Comparison of Postoperative Complications between Simultaneous and Staged Surgery in Cranioplasty and Ventriculoperitoneal Shunt Placement after Decompressive Craniectomy

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ABSTRACT

Objective: Cranioplasty (CP) and ventriculoperitoneal shunt (VPS) are required procedures following decompressive craniectomy (DC) for craniofacial protection and to prevent hydrocephalus. This study assessed the safety and efficacy of simultaneous operation with CP and VPS after DC, and determined the preoperative risk factors for postoperative complications.

Methods: Between January 2009 and December 2019, 81 patients underwent CP and VPS in simultaneous or staged operations following DC. Cumulative medical records and radiologic data were analyzed using univariate analysis to identify factors predisposing patients to complications after CP and VPS.

Results: CP and VPS were performed as simultaneous or staged operations in 18 (22.2%) and 63 (77.8%) patients, respectively. The overall postoperative complication rate was 16.0% (13/81). Patients who underwent simultaneous CP and VPS were significantly more likely to experience complications when compared with patients who underwent staged operations (33.3% vs. 9.6%, \(p<0.01\)). Univariate analysis revealed that simultaneous CP and VPS surgery was the only significant predictor of postoperative complications (\(p=0.031\)).

Conclusion: This study provided detailed data on surgical timing and complications for CP and VPS after DC. We showed that simultaneous procedures were a significant risk factor for postoperative complications.

Keywords: Cranioplasty; Ventriculoperitoneal shunt; Craniectomy; Complications

INTRODUCTION

Decompressive craniectomy (DC) is a critical treatment option for refractory intracranial hypertension. It is caused by traumatic brain injury (TBI), subarachnoid hemorrhage (SAH), intracerebral hemorrhage (ICH), and cerebral infarction. Cranioplasty (CP) is required after DC for craniofacial protection, cosmesis, and improving neurologic outcomes. DC is performed with a large cranial defect for decompression; therefore, it can lead to...
secondary hydrocephalus due to interruptions in cerebrospinal fluid (CSF) circulation and cerebral blood perfusion. Furthermore, 5%-15% of patients with DC require an additional ventriculoperitoneal shunt (VPS).\(^3\),\(^6\),\(^19\)

The correct timing for the CP and VPS is not well established; neurosurgeons decided this by considering the patient’s condition, prognosis, and economic situation. Simultaneous surgery occurs when CP and VPS are performed in one stage. This is advantageous because it shortens patient hospital stays, reduces hospitalization costs, and increases hospital resource efficiency.\(^20\) However, recent studies have reported controversial complication rates when the simultaneous approach is used.\(^12\),\(^18\),\(^22\),\(^24\) Therefore, the purpose of this study was to compare the postoperative complication rates and preoperative risk factors in patients who underwent simultaneous or staged operations with CP and VPS.

**MATERIALS AND METHODS**

**Study population and surgical procedures**

Between January 2009 and December 2019, 81 patients were treated with CP and VPS in simultaneous or staged operations following DC in our institution. DC was performed for refractory intracranial hypertension despite the best medical treatment. Medical records were retrospectively reviewed for patient variables including gender, age, hypertension, diabetes mellitus, hyperlipidemia, antiplatelet medication, smoking or alcohol use, clinical presentation (TBI, SAH, ICH, cerebral infarction, arteriovenous malformation [AVM]), cranial defect size, brain bulging before CP, and hydrocephalus index.

Patients were divided into the simultaneous or staged operation groups based on their surgical treatment. Of the 81 patients, 18 patients underwent simultaneous VPS and CP, and 63 patients underwent staged VPS and CP. Among the patents with staged operations, 37 patients received the CP after VPS and 26 patients underwent VPS after CP. Autologous bone, which had been stored in our bone bank, was placed during CP in 79 patients. Two patients received custom-made titanium mesh (Cusmedi, Suwon, Korea). We inserted a Codman Hakim programmable valve (Codman/Johnson & Johnson, Raynham, MA, USA) in 57 patients, 9 received the Strata adjustable valve (Medtronic, Minneapolis, MN, USA), 7 received a CSF-Flow Control valves (Medtronic), 6 received the Miethke proGAV Programmable Shunt System (Aesculap, Tuttingen, Germany), and 2 received Codman Certas programmable valve (Codman/Johnson & Johnson). We typically set the shunt valve pressure with 70–100 mmH\(_2\)O according to the initial CSF pressure, which was later adjusted with reference to the computed tomography (CT) data within 24 hours of all operations. We selected the CSF-Flow Control valves with reference to the EVD pressure that patients had undergone before the VPS.

