Ventricular pressure monitoring during bilateral decompression with dural expansion

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Object. The management of massive brain swelling remains an unsolved problem in neurosurgery. Despite newly developed medical and pharmacological therapy, the rates of mortality and morbidity caused by massive brain swelling remain high. According to many recent reports, surgical decompression with dural expansion is superior to medical management in patients with massive brain swelling. To show the quantitative effect of decompressive surgery on intracranial pressure (ICP), the authors performed a ventricular puncture and measured the ventricular ICP continuously during decompressive surgery and the postoperative period.

Methods. Twenty patients with massive brain swelling who underwent bilateral decompressive craniectomy with dural expansion were included in this study. In all patients, ventricular puncture was performed at Kocher’s point on the side opposite the massive brain swelling. The ventricular puncture tube was connected to the continuous monitor via a transducer device. The ventricular pressure was monitored continuously, during the bilateral decompressive procedures and postoperative period.

The initial ventricular ICP was variable, ranging from 16 to 65.8 mm Hg. Immediately after the bilateral craniectomy, the mean ventricular ICP decreased to 50.2 ± 16.6% of the initial ICP (range 5–51.5 mm Hg). Additional opening of the dura decreased the mean ICP by an additional 34.5% and reduced the ventricular pressure to 15.7 ± 10.7% of the initial pressure (range 0–15 mm Hg). Ventricular pressure measured postoperatively in the neurosurgical intensive care unit was lowered to 15.1 ± 16.5% of the initial ICP. The ventricular ICP trend in the first 24 hours after decompressive surgery was an important prognostic factor; if it was greater than 35 mm Hg, the mortality rate was 100%.

Conclusions. Bilateral decompression with dural expansion is an effective therapeutic modality in the control of ICP. To obtain favorable clinical outcomes in patients with massive brain swelling, early decision making and proper patient selection are very important.

Key Words • intracranial pressure • decompressive surgery • bilateral craniectomy • dural expansion • massive brain swelling

When medical management fails to alleviate massive brain swelling, treatment options are few. The patients will either die or survive with significant neurological disability.27,28,30,40,41 Despite modern highly developed monitoring systems5,50,59 and medical treatment options,7,37,39,51 the mortality and morbidity rates for patients with massive brain swelling remain high.41,52 Medical treatment is frequently ineffective for such severe brain swelling. The initial strategy for managing these patients is to repair the primary damage from the causative event and to then lower the intracranial pressure (ICP) to minimize subsequent brain damage, or both. Because ICP elevation is a major predictor of death in these patients,41 it is logical to conclude that a maximum effort aimed toward preventing intracranial hypertension is warranted.50,51 Many previous authors have reported the benefits as well as limitations of decompressive craniectomy in patients with stroke12,18,27,33,43,44,49 and trauma.8,10,20–22,52,40,42,54,58 However, there are no reports in the literature that definitely and quantitatively document the decrease in ICP following decompressive craniectomy and dural expansion. To show the quantitative effect of decompressive surgery on the ICP distribution, we performed ventricular punctures and checked ventricular ICP continuously during decompressive surgery and the postoperative period.

Clinical Material and Methods

Patient Population

Between March 1998 and November 1998 20 patients with massive brain swelling treated with bilateral decompressive craniectomy and dural expansion were included in this study. There were 15 males and five females with a mean age of 42.9 years (range 7–62 years). Six patients had head trauma and 14 had cerebrovascular insults (Table 1). Standard management included completion of computerized tomography (CT) scanning as rapidly as possible at the time of presentation to the emergency room or when the neurological deterioration was discovered. Computerized tomography scans obtained in these patients revealed massive brain swelling that was either unilateral (17 patients) or bilateral (three).
Indications for Surgery and Postoperative Management

The indications for decompressive craniectomy were the appearance of massive uni- or bilateral brain swelling on CT scans, with correlating clinical deterioration; worsening of Glasgow Coma Scale (GCS) score and/or dilation of pupils unresponsive to light; midline shift of more than 6 mm; and/or obliteration of perimesencephalic cistern on CT scans. Patients with primary fatal brainstem failure, as indicated by an initial and persisting GCS score of 3 and/or bilaterally fixed and dilated pupils, did not undergo surgical decompression. After the decompressive surgery, conventional medical management, including hyperosmotic agents, hyperventilation, and extraventricular drainage (EVD), were initiated if the ventricular pressure exceeded 20 mm Hg.

