Decompressive Hemicraniectomy in Patients With Supratentorial Intracerebral Hemorrhage

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Background and Purpose—Decompressive craniectomy (DC) lowers intracranial pressure and improves outcome in patients with malignant middle cerebral artery stroke. Its usefulness in intracerebral hemorrhage (ICH) is unclear. The aim of this study was to analyze feasibility and safety of DC without clot evacuation in ICH.

Methods—We compared consecutive patients (November 2010–January 2012) with supratentorial ICH treated with DC without hematoma evacuation and matched controls treated by best medical treatment. DC measured at least 150 mm in diameter and included opening of the dura. We analyzed clinical (age, sex, pathogenesis, Glasgow Coma Scale, National Institutes of Health Stroke Scale), radiological (signs of herniation, side and size of hematoma, midline shift, hematoma expansion, distance to surface), and surgical (time to and indication for surgery) characteristics. Outcome at 6 months was dichotomized into good (modified Rankin Scale 0–4) and poor (modified Rankin Scale 5–6).

Results—Twelve patients (median age 48 years; interquartile range 35–58) with ICH were treated by DC. Median hematoma volume was 61.3 mL (interquartile range 37–83.5 mL) and median preoperative Glasgow Coma Scale was 8 (interquartile range 4.3–10). Four patients showed signs of herniation. Nine patients had good and 3 had poor outcomes. Three patients (25%) of the treatment group died versus 8 of 15 (53%) of the control group. There were 3 manageable complications related to DC.

Conclusions—DC is feasible in patients with ICH. Based on this small cohort, DC may reduce mortality. Larger prospective cohorts are warranted to assess safety and efficacy. (Stroke. 2012;43:3207-3211.)

Key Words: decompressive craniectomy ■ decompressive surgery ■ hemicraniectomy ■ intracerebral hemorrhage

Decompressive craniectomy (DC) is applied for space-occupying lesions such as major ischemic stroke, cerebral sinus venous thrombosis (CSVT), aneurysmal subarachnoid hemorrhage, and traumatic brain injury.1–4 DC is performed to prevent intracranial pressure increase. Of the few published reports on DC in intracerebral hemorrhage (ICH), most of the reports focus on a combined treatment of hematoma evacuation plus DC.5–9 Reports on DC as the only treatment for ICH are scarce, and the surgical decompression in these cases was smaller than a standardized DC.10 The rationale for evacuation of ICH is to prevent the toxic effects of hematoma degradation and the mechanical complication of mass effect.11 Because DC beneficially addresses mass effect, because hematoma evacuation plus additional DC showed favorable outcomes in several patients,5,7,8 and because DC for ICH showed promising results in an animal study,12 we evaluated whether DC of sufficient size without clot evacuation is safe and feasible in patients with ICH.

Material and Methods

We performed a retrospective matched case-control study to compare DC with best medical treatment for ICH. Using the Bern ICH database, we analyzed consecutive patients with ICH treated between November 2010 and January 2012 with DC without hematoma evacuation. Eleven patients were treated at the Department of Neurosurgery of the University Hospital Bern and 1 at the University Hospital Geneva. Control patients were treated in the same period from November 2010 to January 2012 and were matched with respect to age, Glasgow Coma Scale (GCS), National Institutes of Health Stroke Scale, and signs of herniation. The interval from ICH to surgery was recorded, and clinical examination (GCS, National Institutes of Health Stroke Scale, and signs of herniation) was performed daily. The pathogenesis of the ICH was investigated with magnetic resonance imaging and digital subtraction angiography as necessary. Side and location of the hematoma, number of affected lobules, distance to the cortical surface, pre- and postoperative midline shift at the level of the tentorium, and surgical decompression were recorded. The surgical decompression included opening of the dura and evacuation of the hematoma if needed. The interval from ICH to surgery was recorded, and clinical examination (GCS, National Institutes of Health Stroke Scale, and signs of herniation) was performed daily. The pathogenesis of the ICH was investigated with magnetic resonance imaging and digital subtraction angiography as necessary. Side and location of the hematoma, number of affected lobules, distance to the cortical surface, pre- and postoperative midline shift at the level of the tentorium, and surgical decompression were recorded.

