“In-window” craniotomy and “bridgelike” duraplasty: an alternative to decompressive hemicraniectomy

Technical note

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Object. The object of this study was to propose an alternative procedure to the classic decompressive hemicraniectomy using an “in-window” craniotomy and a “bridgelike” duraplasty.

Methods. The authors performed a large, almost rectangular craniotomy involving the frontal, temporal, and parietal bones and part of the occipital squama in 5 patients. The dura mater is opened and its area is enlarged using a rectangular dural patch of the surgeon’s choice in the form of a bridge between the anterior and posterior dural edges. With a vertical cut, the bone flap is divided into 2 similarly sized pieces that function as “window lids.” The outer frontal and occipital sides of the bone are tied to the skull border at 2 points to function as a hinge joint. The angle of the bone cut must be beveled outward (inclination ~ 45° of the bone drill or saw) to allow the bone flap to rest on the adjacent skull and prevent its slippage toward the intracranial cavity.

Results. The above procedures were performed with effective control of intracranial hypertension due to cerebral venous sinus thrombosis, brain trauma, intracerebral hematoma, or malignant cerebral ischemia.

Conclusions. Decompressive surgery, which uses an in-window craniotomy that gradually opens according to the intracranial pressure, is an alternative solution for deploying autologous material. The procedure has the advantage of obviating the need for a second surgical procedure to close the bone defect, and thus preventing the metabolic cerebral impairment associated with the absence of an overlying skull. (DOI: 10.3171/2009.11.JNS09674)

Key Words • stroke • decompressive hemicraniecotomy • cranioplasty • in-window craniotomy • duraplasty • cerebral venous sinus thrombosis • brain trauma • malignant cerebral ischemia

DECOMPRESSIVE hemicraniectomy has been performed as a lifesaving surgical procedure to treat intracranial hypertension. It minimizes intracranial mass effect and reduces the risk of transtentorial herniation, thereby preventing secondary brain injury, distortion of the brainstem, and death. For these reasons, decompressive surgery has been used in a number of emergency settings such as brain trauma,2,16,26 pseudotumor cerebri,13 encephalitis,25 severe lead encephalopathy,14 Reye syndrome,1 and hemispheric infarction.3,6,17,22 More recently the use of DH has been reported in the treatment of acute rupture of cerebral aneurysms.3,15 During this procedure, it is usual for the bone flap to be removed and then stored under the abdominal fat or in a freezer. Replacement of the bone or cranioplasty is performed after the resolution of the hemispheric swelling, 6–20 weeks later in patients who survive.

Although DH has led to a substantial decline in mortality rates, there are problems with the procedure. Although DH is effective in alleviating intracranial hypertension, it can cause harm given that vascular compression occurs at the rigid bone edges and thus can produce parenchymal lesions far from the initial site of ischemia.5,27 The very presence of a bone defect can also cause metabolic derangements that influence functional outcome.28 Furthermore, the gradual acceptance of decompressive craniectomy as a therapeutic tool in a select but significant number of patients with stroke or intracranial hypertension will result in an increased demand for cranioplastic procedures with their inherent costs. In this

Abbreviations used in this paper: DH = decompressive hemicraniecotomy; ICP = intracranial pressure; MCA = middle cerebral artery.

This article contains some figures that are displayed in color online but in black and white in the print edition.
In-window craniotomy

In this paper we present an alternative surgical procedure to replace the classic DH. Using an “in-window” craniotomy alleviates ICP, prevents the development of the trephine syndrome, and avoids a second operative procedure to replace the bone flap. In addition, we describe a form of duraplasty for better decompression of brain structures.