Operative Procedures

The operation was performed after endotracheal induction of anesthesia in the patient. The patient was placed supine, and the ventricular puncture was performed at Kocher’s point on the side opposite the lesion. The EVD tube (EVD catheter: Yushin Medical, Seoul, Korea) was connected to the continuous cerebral perfusion pressure (CPP) monitor (Spiegelberg, Hamburg, Germany) via a transducer device (Druckmesset; Smiths Industries, Kirchseeon, Germany). This monitoring system can measure the mean ventricular pressure continuously, with proven accuracy. Large bicoronal skin flaps were then made. The skin flaps were placed just behind the parietal eminence, extending inferiorly to the zygoma on both sides and curving anteriorly to the midline. This was continued subperiosteally to the level of the supraorbital ridges. The reference points for the bone flaps are: 1) the burr holes in the pterion of frontal bone; 2) the burr holes at the parietal eminences; and 3) the burr holes in the squamous portions. After the ventricular ICP was stabilized, the burr holes were connected using a pneumatic saw, with subsequent removal of the bone flap. The frontal median segment of the bone, which measures approximately 3 to 4 cm in width along the sagittal sinus, was saved to avoid damage to the sagittal sinus and to function as a framework for later cranioplasty. Additional bone was removed at the temporal region to the floor of the middle fossa (Fig. 1). Ten or 15 minutes after completion of the craniectomy, the ventricular pressure was stabilized. The dura was then opened in a large cruciated or curved Z-shaped incision, in the areas involving the frontal, temporal, and parietal lobes. When the dura was opened, the underlying brain or hematoma typically herniated outward. Cortical resection

### TABLE 1

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Diagnosis</th>
<th>Initial GCS Score</th>
<th>After Bilat Craniectomy</th>
<th>After Dura Opening</th>
<th>After ICH Removal</th>
<th>At Recovery Room</th>
<th>6-Mo GOS Score</th>
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* AChA = anterior choroidal artery; AVM = arteriovenous malformation; DAI = diffuse axonal injury; EDH = epidural hematoma; GCS = Glasgow Coma Scale; GOS = Glasgow Outcome Scale; HICH = hypertensive intracerebral hematoma; ICA = internal carotid artery; ICH = intracerebral hematoma; ICP = intracranial pressure checked at ventricle; IVH = intraventricular hematoma; MCA = middle cerebral artery; SAH = subarachnoid hemorrhage; SDH = subdural hematoma.
† Died due to cardiac arrest.
‡ Adult respiratory distress syndrome developed and lowered GOS score at 6 months.
of the brain was not performed. In all 20 patients artificial dura (Lyoplant; Braun Melsungen AG, Melsungen, Germany) was placed underneath the incised dura and secured with several sutures to allow the brain to herniate outward in a more controlled manner and to prevent cortical adhesion. After insertion of a sensor (Air-Pouch System; Spiegelberg) at the posterior temporal bone margin for epidural ICP monitoring, the temporalis muscle and skin flap were then reapproximated with sutures. Typically, the bone flap was maintained in wet gauze at \(-70^\circ C\) until reinsertion and was reinserted 3 to 6 months after the initial surgery (Figs. 1 and 2).

Data Collection

The initial ICP readings, which were checked after the ventricular tapping, were considered to be the highest sustained ventricular pressure. The ventricular pressure obtained after cranietomy and opening of the dura were considered to be decompressive cranietomy and dura opening state ICP, respectively. The ventricular pressure values were collected using the continuous monitor during surgery and the postoperative period (range 2–7 days).

Statistical Analysis

All data are presented as the mean \(\pm\) standard deviation. Comparisons between data groups were computed using Student’s t-test. Statistical significance was defined as a probability value of less than 0.05.