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3207
of the foramen of Monroe, and hematoma expansion were recorded. Hematoma size was estimated by the ABC/2 method. Because there are no standardized criteria to perform DC in patients with ICH, our criteria to perform surgery were at least 1 of the following: GCS <15, National Institutes of Health Stroke Scale >12, clinical deterioration compared with the admission status, or oculomotor nerve dysfunction. However, for individual patients the decision to proceed with DC remained at the discretion of the treating surgeon. Total length of stay in the hospital, in the intensive care unit, and in the intermediate care unit were recorded.

Decompressive Craniectomy

All patients in the treatment group received DC according to a previously published protocol with the cross midline skin incision technique and a DC diameter of at least 150 mm. The opening of the dura was performed in a stellate fashion, and the exposed brain was covered by the loosely replaced dura, then covered with Surgicel (Ethicon, Inc., NJ) in accordance with the rapid closure technique.

Best Medical Treatment (for Both Groups)

Best medical treatment was given according to the American Heart Association/American Stroke Association guidelines. In conscious patients, a systolic blood pressure of 160 mm Hg was targeted. Patients with a GCS ≤8 were ventilated and sedated. In patients with suspected increased intracranial pressure, a pressure probe or an external ventricular drain was placed, and BP was managed to target a cerebral perfusion pressure of 60 to 80 mm Hg. Management of increased intracranial pressure included cerebrospinal fluid drainage by an external ventricular drain, neuromuscular blockade, and sedation.

Phenprocoumon and heparin treatments were stopped and reversed with clotting factors, vitamin K and protamine, respectively. Intermittent pneumatic compression was used for prevention of venous thrombosis and, after 36 hours, low-dose fractionated heparin was used.

Outcome

Outcome was assessed by the modified Rankin Scale, when patients returned to our outpatient clinic after 6 months. Good outcome was defined as modified Rankin Scale of 0 to 4 according to the pooled analysis of 3 randomized trials in patients with malignant middle cerebral artery infarction and 1 in CSVT. Complications were categorized as: (1) related to the DC, (2) related to cranioplasty, and (3) medical complications. Infections, excessive blood loss, and hematoma confined to the surgical field were graded as surgical complications. Thromboembolic complications, adverse effects of medication, and pulmonary or circulatory deterioration in comparison with the admission status were graded as medical complications. Differences in outcome between the treatment and control groups were evaluated by 2-sided Fisher exact test.

The retrospective data analysis was approved by the local ethics committee (E29-03-12/146789).

Matching Procedure

Fifteen medically treated patients who were matched out of a pool of 93 candidates served as controls. Matching was performed with the GenMatch method to improve the balance of observed covariates that may influence decision making for surgical versus best medical treatment, that is, patient age, GCS, equal pupil size, hematoma volume, and midline shift.

Results

DC Group

Demographic, clinical, and radiological results are summarized in Tables 1 and 2.

There were 12 patients in the treatment cohort (7 men, 5 women; median age of 48 years; interquartile range [IQR] 35–58). Hematomas were spontaneous in 7 patients and in 5 were secondary to underlying pathologies such as arteriovenous malformation, CSVT, dural arteriovenous fistula, ischemic stroke, and herpes encephalitis. Median preoperative GCS and National Institutes of Health Stroke Scale were 8 (IQR 4.3–10) and 21 (IQR 20–26.5), respectively. Before surgery, 4 patients showed unilateral oculomotor nerve dysfunction indicating transtentorial herniation. Seven hemorrhages were lobar affecting 1 to 3 lobules and 5 in the basal ganglia. All but 1 lobar hemorrhage reached the surface at some point. Eight of 12 patients had repeated imaging before surgery, and there was hematoma growth between admission and preoperative imaging in 6. Mean preoperative hematoma volume was 61.3 mL (IQR 37–83.5 mL). The main reason for surgery was decreased level of consciousness in 9 patients, oculomotor nerve dysfunction in 4, and a new focal neurologic deficit in 1. One patient had increasing intracranial pressure. Median preoperative midline shift was 8.9 mm (IQR 6.1–10 mm). Median time between ictus and DC was 12 hours (IQR 3.3–56.8), and median time between ictus and cranioplasty 72.5 days (IQR 55.6–81.3).