Methods

Surgical Technique

The surgical procedure involves a large semicircular skin incision starting at the midline and extending to the posterior parietal area, ending at the level of the tragus (Fig. 1 left). In patients with a thick subcutaneous layer, a posterior limb can be added to the incision, creating multiple retractable flaps that facilitate handling of the tissue and access to the craniotomy area. Care must be taken to ensure that the flap base is as broad as the widest point of the flap to prevent a shortage in the blood supply. The scalp border must be elevated from the underlying pericranium to ensure greater elasticity and a looser skin flap to allow stitching up of the skin at the end of the operation. An extensive, almost rectangular craniotomy is performed involving the frontal, temporal, and parietal bones and part of the occipital squama (diameter 12–15 cm; Fig. 2). The angle of the bone cut must be beveled outward (a 45° inclination of the drill or saw) to allow the upper part of the craniotomy bone flap to rest on the adjacent skull and prevent penetration into the intracranial cavity. An anterior temporal craniectomy (subtemporal decompression) is added to the procedure to relieve temporal lobe pressure. Care must be taken to prevent bone spicules and obtain smooth bone edges. Dural incisions are made (Fig. 3A), and the dura mater is fixed at the bone border to prevent epidural bleeding. The major cerebral vessel crossings should be positioned between the corners of the durotomy, since this site is where tension is lowest because of dural bowing. A dural patch consisting of synthetic graft, lyophilized cadaveric dura mater, pericardium, homologous pericranium, fascia lata, or temporal fascia is placed in the incision (~ 13–20 cm in length and 4–8 cm wide; Fig. 3B and C). Using a vertical cut, the bone flap is divided into 2 similarly sized pieces, which will be the opening of the “window lids” (Fig. 4). The outer frontal and parietooccipital sides of the flap are tied to the skull at 2 points using a synthetic nonabsorbable suture (for example, polypropylene) to function as a hinge joint that allows opening of the window but prevents downward movement of the bone inside the skull. We suggest inserting sutures at the edges of the bone in such a way that the lateral portion of the window is divided into 3 parts. A suction drainage tube is inserted and connected to a vacuum bottle to prevent subcutaneous hematoma, without crossing the window lids to avoid a blockage in the opening. The change in the position of the bone lids can be followed by a CT scan series, in accordance with the ICP.

Duraplasty Procedure

A number of difficulties are encountered when performing the duraplasty using a stellate or other similar durotomy. To facilitate the duraplasty we have developed a new form of dural closure resembling an anteroposterior bridge between the dural edges (Fig. 5). The dura mater is opened in a way that resembles 2 semicircular “ears” with the bases facing the upper and lower bone boundaries (Fig. 5B). On the anterior and posterior limits of the craniotomy, 1 cm of dura mater is left to permit a subsequent suture of the rectangular dural graft. To calculate the longitudinal extension of the dural graft, it is important to recall how to calculate the hemicircumference of an ellipse. There is no simple exact formula, but we consider the following ellipse equation: $x^2/a^2 + y^2/b^2 = 1$, with $a > b$ and where $a$ is the ma...
major radius, and b is the minor radius (Fig. 5A). Accordingly, the extension of the rectangular dural graft is equivalent to the hemiperimeter of an ellipse, and simple mathematic formulas, such as for the perimeter of an ellipse, can be used: \[ P \approx \pi \frac{(a + b)}{2}. \]

Considering a maximum height of 3 cm of brain herniation and an anteroposterior 12-cm craniotomy extension including the 1-cm dural edge on each side, \( P \) is approximately \( 3.14 \times (5 \text{ cm} + 3 \text{ cm}) / 2 \). With this calculation, the length of the rectangular graft can be determined, which in the present example was estimated as a 13-cm extension of the dural substitute intended to decompress the herniating brain tissue. In addition, to calculate the width of the rectangular graft to cover a 7-cm distance across the superior inferior extension of the craniotomy, the same calculation is performed, that is, \( \pi (3.5 \text{ cm} + 3 \text{ cm}) / 2 \). A width of 10 cm of dura is needed (bone-to-bone) to guarantee a generous duraplasty. Since the 2 ears of dura mater represent 7 cm of the 10-cm width, the side-to-side extension of the rectangular graft should be a minimum of 3 cm in length plus the sutured dura.

