Hemicraniectomy with dural augmentation in medically uncontrollable hemispheric infarction

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Surgical decompression to alleviate raised intracranial pressure has been reported repeatedly in the past decades in small series of patients. Only recently have there been indications from larger trials that surgical decompression may be beneficial in treating space-occupying hemispheric infarction. However, surgical requirements for the procedure to be effective have not yet been defined.

Based on theoretical criteria, the authors operated on 43 patients with medically uncontrollable hemispheric infarctions. The craniectomies were planned to be as large as possible and performed in combination with a subtemporal decompression. Postoperative computerized tomography scans were evaluated for these criteria.

The mean survival rate for the group of 43 patients was 72.1% and no surviving patient ended up in a vegetative state. The mean area of craniectomy was found to be 84.3 ± 16.5 cm² and the mean distance of the inferior craniectomy margin to the middle fossa was 1.8 ± 1.3 cm. Comparison of survivors and nonsurvivors failed to show a significant difference in the size of craniectomy or the distance to the floor of the middle fossa.

Compared with the reported 80% fatality rate for medically treated stroke patients, in this subgroup the outcome (72.1% survival rate) is remarkably good. The authors conclude that decompressive craniectomy is an effective treatment, able to reduce mortality, and to improve neurological outcome in patients with space-occupying cerebral infarction if the size of craniectomy is large enough. Nevertheless, there is a need for further investigation to identify patients who will benefit from surgery and predictors to optimize the timing of surgical intervention.

Key Words * cerebral infarction * cerebral edema * craniectomy methods * cerebral ischemia

In 1905 Cushing established the technique of decompressive craniectomy for the palliative treatment of increased intracranial pressure (ICP).[4] The tumors in Cushing’s patients would be resected today. There are still conditions of raised ICP in which symptomatic medical and causative treatments fail; one of
these conditions is space-occupying hemispheric infarction. Recent studies have shown a mortality rate of up to 81%[9,10,30] despite aggressive medical treatment strategies to lower ICP, which have included osmotherapy, hyperventilation, barbiturate administration, thromethamine buffer, and anticoagulation therapy guided by ICP monitoring.[23] In addition to anecdotal reports on the beneficial effect of decompressive surgery in space-occupying stroke[13,14,26] and the results from a larger prospective trial,[21,24] there also now is experimental data derived from a rat model to support this treatment.[6,7] The surgical procedures performed range from osteoplastic temporal lobectomy[19] to hemicraniectomy without resection of brain tissue.[5,17,20] However, there are no systematic reports about quantitative analysis of the size of craniectomy required to be effective. Delashaw, et al.,[5] have described a surgical technique but they do not report the size of the decompressed area in their small series.

**CLINICAL MATERIAL AND METHODS**

**Patient Selection**

Forty-three patients aged 17 to 69 years (mean 47 ± 12.6 years) were included in this study and recruited from an ongoing prospective trial of decompressive craniectomy in cerebral infarction. The first results of this study have been previously reported.[21,24] Patients were treated for malignant middle cerebral artery territory infarction, as defined by Hacke, et al.[10] Patients with other underlying intracranial disease causing the infarction (such as, subarachnoid hemorrhage and meningioma) were excluded. A craniectomy was performed if an aggressive medical treatment protocol, including the full range of medical treatment strategies,[9,10,21] failed. In those patients in whom ICP was monitored, an ICP greater than 30 mm Hg was necessary for inclusion in the study. Possible complications and prognoses for both conservative and surgical treatments were discussed with the relatives of the patients before they were asked to give their informed consent.

**Geometric Model to Evaluate the Decompressive Effect**

The decompressive effect depends on the volume gained by craniectomy, which is a function of the area and the amount of brain protrusion. To obtain a semiquantitative description of this relationship we applied the following geometric model. As a first approximation the volume (V[ml]) of a cylinder is \( V = B \times H \), where B is the base in square centimeters and H is the height in centimeters, but this would overestimate the real volume of the decompressive effect because the height, or outward displacement of brain, will be less at the edges of a craniectomy. This was taken into account by calculating 15 mm along the edge of the infarction with only 50% of the volume. The amount of outward brain displacement is limited by the width of the dural graft and the skin. Therefore we calculated only 10% of the diameter of the craniectomy (that is, 6 mm for 6 cm) as height. The relation between diameter of craniectomy and volume gain resulting from this model is shown in Fig. 1. A circular cylinder was assumed to enable calculation.
Fig. 1. Graph showing the relationship between craniectomy size and gained volume, as calculated in a geometric model. For purposes of calculation a circular cylinder was assumed with 10% of its diameter as the height. An area 15 mm along the diameter was calculated with one-half of its volume to take the gradual rise of the dura into account.

Surgical Procedure

The surgical procedures were formulated based on theoretical considerations; craniectomies were planned to be large enough to allow for a substantial amount of volume. The area to be resected was exposed with a skin incision beginning anterior to the external auditory canal, curving occipitally, to the midline and up to the hairline frontomedially. Considering the mechanics of herniation, decompression was extended far enough to the floor of the middle fossa to relieve pressure from the herniating mediobasal temporal lobe[22] and up to the midline to avoid compression of the bridging veins (Fig. 2). Incision of the dura was performed longitudinally in the largest diameter, with radial incisions toward the base and the midline, to avoid shearing caused by dural edges. The defect was then covered with a dural graft of periosteum from the bone flap or temporal fascia. The graft was secured with sutures in a way that allowed the initial incision to spread not more than 2 to 3 cm. This technique achieves smooth bulging rather than fungus like herniation of brain into the craniectomy, avoiding shearing injuries, impairment of venous drainage, and enhancement of cerebral edema, as described by Cooper, et al.[3] Other groups[13,17] have suggested resection of infarcted and even noninfarcted brain tissue; however, we did not perform resections in any patient.
Measurement of Craniectomy Size

Craniectomy sizes were measured in 40 patients on postoperative CT scans. Postoperative CT scanning was not obtained in three patients because of rapid deterioration and death. Computerized tomography scanning was obtained in 8-mm-slice thickness without gap or overlap. Distance between the posterior and anterior margins of the bone defect was measured on each slice using the inner table of the skull bone. The total area of decompression was calculated by multiplying this value by the slice thickness and adding all results. The distance between the inferior margin and the floor of the middle fossa was also determined for each patient. The presence of shearing injuries indicated by intraparenchymal bleeding along the bony edge, epidural hematoma (EDH), or intracerebral hemorrhage (ICH) were registered.