We shaved all patient hair the day before VPS and CP, and draped their head and abdomen with alcohol and povidone-iodine using sterile towels. Prophylactic antibiotics were administered before the skin incision. Radiographic images of chest, abdomen, and skull were checked routinely. CT was performed within 24 hours of all operations, and one week, 2 weeks, and one month after DC. Any neurological deterioration after surgery was immediately assessed via brain CT.
Assessment of hydrocephalus, cranial defects, and brain bulging

If ventricular enlargement was showed on brain CT, we suspected hydrocephalus. This was defined using the following criteria: bifrontal index (the ratio of maximum width of the frontal horn to the width of the inner table) >0.3 on brain CT; increasing ventricular size compared with immediate post-operative brain CT; and improvement of neurological status after lumbar drainage. Cranial defect size was classified into 2 groups based on the maximum diameter. A small unilateral cranial defect was defined as a maximum diameter that was less than half the hemispheric diameter. A large cranial defect was defined as a maximum diameter greater than half the hemispheric diameter. Brain bulging was classified into 2 types: flaccid concave and tense convex cranial defect. The flaccid concave cranial defect was defined as the brain being completely beneath the plane of the cranium. Tense concavity was defined as the brain being completely or partly above the plane of the cranium.

Post-operative complications were classified into epidural abscess, brain abscess, shunt infection, epidural hemorrhage, intraventricular hemorrhage, and pneumocephalus. Furthermore, any complications that triggered severe neurological impairment and caused reoperation were recorded.

Statistical analysis

Continuous variables were expressed as mean±standard deviation (range) and categorical data were expressed as frequencies and percentages. To evaluate risk factors predisposing complications after VPS and CP, univariate analysis was applied and a 2-tailed p-value <0.05 was considered statistically significant. Data were analyzed using and Statistical Package for the Social Sciences (SPSS, Version 25; IBM, Armonk, NY, USA).

RESULTS

Baseline patient characteristics

A total of 81 patients (39 female, 48.1%; mean age 61.3±14.6; age range 24–84 years) were included in this study. VPS and CP were performed in 29 patients (35.8%) with TBI, 31 patients (38.3%) with SAH, 11 patients (13.6%) with ICH, 7 patients (8.6%) with cerebral infarction, and 3 patients (3.7%) with cerebral AVM. Most of the cranial defects were larger than half of the hemisphere (86.4%). In the last brain CT before the CP operation, tense convex and flaccid concave accounted for 90.1% and 9.9% of brain bulging, respectively. The mean hydrocephalus index was 0.36±0.07. Six patients underwent bilateral craniectomy (7.4%). Baseline characteristics between staged and simultaneous groups were similar except incidence of TBI and hydrocephalus index. Detailed characteristics are described in TABLE 1.

Timing of surgery and post-operative complications

The number of patients who underwent VPS after CP was 26 (32.1%), CP after VPS was 37 (45.7%), and simultaneous surgery was 18 (22.2%). Total complications of simultaneous group were significantly higher than those of staged group (33.3% vs. 9.6%, p<0.01). Among the 13 (16.0%) patients with complications that required an additional surgery, 4 (30.8%) were in the VPS after CP group, 3 (23.1%) were in the CP after VPS group and 6 (46.1%) were in the simultaneous group. The mean interval time (days) from DC to CP was 93.9±74.7, 115.4±94.5, and 59.8±29.4, respectively, in the staged VPS after CP, CP after VPS, and simultaneous groups. The interval times (days) from DC to VPS were 270.4±300.5, 76.7±72.6, and 59.8±29.4 respectively. The mean CP surgery times (minutes) were 149.0±52.6,
Risk factors analysis for complications

The overall postoperative complication rate was 16.0% (13/81). Intracranial abscesses (epidural and brain abscesses) developed in 7 patients (8.6%) and mechanical infection in 103 patients. Intracranial abscesses developed in 7 patients (8.6%) and mechanical infection in 103.