Because of the flexibility of both the dura mater and the material used as a graft toward the end of the procedure, the duraplasty assumed a shape resembling a 1/2 scalene ellipsoid. Since the volume of an ellipsoid (scalen) is \( \frac{4}{3}\pi abc \), by performing the described duraplasty we would create a space of \( \sim 110 \text{ ml} \) [for example, \( \frac{4}{3} \times 3.14 \times 5 \text{ cm} \times 3 \text{ cm} \times 3.5 \text{ cm} / 2 \)].

### Illustrative Cases

The in-window craniotomy was performed in 5 patients, with immediate control of the ICP.

**Case 1**

This 23-year-old woman experienced cerebral venous sinus thrombosis, and 12 hours after becoming unconscious with severe right hemiparesis she underwent a left-sided in-window craniotomy (Figs. 1–4 and 6). Magnetic resonance imaging showed a large cerebral hemisphere lesion causing a major midline shift (Fig. 1B). One day after the procedure the patient improved neurologically, and although conscious, she still experienced aphasia and...
In-window craniotomy

Case 1

Right hemiparesis. One week later she was walking with a minor deficit in language function. Figure 6 shows a CT scan of the head with transcalvarial herniation of brain tissue through the in-window craniotomy. Six months after surgery her neurological function was practically normal, apart from a slight right pyramidal deficit. The cosmetic result of the in-window craniotomy was excellent.

Case 2

Three days after suffering a severe brain trauma, this 18-year-old man was admitted unconscious to the emergency department. During the neurological examination his eyes were closed, and no movement of the limbs was observed, even after painful stimulation. Anisocoria was present: LP < RP. A head CT scan disclosed brain contusion and edema. A right-sided in-window craniotomy was performed, and while opening the dura a severe brain herniation occurred, indicating intracranial hypertension. An ICP monitor was inserted along with an external ventricular shunt. The postoperative ICP was 4–8 mm Hg during the 7 days of ICP monitoring. The patient's condition slowly improved, and 8 weeks later he was discharged from the hospital with his eyes open, but still exhibiting decerebrate posturing bilaterally.

Case 3

This 26-year-old woman, who had a history of severe brain trauma, was admitted unconscious to the intensive care unit. A head CT scan demonstrated the presence of contusion and cerebral edema. Intracranial pressure monitoring revealed a fluctuation between 15 and 35 mm Hg. On the 3rd day after the brain injury, ICP was sustained at 30–35 mm Hg and a right-sided in-window craniotomy was performed. Immediately after the procedure, the ICP decreased to 5–8 mm Hg. During the 7 days of ICP monitoring, the pressure was < 17 mm Hg. The patient improved neurologically, and although she is able to spontaneously open her eyes, she still does not obey simple commands 14 months after the procedure and she has a moderate motor deficit in all four limbs. Figure 7A shows the transcalvarial hernia of the right cerebral hemisphere. The final cosmetic result was excellent.

Case 4

This 76-year-old right-handed woman with a history of left carotid artery occlusion and severe left cerebral hemisphere ischemia was admitted unconscious to the intensive care unit. Right hemiplegia was also present. Three days after her admission, an MR image showed a large left ischemic cerebral hemisphere lesion with a major midline shift. The patient underwent a left-sided in-window craniotomy. Immediately after the procedure the ICP was 4–12 mm Hg. One day after the procedure the patient improved neurologically, and although she was conscious, she still demonstrated aphasia and right hemiplegia. By 4 months after surgery she had good interactions with her family, apart from a severe motor aphasia, mild/moderate sensitive dysphasia, and right pyramidal deficit (Grade 0/5 superior limb, Grade 2/5 inferior limb). The cosmetic result was excellent. Figure 7B and C features head MR images obtained 3 months after brain decompression with the in-window craniotomy.

Case 5

This 59-year-old woman was admitted conscious to the intensive care unit 4 hours after presenting with aphasia and right hemiplegia. A CT scan showed a large left intracerebral hematoma (Fig. 8A). A few hours later she became unconscious and a left-sided in-window craniotomy with hematoma evacuation was performed. Immediately after the procedure the ICP was 12–20 mm Hg. A few days after surgery the patient improved neurologically, and although she was conscious, she still presented with apha-
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sia and right hemiparesis. Three months after surgery she was walking (Grade 1/5 superior limb, Grade 4/5 inferior limb) with a mild/moderate motor-sensitive dysphasia. The cosmetic result of the in-window craniotomy was excellent (Fig. 8B–D).