Postoperative imaging was performed between 4 and 37 hours after ictus. Hematoma growth compared with preoperative imaging occurred in 3 patients (12–54 mL), all with impaired coagulation because of heparin, phenprocoumon, or recombinant tissue plasminogen activator. In 2 of them, hematoma had already expanded preoperatively, and in the third preoperative imaging was performed only once. Postoperative midline shift was 2.2 mm (IQR 0.3–4.7 mm) and significantly decreased compared with preoperative values (P<0.001).

Comparison Between DC and Control Group

Ninety-three of 143 patients with ICH had been treated conservatively and were eligible for matching. After matching for age, GCS, anisocoric pupils, hematoma volume, and midline shift, 15 patients were included in the control group. There were no significant differences between the treatment and control groups for these parameters.

Safety Analysis

Complications Related to DC

After DC, 1 patient suffered small cerebellar and contralateral frontal hemorrhages, most likely due to incidental excessive drainage of cerebrospinal fluid via subdural drainage in the first 12 hours after surgery. One patient with perioperative heparin therapy because of CSVT needed reoperation because of a subdural hematoma that was diagnosed on postoperative computed tomography imaging 18 hours after DC. The third patient suffered an empyema with fever and periorbital swelling (Table 1). The empyema was recognized 8 days after DC, and the patient was reoperated.

Complications Related to Cranioplasty

Cranioplasty was performed by reinsertion of the autologous bone flap without immediate complications. During
follow-up, we observed 1 aseptical resorption of the autologous bone flap after 14 months. A second cranioplasty with polymethyl methacrylate cement was successful.

### Medical Complications

Within the DC group, 6 complications related to ICH and neurointensive care were observed. One patient suffered an angioedema related to angiotensin-converting-enzyme inhibitors. Pneumonia and urinary tract infections were each noted in 2 and bacteremia in 1 patient.

Within the control group, there were 6 complications: meningitis in a patient after external ventricular drain placement, pleural effusion in 1 patient, and pneumonia in 3 patients. Another patient suffered new ischemic lesions, possibly of thromboembolic origin.

### Length of Stay

Median length of stay for the DC group was 12 days (IQR 5.75–17.5) compared with 4 days (IQR 1–12; $P=0.0911$) for the control group. Median duration of treatment in the intensive care unit plus intermediate care unit was 8 days (IQR…

### Table 1. Demographic and Clinical Data of the DC and Control Groups

<table>
<thead>
<tr>
<th></th>
<th>DC group</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. (men/women)</td>
<td>12 (7/5)</td>
<td>15 (8/7)</td>
</tr>
<tr>
<td>Age*</td>
<td>48 (35–58)</td>
<td>51 (47–68)</td>
</tr>
<tr>
<td>Pathogenesis of intracerebral hemorrhage</td>
<td>Spontaneous (7)</td>
<td>Spontaneous (10)</td>
</tr>
<tr>
<td>Cerebral sinus venous thrombosis (1)</td>
<td>Cerebral sinus venous thrombosis (1)</td>
<td></td>
</tr>
<tr>
<td>Arteriovenous malformation (1)</td>
<td>Arteriovenous malformation (1)</td>
<td></td>
</tr>
<tr>
<td>Stroke (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dual AV fistula (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herpes encephalitis (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glasgow Coma Scale*</td>
<td>8 (4.3–10)</td>
<td>8 (3–14)</td>
</tr>
<tr>
<td>National Institute of Health Stroke Scale*†</td>
<td>21 (20–26.5)</td>
<td>17 (11–31)</td>
</tr>
<tr>
<td>Preoperative herniation</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Time from ictus to surgery, h*</td>
<td>12 (3.3–56.8)</td>
<td></td>
</tr>
<tr>
<td>Indication for surgery, n</td>
<td>Decreased level of consciousness (9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oculomotor nerve dysfunction (4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New focal deficits (1)</td>
<td></td>
</tr>
<tr>
<td>Anticoagulants, thrombolytics, n</td>
<td>Heparin (1)</td>
<td>Warfarin (2)</td>
</tr>
<tr>
<td></td>
<td>Warfarin (1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intravenous recombinant tissue-type plasminogen activator (1)</td>
<td></td>
</tr>
</tbody>
</table>