**TABLE 1.** Comparison of baseline characteristics of patients with CP and VPS

| Variables                  | Total (n=81) | Simultaneous surgery (n=18) | Staged surgery (n=63) | p-value |
|----------------------------|--------------|------------------------------|-----------------------|---------|
| Mean age (years)           | 61.3±14.6    | 60.9±15.3                    | 62.5±12.4             | 0.68    |
| Female                     | 39 (48.1)    | 12 (66.7)                    | 27 (42.9)             | 0.13    |
| Smoking                    | 26 (32.1)    | 3 (16.7)                     | 23 (36.5)             | 0.15    |
| Alcohol                    | 35 (43.2)    | 5 (27.8)                     | 30 (47.6)             | 0.22    |
| Antiplatelet medication    | 20 (24.7)    | 5 (27.8)                     | 15 (23.8)             | 0.97    |
| Hypertension               | 39 (48.1)    | 7 (38.9)                     | 32 (50.8)             | 0.53    |
| Diabetes mellitus          | 14 (17.3)    | 1 (5.6)                      | 13 (20.6)             | 0.17    |
| Hyperlipidemia             | 7 (8.6)      | 2 (11.1)                     | 5 (7.9)               | 0.65    |

Initial presentation

| TBI                        | 29 (35.8)    | 2 (11.1)                     | 27 (42.9)             | 0.01    |
| SAH                        | 31 (38.3)    | 10 (55.6)                    | 21 (33.3)             | 0.15    |
| ICH                        | 11 (13.6)    | 2 (11.1)                     | 9 (14.3)              | 1.00    |
| Cerebral infarction        | 7 (8.6)      | 3 (16.7)                     | 4 (6.3)               | 0.18    |
| AVM                        | 3 (3.7)      | 1 (5.6)                      | 2 (3.2)               | 0.53    |

Cranial defect size

| Less than half hemisphere  | 11 (13.6)    | 4 (22.2)                     | 7 (11.1)              | 0.25    |
| More than half hemisphere  | 70 (86.4)    | 14 (77.8)                    | 56 (88.9)             | 0.25    |

Brain bulging before CP

| Tense convex               | 73 (90.1)    | 18 (100)                     | 55 (87.3)             | 0.19    |
| Flaccid concave            | 8 (9.9)      | 0 (0)                        | 8 (12.7)              | 0.19    |
| Hydrocephalus index        | 0.36±0.07    | 0.37±0.08                    | 0.34±0.03             | 0.01    |

Bilateral craniectomy

| Less than half hemisphere  | 4 (7.4)      | 1 (1.6)                      | 5 (7.9)               | 1.00    |
| More than half hemisphere  | 56 (86.4)    | 14 (22.2)                    | 42 (65.3)             | 1.00    |

Values are presented as mean±standard deviation or number (%).

CP: cranioplasty, VPS: ventriculoperitoneal shunt, TBI: traumatic brain injury, SAH: subarachnoid hemorrhage, ICH: intracerebral hemorrhage, AVM: arteriovenous malformation.

**TABLE 2.** Comparison of complications between staged and simultaneous surgery

| Complications              | Simultaneous surgery (n=18) | Staged surgery (n=63) | p-value |
|----------------------------|----------------------------|-----------------------|---------|
| Total                      | 7 (31.3)                   | 6 (11.1)              | <0.01   |
| Epidural abscess           | 4 (6.3)                    | 1 (5.6)               |         |
| Brain abscess              | 1 (5.6)                    | 1 (5.6)               |         |
| Shunt infection            | 2 (3.2)                    | 0 (0)                 |         |
| Epidural hemorrhage        | 0 (0)                      | 2 (3.2)               |         |
| Intraventricular hemorrhage| 0 (0)                      | 1 (5.6)               |         |
| Pneumocephalus             | 0 (0)                      | 1 (5.6)               |         |

Values are presented as number (%).