**Discussion**

As DH has increased in popularity among neurosurgeons as a life-saving treatment in patients with malignant intracranial hypertension following a major vascular insult or brain trauma, reports concerning its technical execution and possible complications have been appearing in the literature. Wagner et al. have demonstrated that parenchymal hemorrhages and infarcts due to the initial site of ischemia and associated with the hemicraniectomy occur with frequency rates of 41.6% and 28.4%, respectively. The occurrence of hemicraniectomy-associated bleeding was related to the size of the craniectomy performed—that is, the smaller the hemicraniectomy, the more often lesions appeared. Hemicraniectomy-associated bleeding was also related to an increased risk of death. A plausible mechanism leading to hemicraniectomy-associated lesions is the shear forces at the edges of the trephination. Small craniectomies cause greater shear stress on the swollen brain, especially if the edges of the craniectomy are sharp. Csókay and associates have proposed the creation of vascular channels to reduce the risk of vascular congestion in the herniated tissue, thereby decreasing the secondary injury caused by the craniectomy.

Nowadays, malignant hemispheric infarction is the main indication for DH when the patient does not respond to conventional therapies (that is, osmotic therapy, hyperventilation, and so forth) or when there is a significant brain shift of the midline structures, or both. About 10–20% of the patients with infarction in the territory of the MCA or the internal carotid artery demonstrate hemispheric cerebral edema/swelling, manifesting clinical signs of uncal, cingulate, and tonsillar herniations along with neurological deterioration. The clinical deterioration of patients with massive MCA infarction occurs in connection with the formation of brain edema, which peaks on Days 3–5, with a progressive edema reduction within the following 2 weeks. This form of malignant cerebral infarction is often not controlled by medical treatment and is associated with a high mortality rate, occurring in up to 70–90% of cases.

In 1995 Rieke and colleagues reported on the first prospective study on the use of DH in space-occupying supratentorial infarction, in which they obtained a significant benefit with the combination of bone removal and dural patch enlargement. Subsequently, Schwab and associates demonstrated a further decline in mortality rates to 16% if the patients were submitted to decompressive surgery within the first 24 hours, even before any significant shift of the midline structures. Do all patients with early (predictive) clinical/neuroimaging signs of malignant cerebral infarction require DH for the correction of intracranial hypertension? False-positive classification as malignant infarction is a major concern because it can lead to unnecessary surgical treatment. We think that the performance of an in-window craniotomy would be a less harmful alternative to at least some of these patients, since in the absence of a gradual mass effect, the craniotomy “window lids” stay unopened in a normal anatomical position. In addition, Engelhorn and colleagues have demonstrated experimentally that the combination of reperfusion and hemicraniectomy caused an increase in brain edema and a breakdown in the blood-brain bar-

![Fig. 8. Case 5. A: Head CT scan showing a left-sided intracerebral hematoma (5.0 × 2.5 × 2.5 cm). B: Very satisfactory cosmetic appearance. C and D: Two-dimensional and 3D head CT scans, respectively, showing good alignment of the craniotomy flaps on the adjacent calvaria 3 months after brain decompression with the in-window craniotomy (see where the sutures were placed for the bone replacement).](image-url)
In-window craniotomy

erier, even though a reduction in the infarction extension was found. Similar results were obtained by Cooper and colleagues in edema induced by cold in dogs, with the edema volume 7 times greater in the craniectomized animals. Since the driving force in edema pathophysiology is the pressure gradient across the injured capillaries, cerebral decompression may decrease interstitial fluid pressure and, as a result, increase edema formation. In this regard, craniectomy has caused a significant decline in tissue pressure in the cortical gray matter in cat models, a phenomenon that probably occurred after decompressive craniectomy in a patient with brain infarction due to traumatic vessel occlusion who had a poor outcome. This increased edema can lead to higher shear forces and contribute to hemisindrome-associated lesions.