RESULTS

Surgical Outcome

Forty-three patients with massive space-occupying hemispheric infarction underwent decompressive surgery; 31 (72.1%) of these survived. The causes of death were tentorial herniation in 11 and medical complications in one. None of the survivors remained in a vegetative state and only seven (23.3%) of the surviving patients sustained a severe disability and required assistance with activities of daily living. The mortality rate and neurological outcome for most of the patients involved in this study compared with those assessed on admission have been reported in detail previously.[21,24] There was no difference in age between those patients who survived (47.1 ± 12.2 years) and those who did not (46.9 ± 14.7 years).

Assessment of Craniectomy

Three patients deteriorated and died before a postoperative CT scan could be obtained; the following data
are based on assessments in the remaining 40 patients. The mean craniectomy size was 84.3 ± 16.5 cm² and it ranged from 59.2 to 128.4 cm². According to the geometric model, the mean diameter was 10.4 cm and the mean decompressive volume was 66.5 ml. No difference was found between survivors and nonsurvivors for the mean area of craniectomy, 84.7 ± 16.7 cm² and 82.8 ± 15.6 cm², respectively. The mean distance to the temporal skull base was 1.8 ± 1.3 cm. In surviving patients the mean distance was less (1.7 ± 1.2 cm) than for those who did not survive (2.3 ± 1.3 cm); however, the difference did not reach statistical significance (p = 0.27). Shearing injuries, ICH, and EDH were each found five times (12.5%). In two patients an ICH occurred with shearing injuries and in one EDH and shearing injuries were found together. None of the patients with shearing injuries or ICH underwent a second procedure because of the complications, although the ICH was clinically significant in two patients. In two patients the EDH had to be surgically evacuated: both survived without impaired neurological function compared with their preadmission status.

**DISCUSSION**

Decompression of the brain by turning the closed cavity of the skull into an open one is an old neurosurgical technique[4] and it has been applied to treat conditions of uncontrollably elevated ICP. Indications include rare clinical situations such as Reye's syndrome[1] or hepatic failure[27] as well as epidemiologically more important conditions such as head injury,[15,28] cerebellar infarction,[13] and massive stroke.[14,31] In trauma the role of decompressive surgery is still under debate, although its use has been repeatedly reported in rather large numbers of patients.[28] Today the only indication that seems to be widely accepted for performing decompressive surgery is in cerebellar infarction with continuous clinical deterioration, as shown in several large trials.[2,12,16,18] There have been, however, only anecdotal reports in the past on patients with hemispheric infarction.[5,13,17,20] Only recently has a prospective trial, involving a majority of the patients reported herein, investigated decompressive surgery for space-occupying hemispheric infarct and demonstrated benefits regarding survival and neurological outcome.[21] These results were confirmed in the present study, which demonstrated a reduction of mortality rate to 27.9%, less than half that reported for medical therapy alone, even using aggressive protocols.[10,11,30]
Fig. 3. Representative examples of the decompressive effect of a large craniectomy. Upper: Preoperative CT scans showing the shifting effect of right hemispheric stroke, which leads to compression of the brainstem. Lower: Postoperative CT scans showing how decompression of the temporal lobe has caused the mediobasal parts to retreat from the tentorial incision.

All patients were treated according to the same surgical regimen based on theoretical considerations, which might explain the lack of differences in craniectomy size between the outcome groups in this study. Furthermore, it might be that this difference indicates that the mean size found to improve the mortality rate in this clinical setting is appropriate because a clearly smaller mean size for the fatal outcome group would indicate that our decompressions were too small and vice versa. We could not derive a minimally effective craniectomy size from our data or answer the question of whether even larger craniectomies would be more effective. Achieving a decompression down to the floor of the middle fossa seems to be important in this surgical technique, because this procedure relieves pressure from the basal temporal lobe. Regarding this point we find ourselves in agreement with several other authors who have all used a subtemporal decompression together with hemicraniectomy.[4,5,20] Figures 3 and 4 illustrate the results of decompression on the medial temporal structures in cases with and without sufficient subtemporal decompression.
Principles in the treatment of acute ischemic stroke aim to minimize secondary tissue damage caused by impaired microcirculation.[8,25] One way to achieve this is the reduction of ICP, which improves leptomeningeal reperfusion of the medial territory. Implying that this can be achieved with decompressive surgery, thus reducing infarction size,[6,7] raises the important question of timing of surgery. Computerized tomography might be able to predict the dynamics of the ensuing clinical course to assist in indicating early intervention in some patients.[29] Our group of patients is still too small to identify other significant factors regarding outcome, but we hope to be able to give more detailed reports as the study progresses.

We conclude that decompressive craniectomy is an effective treatment, able to reduce mortality and to improve neurological outcome in space-occupying cerebral infarction if the size of craniectomy is large enough. Nevertheless, there is a need for further investigation to identify early predictors to exclude patients who will not benefit from surgery and to optimize the timing of surgical intervention for a maximum beneficial effect.

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