**TABLE 3.** Comparison of characteristics and complications according the surgical timing

| Variables                  | VPS after CP (n=26) | CP after VPS (n=37) | Simultaneous surgery (n=18) |
|----------------------------|---------------------|---------------------|----------------------------|
| Interval from DC to CP     | 93.9±74.7           | 115.4±94.5          | 59.8±29.4                  |
| Interval from DC to VPS    | 270.4±300.5         | 76.7±72.6           | 59.8±29.4                  |
| CP surgery time            | 149.0±52.6          | 142.5±39.7          | 180.8±47.1*                |
| VPS surgery time           | 67.1±32.1           | 62.1±27.6           | 180.8±47.1*                |
| Surgery site               |                      |                     |                            |
| Same side                  | 8 (30.8)            | 7 (18.9)            | 7 (38.9)                   |
| Opposite side              | 18 (69.2)           | 30 (81.1)           | 11 (61.1)                  |

DC: decompressive craniectomy, CP: cranioplasty, VPS: ventriculoperitoneal shunt.

*The sum of the time of CP and VPS.
Intracranial hemorrhage (epidural and intraventricular hemorrhage) developed in 3 patients (3.7%) and pneumocephalus in one patient. The risk factors for VPS and CP complications were evaluated using the following variables: sex, age, hypertension, diabetes mellitus, hyperlipidemia, antiplatelet medication, smoking or alcohol use, clinical presentation (TBI, SAH, ICH, cerebral infarction, AVM), cranial defect size, brain bulging before CP, location of surgery site, and simultaneous surgery. The univariate analysis revealed that simultaneous surgery was indicated as the sole significant risk factor of postsurgical complication after VPS and CP ($p=0.031$) (TABLE 4).

**DISCUSSION**

DC is one of the important neurosurgical practice controlling intracranial pressure for traumatic and hemorrhagic patients with refractory intracranial hypertension. However, some of these patients also have post-hemorrhagic or port-traumatic hydrocephalus and VPS is required for patients undergone DC in 8%–10% after all acute phases of management. In addition, CP is required after DC for brain protection, to improve brain perfusion, and stabilize CSF hydrodynamics. However, VPS and CP remain a concern for neurosurgeons because of the risk of unexpected complications (such as surgical site infection, intracranial hemorrhage, and mechanical malfunction). Furthermore, the proper timing of these 2 procedures relies on the surgeon’s individual preferences and policies due to the lack of evidence or comprehensive guidelines. Many factors are associated with an increased risk of postoperative complications. In line with the results of this study, previous reports have shown that patients who underwent simultaneous VPS and CP had a higher rate of complications when compared with the staged group.

Traditionally, a prolonged time interval between DC and CP is used to reduce the incidence of complications. However, early CP within 3 months after DC has been reported. Several studies have shown a similar postoperative complication rate between early CP and prolonged CP groups.

### TABLE 4. Risk factor analysis for complication after CP and VPS

| Variables                      | Complication | Univariate analysis |
|-------------------------------|--------------|---------------------|
|                               | (-) (n=68)   | (+) (n=13)          | OR (95% CI) | p-value |
| Female                        | 31 (45.6)    | 8 (61.5)            | 1.910 (0.567–6.436) | 0.297   |
| Age (<60 years)               | 35 (51.5)    | 8 (61.5)            | 1.509 (0.448–5.081) | 0.505   |
| Hypertension                  | 31 (45.6)    | 8 (61.5)            | 1.910 (0.567–6.436) | 0.297   |
| Diabetes mellitus             | 11 (16.2)    | 3 (23.1)            | 1.555 (0.367–6.579) | 0.549   |
| Smoking                       | 22 (32.4)    | 4 (30.8)            | 0.929 (0.258–3.351) | 0.911   |
| Alcohol                       | 30 (44.1)    | 5 (38.5)            | 0.792 (0.235–2.670) | 0.706   |
| Antiplatelet medication       | 16 (23.5)    | 4 (30.8)            | 1.444 (0.392–5.323) | 0.581   |
| TBI                           | 26 (38.2)    | 3 (23.1)            | 0.485 (0.102–1.926) | 0.303   |
| SAH                           | 26 (38.2)    | 5 (38.5)            | 1.010 (0.298–3.419) | 0.988   |
| ICH                           | 8 (11.8)     | 3 (23.1)            | 2.250 (0.509–9.946) | 0.285   |
| Cerebral infarction           | 5 (7.4)      | 2 (15.4)            | 2.291 (0.394–13.229) | 0.356   |
| Cranial defect size (>half hemisphere) | 60 (88.2)  | 10 (76.9)         | 0.444 (0.101–1.965) | 0.285   |
| Brain bulging before CP (flaccid concave) | 6 (8.8)    | 2 (15.4)            | 1.879 (0.335–10.534) | 0.473   |
| Bilateral craniectomy         | 5 (7.4)      | 1 (7.7)             | 1.050 (0.112–9.804) | 1.000   |
| Surgery site (same side)      | 18 (26.5)    | 4 (30.8)            | 1.235 (0.338–4.508) | 0.750   |
| Simultaneous surgery          | 12 (17.6)    | 6 (46.2)            | 4.000 (1.139–14.047) | 0.031   |