The better results following DH in patients with hemispheric lesions (for example, stroke) compared with the outcomes in those with severe brain trauma could be explained by the fact that lesions in unconscious patients with trauma are usually diffuse rather than restricted, as in a unilateral cerebral hemispheric lesion such as MCA ischemia. In such a setting, the immediate removal of the bone corrects the cerebral displacement, relieving the pressure exerted on the rostral midbrain structures. In theory, DH may also improve perfusion of the collateral leptomeningeal vessels, improve retrograde perfusion of the MCA, optimize perfusion of the penumbra, and consequently reduce the size of the infarct and neurological deficit.

The technical recommendations for the performance of decompressive hemissectomy stress that craniectomy should be performed in the frontotempoparietal region, reaching the base of the frontal bone and sparing the calvaria ~ 1 cm from the midline to prevent injury to bridging veins and additional bleeding. A diameter of ≥ 12 cm is desirable, as it has been shown that doubling the diameter from 6 to 12 cm results in an increase in decompressive volume/area from 9 to 86 cm. The bone removal toward the occipital squama adds little to the decompressive procedure itself, as the falx prevents the medial incursion of cerebrum in this region and has a constant length of ~ 6 cm besides, it might produce problems in stability and patient positioning. The recommended duraplasty involves one longitudinal and three radial incisions that almost reach the osseous rim and are associated with a 2- to 3-cm patch of replacement located within the incision. In the present study we suggested a new form of duraplasty. In fact, in the first few cases we did use the cruciate dural incision as shown in Fig. 3A, but we found it difficult to perform the duraplasty. The “ear-shaped” dural incision was therefore devised as an alternative to dural opening.

Given that a larger-sized hemisectectomy is desirable to prevent the complications discussed above, the number of problems related to a sinking defect might be expected to increase. The “syndrome of the trephined” involves the occurrence of severe headache, dizziness, undue fatigability, poor memory, irritability, convulsion, and intolerance to vibration. Also known as the “syndrome of the sinking skin flap,” it has been related to the action of atmospheric pressure and changes in the hydrostatic pressure of CSF that have resolved after cranioplasty. It is known that skull defects are associated with a blood flow decrease related to postural changes, suggesting that DH has an impact on dynamic cerebral blood flow regulation. Winkler and colleagues have demonstrated that cranioplasty affects postural blood flow regulation, cerebrovascular reserve capacity, and cerebral glucose metabolism. These effects were associated with a clinical improvement in all patients except those whose cranioplasty was delayed for a long time after the HD. This fact led the authors to conclude that an early cranioplasty is warranted to facilitate rehabilitation in patients following HD.

Hydrocephalus is also a common complication after DH, especially in cases of brain trauma. Its causes are multiple, but we believe that the absence of the bone flap causes a major disturbance to the ICP regulatory mechanisms. As a result of the lower ICP, CSF absorption may be deficient, since a pressure gradient between CSF and the venous blood is required for this to happen. With the use of the in-window technique, we suppose that a “normal” intracranial biomechanical condition is reestablished after 1–2 months, depending on the severity of the lesion. Thus, if this assumption were correct, we would expect a lower incidence of hydrocephalus with the proposed procedure. In our series of 5 patients shunt-dependent hydrocephalus developed only in the patient in Case 2.

Another point to be discussed is whether to use a generous duraplasty, which would cause a significant reduction in ICP. It is estimated that only a 15% reduction is achieved with craniectomy alone and duraplasty may decrease ICP by an additional 55%. In a recent study the deep wound infection rate was significantly higher when a foreign material was used (for example, NeuroPatch [15%]) as compared with pericranium used as a dural graft (5%). Furthermore, CSF leaks were significantly more frequent in the Neuro-Patch group (13 vs 1.6%). The authors concluded that synthetic dural grafts should be reserved for times when autologous grafts are insufficient or impossible. A very large skin incision allows sufficient quantities of pericranium to be used as a dural graft.

