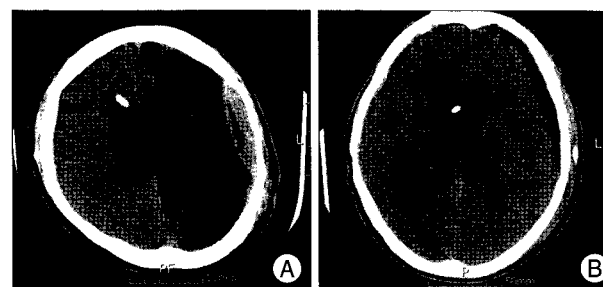

Fig. 2. Computed tomographic images showing epidural hematoma (A) and subdural fluid collection (B) in two different patients who underwent VP shunt operation after cranioplasty.

severe a headache and nausea and scalp flap concavity, repeated CT scans showed the slit ventricle followed by changing the shunt device to programmable shunt device and there were complications of EDH in 2 cases, SDF in 2 cases (Fig. 3), and the postoperative infection in 1 case. Seizure occurred in two cases (Table 5).

Outcomes in group 1 had a tendency to be better than in group 2, but there was no statistically significant difference in outcomes in two groups ($p>0.05$).

DISCUSSION

Commonly, as for RICH in which the non-operative management is ineffective, wide decompressive craniectomy may have an impact on reducing ICP by allowing expansion of edematous brain tissue away from the lateral ventricle, the diencephalon, and mesencephalon by removing portions of the osseous skull[8,16,22]. However, the kinds of complica-

Table 5. Complications after second operation*

Complications	Group 1	Group 2
EDH	1	2
SDF	1	2
Vent. dilatation	1	0
Slit ventricle / Severe concavity	0	2
Infection	0	1
Seizure	0	2

*second operation : shunt after cranioplasty or cranioplasty after shunt. EDH : epidural hematoma, SDF : subdural fluid, Vent. : ventricle
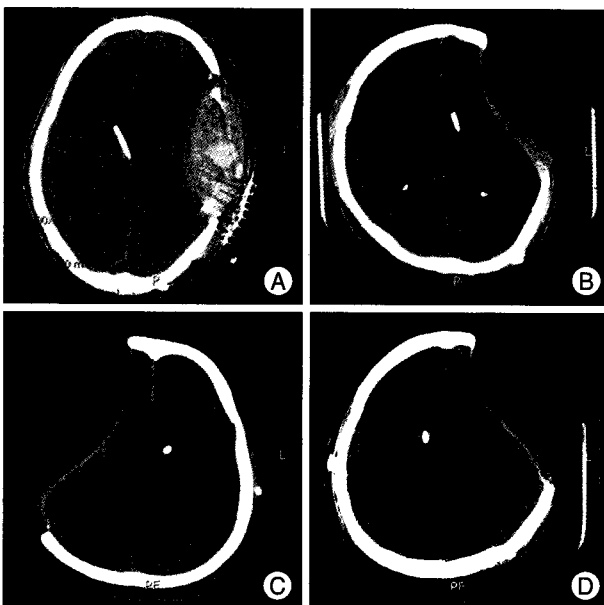

Fig. 3. Computed tomographic images showing complications developed in cranioplasty after VP shunt operation group. A : Epidural hematoma developed after removal of bone flap due to infection. B : Subdural fluid collection. C and D : Severe concavity of skin flap and slit ventricle after shunting.

tions may follow the operation such as skin flap concavity or convexity (the herniation of brain through craniectomy site), EDH, SDF, and hydrocephalus which are disadvantageous to the recover of the patient's neurological function. The symptoms following large craniectomy were reported to described the "syndrome of the trephined (ST)" or "sinking skin flap syndrome (SSFS)"[13,27,30], while Gardner (1945)[12] reported clinical improvement after cranioplasty with tantalum repair.

The physiopathology of ST or SSFS may involve a number of factors. Atmospheric pressure, cerebral blood flow (CBF), cerebrospinal fluid (CSF), and the impediment of venous return have all been implicated in the neurological changes observed before cranioplasty[3,9-11,21,23,24,28]. Gardner's theory[12] that the neurological and cognitive improvement observed in patients subjected to cranioplasty was secondary to the effects of barometric pressure on the cerebral vasculature. The large cranial defects and the sinking of skin onto the dura and brain create a reduction in CBF following by contributing to a change in cerebral perfusion. Therefore, the larger the area of cranial defect, the lower the flow.

Additionally, reductions of metabolism associated with hemicraniectomy in the normal brain tissue were clear. In particular, reduction cerebral metabolic rate of glucose (CMRglc) documented the high susceptibility of oxygen metabolism to perfusional disturbances[22]. The increase of glucose metabolism not only correlates with the restitution of CBF but is a good predictive value for clinical outcome after cranioplasty. Yoshida et al.[31] observed decreased activity of phosphocreatine (PCr) before and a significant improvement after cranioplasty. Phosphocreatinine plays a pivotal role in cellular metabolism, and the increase in its activity after cranioplasty reflects profound changes in mitochondria and neuronal metabolism. Their results showed that there is the correlation between cognitive and clinical function with changes in cerebral perfusion and metabolism. Dujovny et al.[7] explained that large cranial defects induce changes at the cellular level, particularly in the mitochondria and the clinical outcomes observed in cranioplasty is directed to mitochondrial function where the peri-neuronal environment may trigger a switch from the glycolytic pathway towards a more efficient energy state.