Values are presented as number (%).
CP: cranioplasty, VPS: ventriculoperitoneal shunt, OR: odds ratio, CI: confidence interval, TBI: traumatic brain injury, SAH: subarachnoid hemorrhage, ICH: intracerebral hemorrhage.
Complication rates are related to many factors, such as cranial defect size and surgical materials. Park et al.\textsuperscript{16} have reported that a large cranial defect can cause insufficient blood supply to the end of the skin flap, which increases complications, and the infection rate of the autogenous bone is reported as 0%–33%\textsuperscript{14,15}. In this study, the autogenous bone was placed during CP in 79 patients and 2 received custom-made titanium mesh. All of 13 patients with complication were autogenous bone.

Hydrocephalus is the most common morbidity in post-traumatic or post-hemorrhagic patients with DC. It affects intracranial pressure, CSF circulatory, and cerebral blood perfusion. VPS is required to manage hydrocephalus in patients with progressive ventricular dilation on serial CT, and the complications of VPS include intracranial hemorrhage, surgical site infection, wound healing problems, and mechanical valve malfunction.\textsuperscript{17}

Simultaneous surgery of CP and VPS is associated with a higher incidence rate than staged surgery. Heo et al.\textsuperscript{12} have retrospectively reviewed 51 patients who underwent CP and VPS procedures. The overall complications rates after CP and VPS are 56% and 21% in the simultaneous and staged groups, respectively, including a significantly higher rate of infection (19% vs. 5%). The authors suggest that the difficulty of adjusting shunt pressure during the simultaneous procedure could have caused subdural fluid collection and subdural hematoma. Moreover, Schuss et al.\textsuperscript{18} have reported 100 patients with similar results and reveal that simultaneous CP and VPS has a higher risk of complications than staged surgery (47% vs. 12%). Furthermore, patients have a significantly higher rate of infection in the simultaneous group (41% vs. 0%). In the present study, we retrospectively reviewed 81 patients who had undergone VPS and CP. The complication rate of simultaneous vs. staged CP and VPS was analyzed. We found significantly different complication rates of 33.3% and 11.1% in the simultaneous and staged groups, respectively. Interestingly, the infection rate was 11.1% in both groups. The rate of non-infective complications, such as epidural hemorrhage, intraventricular hemorrhage, and pneumocephalus was 22.2% and 0% in the simultaneous and staged groups, respectively. Compared with other studies, our study showed a higher rate of non-infective complications than infective complications.

The advantages of simultaneous surgery include shortening the patient hospital stay, reducing hospitalization costs, and increasing hospital resource efficiency; however, the safety of these procedures is an important consideration. Both CP and VPS are vulnerable to infection caused by the materials used, such as autogenous bone and mechanical shunt valves. Our results showed that simultaneous surgery may increase the incidence of complications, which should aid the surgeon in their decision for such operations.

The limitations of this study include its retrospective design and confinement to a single institution with a small sample size. The treatment decision was based on the patient’s clinical status and the preference of neurosurgeons, which potentially introducing bias. However, we believe that our data can be used to support treatment decisions. Simultaneous CP and VPS surgery was associated with higher non-infection complication rates than infections, which is different from other studies. Further, prospective studies are required to definitively evaluate complication rates of CP and VPS patients.
CONCLUSION

Simultaneous surgery was the sole significant risk factor of postsurgical complication after CP and VPS. We conclude that simultaneous surgery should be avoided, and staged operations should be performed when possible after DC.

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