International Journal of Medical Sciences
2010; 7(6):385-390

Review

Technical Considerations in Decompressive Craniectomy in the Treatment of Traumatic Brain Injury

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Received: 2010.08.02; Accepted: 2010.11.03; Published: 2010.11.08

Abstract

Refractory intracranial hypertension is a leading cause of poor neurological outcomes in patients with severe traumatic brain injury. Decompressive craniectomy has been used in the management of refractory intracranial hypertension for about a century, and is presently one of the most important methods for its control. However, there is still a lack of conclusive evidence for its efficacy in terms of patient outcome. In this article, we focus on the technical aspects of decompressive craniectomy and review different methods for this procedure. Moreover, we review technical improvements in large decompressive craniectomy, which is currently recommended by most authors and is aimed at increasing the decompressive effect, avoiding surgical complications, and facilitating subsequent management. At present, in the absence of prospective randomized controlled trials to prove the role of decompressive craniectomy in the treatment of traumatic brain injury, these technical improvements are valuable.

Key words: Decompressive Craniectomy, Traumatic Brain Injury

Introduction

Decompressive craniectomy, which is performed worldwide for the treatment of severe traumatic brain injury (TBI), is a surgical procedure in which part of the skull is removed to allow the brain to swell without being squeezed.[1] Although there is still controversy about the efficacy of the procedure in improving patient outcome, it is still widely used as a last resort in those patients with uncontrollable intracranial pressure (ICP). Several retrospective and prospective studies have suggested the efficacy of decompressive craniectomy in decreasing ICP and improving prognosis in patients with refractory intracranial hypertension after TBI.[2-8] Presently, the European Brain Injury Consortium and Brain Trauma Foundation guidelines for severe TBIs refers to decompressive craniectomy as a second-tier therapy for refractory intracranial hypertension that does not respond to conventional therapeutic measures.[9, 10] To further determine the risks and benefits of this procedure and to define the role of decompressive craniectomy in the management of patients with severe TBI, several prospective randomized trials are underway.

As early as 1901, Kocher was the first surgeon to promote surgical decompression in post-traumatic brain swelling.[11] There are currently various decompressive craniectomy methods and technical improvements that have progressed the treatment of TBI. In this article, the technical changes in decompressive craniectomy in the treatment of severe TBI are reviewed.

Different methods of decompressive craniectomy in the treatment of TBI

Different methods of decompressive craniectomy have been developed for, or applied to, decompression of the brain at risk for the sequelae of traumatically elevated ICP. These include subtemporal decompression,[12-14] circular decompression,[15] fronto- or temporoparietal decompressive craniectomy,[8, 16] large fronto-temporoparietal decompressive craniectomy, hemisphere craniectomy, and bifrontal decompressive craniectomy.[7-10, 17]

Circular decompression was introduced decades ago. However, for patients who develop refractory intracranial hypertension, it is unable to take effect, because of the limited space.[15] The procedure of subtemporal craniectomy, which was introduced by Cushing,[11] involves removing the part of the skull beneath the temporal muscle by opening the dura. This was an important surgical method for the treatment of severe TBI with refractory intracranial hypertension for a time, and was shown to produce good results by some investigators.[12-14] Although it is still used in many centers, similar to circular decompression, the area of the skull removed is small and the room that it can provide for the expansion of the brain is restricted; furthermore, this procedure may lead to temporal lobe herniation and necrosis.[18] A study performed by Alexander et al. demonstrated that the calculated additional space provided by subtemporal decompression ranged from 26 to 33 cm^3.[12] Generally, this space is inadequate when a patient develops diffuse cerebral swelling. By removing part of the skull, decompressive craniectomy seeks to prevent herniation and to reconstruct cerebral blood perfusion to improve patient outcome. The decompressive effect depends primarily on the size of the part of the skull removed. A small craniectomy may be helpful for preventing herniation; however, considering its limited effect on refractory intracranial hypertension, the aim of reconstructing cerebral blood perfusion is almost impossible. At present, the more widely used methods are large unilateral fronto-temporoparietal craniectomy / hemisphere craniectomy for lesions or swelling confined to one cerebral hemisphere, and bifrontal craniectomy from the floor of the anterior cranial fossa to the coronal suture to the pterion for diffuse swelling. Munch et al. found that large fronto-temporoparietal craniectomy could provide as much as 92.6 cm^3 additional space (median, 73.6 cm^3).[14] Large decompressive craniectomies, including fronto-temporoparietal/hemisphere craniectomy and bifrontal craniectomy, seemed to lead to better outcomes in patients with severe TBI compared with other varieties of surgical decompression in previous literature.[7, 8, 18] The most direct proof was provided by Jiang et al: a prospective, randomized, multi-center trial suggested that large fronto-temporoparietal decompressive craniectomy (standard trauma craniectomy) significantly improved the outcome in severe TBI patients with refractory intracranial hypertension, compared with routine temporoparietal craniectomy, and had a better effect in terms of decreasing ICP.[8] Consequently, large decompressive craniectomy has been recommended by most authors, and prospective studies that are underway to further determine the role of surgical decompression in the management of TBI have adopted it as a standard procedure. Decompressive craniectomy is sometimes combined with a simultaneous lobectomy.[19, 20] In our opinion, this should be performed with caution because excessive excavation of brain tissue may lead to poor results, though the ICP could be reduced rapidly.[19]