Post-traumatic hydrocephalus (PTH) as other complication after large craniectomy was first recognized as early as 1914 by Dandy and Blackfan[6] who described a case of hydrocephalus developing in child after a severe fall. PTH may have a wide range of etiological factors : starting from neuronal loss due to head injury and possible secondary ischemic insults, to obstruction of CSF circulation resulting in hydrocephalus. Most cases of PTH seem to result from

am impairment in the flow and absorption of CSF. Several mechanisms have been proposed to explain the blockage in flow around the convexities, the major one being subarachnoid hemorrhage into the subarachnoid spaces, which tends to block absorption of cerebrospinal fluid secondary to adhesive arachnoiditis of the basal cistern for some time after accident, with subsequent impairment of CSF flow over the cerebral convexities[1,2,5,20]. Blockage of CSF flow also has been associated skull fracture, especially basotemporal fracture[19]. The effect of the skull and dura on CSF hydrodynamics has been explored experimentally : the resistance to CSF outflow after craniectomy decreases two fold and brain compliance (expressed using the pressure-volume index, PVI) increase. This process may be reversed after cranioplasty- that is, a decrease in PVI may be followed by an increase in the resistance to CSF outflow[25].

Commonly, cranioplasty is recommended to be performed 3 to 6 months after the craniectomy, with skull defects bigger than 6 cm[2,23]. This study included patients with large flaccid concave cranial defect (bigger than 80 cm²) and PTH (HI>40). Because a large cranial defect for a long period may result in the impairments of neurological functions, this study was retrospectively reviewed 23 patients undergoing early cranioplasty (8-12 weeks after craniectomy). But, because the skin flap (the scar-plate formed between the cortex, dura, and skin) absorbs the atmospheric pressure in smaller tense cranial defects, they were excluded in this study. Large convex cranial defect with PTH (persistent bulging of brain or even herniation through the craniectomy site) was also excluded in this study, because the shunt operation is first option in little doubt. As for the material for cranioplasty, auto-bone flap was used in all cases, which is cheaper and provide simplified surgical procedure, superior esthetical and psychological effects.

It was well known that atmospheric pressure is transmitted to intracranial fossa by way of systemic circulation. Therefore, the gradient between the atmospheric pressure and intracranial pressure causes an inward displacement of the scalp over a cranial defect[17,29]. We thought that if shunt operation was performed first in patients with flaccid concavity of the large skull defect and PTH, these pressure gradient may be more increased than preoperative state followed by an increase of an inward displacement of the scalp, reduction of CSF circulation and regional perfusion, and a contralateral shift of the midline structures, thus contributing to the impairment of normal brain function and metabolism and the intracranial contents. Therefore, in this study we hypothesized that the outcomes in shunt operation after cranioplasty would be better than cranioplasty after shunt operation in patients with large, flaccid or mild convex cranial defect including PTH.

In group 1 and group 2, the neurological conditions at second operation after craniectomy for RICH was markedly improved compared to at craniectomy. There was no case involved in GCS 5-6 after craniectomy (12 cases at craniectomy), and 13 cases in GCS 11-12 (absent at craniectomy). These findings indicate the good effect of large cranictomy for RICH.

Neurological conditions in both groups, 6 months after the second operation, were improved compared to at the second operation : there were 6 cases (60%) in group 1 and 6 cases (46%) in group 2. Applying to GOS, after second operation, the outcomes in group 1 (80%) and group 2 (46%) were improved compared to at the second operation. But, there was no statistical significance between two groups ($p>0.05$). This may be due to small number of cases and short follow-up period, but outcomes in group 1 had a tendency to be more improving compared to group 2.

In this study, shunt devices with medium pressure were usually used for PTH, to reduce the risk of some complication such as EDH, SDF, and slit ventricle. In this study, there were 1 case of EDH, 1 case of SDF, and 1 case of ventricular dilatation in group 1. In case of ventricular dilatation, shunt device was changed with programmable shunt device followed by improvement of clinical features. We thought that after cranioplasty, the expanded ventricles may, via the cerebral mantle, obstruct the lumen of the cortical subarachnoid space and increase the resistance to CSF flow. Conservative care was taken for EDH or SDF for small amount.

In group 2, there were 2 cases of EDH, 2 cases of SDF, 2 cases of slit ventricle, 1 case of infection, and 2 cases of seizure such as a complication after second operation. In 2 cases with slit ventricle, one week later, the craniectomy site became excessively sunken, followed by neurological deterioration and aggravated concavity of the scalp flap, especially in an upright position. They improved significantly after changing shunt device (programmable shunt device) and cranioplasty. Programmable shunt device was initially programmed between 130 to 150 mmH₂O to avoid excessive brain collapse. We believe that this benefit was due to the relief of the pressure gradient between the atmosphere and the intracranial space.

Neurological impairments such as hemiparesis, visual defect acuity, and dysphasia were improved or relieved more or less, but memory disturbance was minimally affected.

It is very important how to expand the concave space. Therefore, a simple procedure for expansion of the depressed concave space before performing cranioplasty is prudent and valuable. In this study, we proposed a simple technique to occlude the shunt tube before cranioplasty and to be the

head-down position on operation. It is supposed to be a simple, useful, minimally invasive procedure to safely and effectively eliminate the dead space between the skull plate and the dura, and lessen the risk of hematoma complicating a cranioplasty.

Although the number of patients studied was still small, we are going to try prospective and retrospective contrastive studies to further confirm the effects of these procedures on large concave flaccid cranial defect with PTH. More long term follow-up studies with the large numbers of patients are necessary in order to fully evaluate the difference between two groups.

CONCLUSION

We conclude that the outcomes of shunt operation after cranioplasty tend to be better than cranioplasty after shunt operation and if cranioplasty is not contraindication in these patients with large, concave flaccid skull defect, the implantation of patient's own skull bone as early as possible may be better than later cranioplasty (>3-6 months) prior to appearance of delayed neurological impairment.

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