Results

Ventricular ICP Changes Seen in Accordance With Decompression Steps

The initial ventricular pressures, which were checked 5 to 10 minutes after the ventricular puncture, varied from 16 to 65.8 mm Hg. This correlated well with the initial GCS score \((p < 0.05)\). After bilateral cranietomy with intact dura, the ventricular pressure decreased to 50.2 \(\pm\) 16.6% of the initial ICP. After the dura was opened, the ventricular ICP decreased further to 15.7 \(\pm\) 10.7% of the initial ICP. Finally, the ventricular pressure being measured in the neurosurgical intensive care unit was also lowered to 15.1 \(\pm\) 16.5% of the initial ICP (Fig. 3). Intracerebral or intracranial hematoma removal further lowered the ventricular pressure, with the decrease ranging from 2 to 9.5 mm Hg more (Table 1).

Neurological Outcome

The overall mortality rate was 20%. One patient died of cardiac arrest, whereas three patients (15%) died as a result of elevated ICP. These three patients had ventricular ICP readings greater than 35 mm Hg during the first 24 hours after decompressive surgery despite conventional ICP-controlling measures such as infusion of hyperosmotic solution, hyperventilation, and EVD (Fig. 4). These patients died of elevated ICP. The Glasgow Outcome Scale\(^28\) (GOS) scores were determined at 6 months postsurgery, and 11 (69%) of the 16 surviving patients had a good out-
come (GOS score 4 or 5), whereas five (31%) of the surviving patients had a poor outcome (GOS score 2 or 3; Table 1).

Postoperative Complications

Almost always, enough cerebral edema was present to result in bulging out of the craniectomy site (Fig. 2) and some degree of hygroma, but immediate surgical management was not required; the edema subsided spontaneously without definite brain cortical injury. Two (13%) of the 16 surviving patients required burr hole trephination for subdural hygroma after cranioplasty. Two patients (13%) experienced wound infection after reimplantation of the bone flap, and in three patients (19%) we placed ventriculoperitoneal shunts for hydrocephalus.

Discussion

Many attempts have been made to control the massive brain swelling that can be caused by trauma, cerebral infarction, and various other causes. There are many medical and surgical treatment modalities, and moderate success has been obtained using each of them. Elevated ICP has been known to correlate with adverse outcomes from massive brain swelling. Therefore, it appears that accurate knowledge of ICP and its proper management are important tools to improve outcomes in patients with massive brain swelling. Therapies directed at controlling abnormally elevated ICP to improve CPP have resulted in better outcome for these critically ill patients.

Surgical decompression accompanied by removal of infarcted brain areas or mass lesions has previously been shown to be effective in selected patients with cerebellar lesions. Results of clinical reports and animal studies have also indicated that craniectomy may be an effective means of treating edema secondary to supratentorial infarctions as well.

Severe head trauma is usually a diffuse process with irreversible bilateral cerebral and brainstem injury. Craniectomy for head trauma may not be as effective a treatment as for stroke because a patient’s neurological outcome may be limited in a diffusely damaged brain.
ry alterations, can be seen to be dependent entirely on the position of the foreign body, what areas are involved in the local anemia, and how far-reaching are the congestion effects." In animal studies, decompression of the brain by bone removal probably results in a reduction of interstitial fluid pressure and edema enhancement.\(^9,25,38\) However, removal of bone over large areas of the calvaria converts a "closed box" with a finite volume into an open one.\(^9,36\) Intracranial pressure is thus controlled and CPP is maintained at levels adequate to prevent ischemic injury.\(^20,24,58\) Moreover, edematous brain may herniate through the craniectomy opening rather than through the tentorial incisura, therefore avoiding brainstem compression.\(^9\) Wolff and colleagues\(^56,57\) reported the following formula for the brain tissue gradient in right frontal mass lesions: right frontal = left frontal > right temporal = left temporal > midbrain > cerebellum, and the formula for the right temporal mass lesions was as follows: right temporal > left frontal = left temporal > right frontal > midbrain > cerebellum.