**Surgical**

Remote hemorrhage because of cerebrospinal fluid drainage (1)

Subdural hematoma (1)

Subdural empyema (1)

Aseptical bone resorption (1)

**Medical**

Angioedema (1)

Pneumonia (2)

Urinary tract infection (2)

Bacteremia (1)

Meningitis (1)

Pneumonia (3)

Pleural effusion (1)

Ischemic lesion (1)

DC indicates decompressive craniectomy; AV, arteriovenous; NIHSS, National Institutes of Health Stroke Scale.

*Values are given as median (interquartile range).

†Preoperative NIHSS for DC group and admission NIHSS for best medical treatment group.

### Table 2. Radiological Data of Hematoma in DC Group and Controls

<table>
<thead>
<tr>
<th></th>
<th>DC group</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intracerebral hemorrhage location, n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lobar</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Basal ganglia hemorrhage</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Side of hematoma, n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Right</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Both</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Distance to surface, mm*</td>
<td>5.25 (0–15.08)</td>
<td>5 (0–18)</td>
</tr>
<tr>
<td>Hematoma volume, mL*</td>
<td>61.25 (37–83.5)</td>
<td>48 (15–96.2)</td>
</tr>
<tr>
<td>Midline shift, mm*</td>
<td>8.9 (6.1–10)</td>
<td>6.5 (1–11.7)</td>
</tr>
<tr>
<td>Preoperative hematoma expansion and expansion in best medical treatment group, n</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Postoperative hematoma expansion, n</td>
<td>3</td>
<td>…</td>
</tr>
</tbody>
</table>

DC indicates decompressive craniectomy. 

*Values are given as median (interquartile range).
2.5–10.5) for DC patients and 2 days (IQR 1–12; \( P=0.3229 \)) for control patients.

The decision to withdraw active care influenced the length of stay. Excluding patients for whom care was withdrawn, the median hospital stays were 11 days (IQR 6.5–20) for DC versus 8.5 days (IQR 1.75–13.25; \( P=0.21 \)) for controls, and median intensive care unit/intermediate care unit stays were 8 days (IQR 1.5–10) versus 7.5 days (IQR 1.75–13.25), respectively.

### Outcome

Nine patients (75%) in the treatment group had a good and 3 (25%) a poor outcome (Figure). In the matched control group, 7 patients (46.7%) had good and 8 patients (53.3%) a poor outcome \(( P=0.24)\). Within the treatment group, 3 patients died because of acute myeloid leukemia, stroke, and a massive ICH, and therapy was discontinued according to their will. In the control group, 8 patients died, 5 after withdrawal of therapy because of malignant melanoma, prostate cancer, increasing hemorrhage, the patient’s will, and transtentorial herniation.

### Discussion

ICH is devastating with mortality rates up to 44% at 30 days.\(^{20,21}\) Despite the International Surgical Trial in Intracerebral Haemorrhage (STICH), surgical treatment in ICH remains a matter of debate and attempts to improve outcome using surgical therapy are ongoing.\(^{22}\) Trauma of open craniotomy and especially trauma to the brain parenchyma for hematoma evacuation were considered to outweigh the benefits of surgery.\(^{22}\) Therefore, many efforts were made to minimize the invasiveness of operative procedures related to clot evacuation.\(^{23–25}\) Driven by recent promising results of DC in ischemic stroke, DC could also be promising for treatment of space-occupying ICH.\(^{1} \) In addition, DC showed good results for ICH after CSVT and in animal experiments.\(^{4,12}\) We started to apply DC in a patient with ICH because of sinus venous thrombosis and, encouraged by the good results, extended the indication for DC to patients with spontaneous or symptomatic ICH.