The modified HD technique presented here might be the embryo of the ideal technique. This procedure allows for the performance of a large hemissectectomy to adequately decompress the ischemic or lesioned brain and avoid hemisindrome-associated lesions. At the same time, it offers an anatomical, inexpensive solution that gradually accommodates the herniated brain tissue with a decrease in the ICP after brain insult. This surgical treatment may avoid edge trauma and ischemia, since the transcalvarial herniation can be more uniformly directed toward the center of the craniectomy by the angle formed between the skull and the partially opened bone flaps. Again, the principle of the in-window craniotomy prescribed here mimics the opening of the sutures observed in childhood hydrocephalus. On the other hand, recomposing a resistant barrier between the brain and the environment could prevent the sinking flap symptoms that detract from the functional outcome. Recently, a comparable procedure—hinge craniotomy—was described.

The recommended beveling of the craniotomy edges is important in the upper part of the craniotomy. Nonetheless, we believe that four factors, besides the above-men-
tioned aspect, mainly prevent the bone from sinking in: 1) the underlying attached dura mater, which means that the dura-bone stitches should be placed 0.5 cm from the bone edge; 2) good alignment of the bone flaps with the calvaria; 3) the ICP; and 4) closing of the bone window and cranial vault reconstruction according to the principles used in the construction of vaults—a semicircular, arch-shaped structure—where many segments are held in place by lateral thrust. The anterior and posterior parts of the craniotomy—the suture placement—should be cut vertically to permit good alignment of the bone flaps with the calvaria. Thus, the central, bisected portion of the bone does not sink in when the brain later atrophies after an infarction or major trauma (at least not in the cases presented in this study). In our experience we have seen a good aesthetic result as early as 2–3 months following the procedure, although a foreseeable defect at the edge and along the central vertical line of the craniotomy can be felt on palpation. After 5 months of follow-up the appearance of the in-window craniotomy was similar to that of a classic “fixed” craniotomy with no signs of movement of the partially free bone flaps. Magnetic resonance imaging and CT studies were performed 3 months after the procedure and showed a good anatomical position of the flaps, except in the patient in Case 2 who was lost to follow-up.

As to whether a young survivor could resume sports after the in-window procedure, we lack sufficient evidence to confidently state that after 1 year the bone has healed sufficiently to allow sporting activities, although we believe that such activities can be recommended without the need for further surgery to stabilize the bone. To be certain, however, further studies are required to clearly demonstrate bone resistance sufficient to sustain significant impacts—not only in the case of the procedure described here, but also after the subsequent repositioning of bone to correct the defect left by a conventional DH, since bone resorption might occur.24

Note that there are very few data in the literature regarding the use of DH to treat large cerebral hemisphere lesions with midline shift due to cerebral venous sinus thrombosis. In this regard, the patient in Case 1 had an excellent result with the in-window craniotomy.

Data in the present study indicate that although the in-window technique is an excellent substitute for conventional DH, it could be improved by the development of 2 devices: 1) a hinge; and 2) a synthetic dura mater substitute in the form of an ellipsoid “bag,” which would save time during the duraplasty (although we strongly agree that the use of the pericranium produces fewer complications). We wonder about the possibility of using metal hinges to replace the synthetic nonabsorbable sutures. To this end, the hinges (2 on each side of the craniotomy) should be fixed into the calvaria and to the bone flaps by using screws. Such metallic implants must be compatible with the use of MR imaging. The opening must be situated toward the outer calvaria, a kind of hinge designed to lock the bone flaps in a natural anatomical position (horizontal plane), thus preventing the central portion of the bone from sinking in when the brain later atrophies.

Conclusions

In summary, the described decompressive surgery using a craniectomy in an in-window fashion presents several advantages. First, it permits the edematous cerebral parenchyma to herniate with a gradual opening, simultaneously relieving elevated ICP. Second, it is an anatomical option that to some extent preserves the brain-skull biomechanics and avoids the use of expensive bioprosthetic materials. Third, it may avoid the development of sinking skin flap symptoms. And fourth, it obviates the need for a second bone replacement surgery at a later stage, which would have an impact on the overall treatment cost. Thus, like the classic hemicraniectomy, in-window craniotomy allows an appropriate decompression that may be lifesaving.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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