Taking into account the brain tissue pressure gradi-

tents,\(^1,24,34,35,57\) we performed bilateral craniectomy with dura-

plasty for decompressive surgery. This procedure was more convenient for inspecting the posterior area of the brain and enlarged the area available for upward and out-

ward brain shift. The EVD tubes were kept in place for ad-

ditional ICP control and monitoring during the acute brain

swelling period. When increased ICP is caused by a mass

effect from hematoma, direct surgery for removal of the

mass is usually performed.

Many authors have insisted that maximum brain swell-
ing develops within 2 or 3 days after the ischemic in-
sult.\(^1,5,19,20,30,42\) In our study, the ICP trend verified in the first 24 hours after decompressive surgery showed a corre-

lation with the mortality rate of the patients: if it exceed-
ed 35 mm Hg, these patients did not respond to any other

therapeutic management and the mortality rate was 100%.

In our opinion, once the ventricular ICP was high enough
to compromise the cerebral blood flow, injured neurons

never recovered. This can be partly explained by Hoss-

mann’s\(^26\) report, in which resuscitation of the brain after

a period of global ischemia is said to be limited by two
classes of posts ischemic pathological conditions, namely

hemodynamic disturbances that prevent adequate reoxy-
genation of ischemic brain, and metabolic disturbances

that may lead to delayed neuronal death in so-called selec-
tively vulnerable brain regions. The most important meta-
bolic disturbance leading to delayed neuronal death is pro-
longed inhibition of protein synthesis. The inhibition of

protein synthesis occurs at the translational level and is

probably the consequence of a selective inactivation of

polypeptide chain initiation factors. The reason for this

reactivation has not been clarified but may be related to
turbances of intracellular calcium homeostasis. Ac-
cording to some authors’ clinical observations, when cere-
bral blood flow and/or CPP pressure was lower than criti-
cal values, the neurons were not viable.\(^13,30,59\)

We performed decompressive surgery as soon as possi-
ble, once the patients showed impending signs of brain
herniation. This early decision making may decrease the

mortality rate compared with that in previous reports, but

clinical outcomes in surviving patients were almost the

same as previously reported.\(^4,20,22\)

Almost always, we saw cerebral edema severe enough
to result in bulging of the craniectomy site (Fig. 2). This

occurred during the early postoperative period even if the

patients’ ICP was not elevated. However, brain damage

from entrapment under the craniectomy margin did not

develop because all surviving patients’ epidural pressure,

which was checked using the air-pouch system at the

craniecyotomy margin, was not high. Serious complication

rates accompanying the decompressive craniectomy with

dural expansion were low and did not influence the pa-

tients’ prognosis.

Decompressive craniectomy is a treatment modality

that saves lives by decreasing the ICP.\(^31,42,51\) No previous

articles have shown the quantitative effect of each of the
available procedures on ICP decrease. This is also true when considering which method of decompressive surgery is more effective at ICP control. Polin, et al., reported that bifrontal decompression with dural expansion in patients with trauma decreased ICP by 66.4% of the initial level, and Ito and his colleagues reported that hemiocraniectomy with removal of the hematoma decreased ICP by 13 to 19% of the initial reading in a limited number of cases. However, these studies only compared pre- and postoperative epidural ICP.

In our study, bilateral decompressive craniectomy with dural expansion was performed for various disease entities by using a prospectively designed method, and we checked ventricular ICP during the operative procedures. The result showed that bilateral craniectomy with dural expansion is more effective in control of ICP than other types of decompressive craniectomy. In this study, we were able to show the effect of bone removal and dural opening on the control of ICP, in a stepwise fashion. We believe this surgical method can be applied to massive brain swelling from many causes.

Conclusions

Bilateral decompressive craniectomy alone can lower the ventricular pressure by approximately 50% of the initial ICP, and dural expansion can further decrease it by 35%. This resulted in recovery room ICP levels 15% of the initial pressure, and in these craniectomy patients the epidural and ventricular ICP were nearly the same. In our opinion, bilateral decompressive craniectomy with dural expansion is a more effective treatment modality than any other decompressive surgery. In the management of patients with massive brain swelling, this will allow the neurosurgeon to contribute more to the survival and better neurological outcome of his or her patients.

References

Ventricular ICP monitoring during decompressive surgery


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