![Figure. Outcome after decompressive craniectomy (DC) and medical management. Outcome of treatment with DC (N=12) and medical management (N=15). mRS indicates modified Rankin Scale.](http://stroke.ahajournals.org/)

### Complications

Complications related to DC were observed in 3 of our 12 patients. Yet, all 3 patients had good outcomes. Similar complications have been reported after DC and are probably not specifically related to DC in ICH.\(^{1,11}\) Cranioplasty was successful in 11 of the 12 patients and in 1 patient bone resorption occurred after 14 months. Our experience with this small number of patients indicates that the surgical risk of DC in the setting of ICH may not be increased. In addition, 6 medical complications occurred. However, such medical complications are common in a neurointensive care unit, and 6 medical complications were also observed in the 15 matched controls.

### Hematoma Expansion

Hematoma expansion is well described in the literature; early hematoma growth is most common, with up to 37% hematoma growth within 3 hours of onset and up to 13.3% between 3 and 24 hours.\(^{26–28}\) There is a possibility that surgical decompression raises the risk of rebleeding. In the DC group, 3 of 12 patients (25%) showed increasing hematoma after DC. Whether hematoma growth in these 3 patients was because of the natural course, because of DC, or because of impaired coagulation remains unanswered. Two were anticoagulated, and 1 had received thrombolytics and 2 showed hematoma expansion already before DC. DC was performed 2, 15, and 20 hours after symptom onset, that is, in the time window when hematoma growth naturally occurs most frequently. There was, however, no rebleeding in patients undergoing DC >20 hours after the onset of symptom. Because there was no rebleeding when DC was performed late (>20 hours), it is unlikely that DC itself poses an additional risk for rebleeding that is greater than the risk of hematoma enlargement because of the natural course. Nevertheless, we conclude that ultraearly DC should be used with caution and preferably only in further trials.

Our results show that DC after ICH is feasible and may also be safe. There were no deaths related directly to surgery and all complications were manageable and without long-term sequelae. The mortality with ICH volumes of >60 mL is up to 93% with conservative treatment,\(^{29}\) whereas only 2 of our 6 patients with hematoma volumes of >60 mL died. Within the control group, all 7 patients with hematoma volumes of >60 mL died. The median hematoma volume (60 mL) in our small study was larger than that in the STICH trial (40 and 37 mL for surgery and conservative treatment, respectively).\(^{22}\) Besides hematoma volume, perihemorrhagic edema may cause secondary deterioration of ICH patients. Kollmar et al showed that mild hypothermia prevented the increase of edema\(^{30}\) and Zazulia et al\(^{31}\) reported an increase in edema formation measured by an increasing midline shift. Although the direct effect of DC on perihemorrhagic edema remains unknown, our data show that DC significantly reduced midline shift, thereby possibly counteracting the space-occupying effects of the hematoma and edema formation.

To our knowledge, this is the first matched case-control study on treatment of ICH by large DC without clot evacuation. Rannarayan et al published a series including 23 patients with DC for ICH.\(^{10}\) Illustrations suggest that the DC was probably of insufficient size, which may cause additional
complications. The remaining literature deals with DC in addition to clot evacuation.

The limitations of our study are its retrospective design, the small sample size, and the heterogeneity of the patient cohort with respect to the origin of ICH. Our results may be a chance finding. Nevertheless, our preliminary results are encouraging and justify the initiation of a prospective study.

Conclusions
We conclude that DC is feasible and may be safe for treatment of ICH. Based on our results, a prospective randomized trial to evaluate the safety and efficacy of DC for treatment of ICH is justified.

Sources of Funding
Bern University Hospital sponsored the study.

Disclosures
Dr Gralla has served as a Consultant for STAR-TRIAL.

References
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