Dura opening or not

Normally, decompressive craniectomy is performed together with dura opening, and it was believed that this could maximize brain expansion after removal of part of the skull. However, opening the dura with no protection for the underlying brain tissue may increase the risk of several secondary surgical complications, such as brain herniation through the craniectomy defect,[21, 22] epilepsy,[23, 24] intracranial infection,[4] and cerebrospinal fluid (CSF) leakage through the scalp incision[16] or contralateral intracranial lesion.[25] Currently, decompressive craniectomy combined with augmentative duraplasty is widely performed and is recommended by most authors.[11, 26] The temporary removal of a piece of skull followed by loose closure of the dura and skin layers presumably allows for expansion of the edematous brain into a durotomy "bag" under the loosely closed scalp without restriction by the hard skull; the dura would also protect the underlying brain tissue with prevention from over-cephalocele. Yang et al. found that the patients who underwent decompressive craniectomy combined with initially augmentative duraplasty had better outcomes and lower incidences of secondary surgical complications (such as hydrocephalus, subdural effusion, and epilepsy) compared with those who only underwent surgical decompression, leaving the dura open.[16] At present, large decompressive craniectomy combined with enlargement of the dura by duraplasty is used by most research groups and seems to have the most favorable results. Several prospective studies have agreed that the procedure of decompressive craniectomy with simultaneous augmentative duraplasty would also be able to control refractory intracranial hypertension and play a beneficial role in patients with severe TBI. Coplin et al. performed a prospective trial on the feasibility of craniectomy with duraplasty versus "traditional craniotomy" as a control group in patients who developed brain swelling, and found that despite more severe head trauma, the patients in the study group had similar outcomes to the control group.[27] Ruf et al. performed decompressive craniectomy and simultaneous dural augmentation with duraplasty in six children whose elevated ICPs could not be controlled with maximally intensified conservative therapies. Subsequently, the ICP normalized, with improved outcomes after the procedure.[4] Figaji et al. reported prospective studies on 12 patients who had undergone decompressive craniectomy with augmentative duraplasty. In this case series, the mean ICP reduction was 53.3% and clinical improvement as well as reversion of radiographic data was attained in most patients (11/12); all 11 survivors had good outcomes (GOS 4 or 5).[28] Additionally, several other pathological indices improved after this combined procedure, including cerebral blood perfusion and cerebral oxygen supply.[29, 30] These results showed that large decompressive craniectomy combined with augmentative duraplasty has favorable decompressive effects in the treatment of traumatic refractory intracranial hypertension compared with surgical decompression with dura opening. However, no well-planned study has compared the two methods, and in many centers, decompressive craniectomy with complete dura opening is still performed routinely.

Technical improvements

Technical improvements have been made to this surgical procedure. As mentioned above, whether it is combined with augmentative duraplasty or dura opening, decompressive craniectomy is recommended to be performed as a large craniectomy for severe TBI, including large fronto-temporoparietal/hemisphere craniectomy and bifrontal craniectomy.[5, 8, 10, 17] In decompressive craniectomy, preserving the inferior temporal lobe venous return requires that the craniectomy comes down to the floor of the middle cranial fossa, at the root of the zygoma; this ensures adequate lateral decompression of the temporal lobe, allowing it to "fall out" of its usual calvarial boundaries. Moreover, the following discussion about technical improvements is based on the procedure of large decompressive craniectomy.

Two main methods are used for dural augmentation with duraplasty: the dura is enlarged with the patient's own tissue, such as temporal fascia, temporal muscle, or galea aponeurotica,[16, 18, 31] or this is performed with artificial or xenogeneic tissue, such as artificial dura substitute or bovine pericardium.[27, 28] In our institute, dural augmentation was performed with temporal fascia or artificial meninges. The method using temporal fascia is similar to the one introduced by Yu et al.[32] They separated the temporal deep fascia from the temporal muscle to the zygomatic arch, and then cut the fascia from the base backwards along the zygoma but left the fascia base 1-2 cm long for the blood supply. Finally, they turned the temporal fascia beneath the temporal muscle and sutured it to the dura. They performed this method in 36 patients, and 33 survived. Generally, temporal deep fascia is large enough for the enlargement of dura in during decompressive craniectomy, and forms a pedicle of temporal fascia that maintains the blood supply.

Brain herniation via the craniectomy defect may lead to compression of vessels and result in ischemic necrosis of the portion of the herniated brain. Coskay et al. introduced an interesting method called the "vascular tunnel" to avoid this complication.[33] Following removal of part of the skull, they performed dural incisions in a stellate fashion. In this step, it is important that entrance points of major vessels are close to the midpoint between the angles of the dural opening. The most significant step involves constructing small supporting pillars on the bilateral sides of the vessels as they pass the edge of the dural window (the pillars were made of hemostastic sponge wrapped by absorbable thread), and then the superficial vessels supporting the portion of brain run in the artificial "vascular tunnel" between the brain tissue and dura. Finally, the dura was closed as in augmentation duraplasty. In the latest report, they performed this new technique with decompressive craniectomy in 21 patients, and the "vascular tunnel" method seemed to improve patient outcome compared with a control group consisting of 20 patients who underwent ordinary large decompressive craniectomy.[34] Another method, lattice duraplasty, was also introduced by Mitchell et al.[35] to avoid herniation of the brain through the cranial defect. After conventional craniotomy, they made a series of dural incisions, each 2 cm long and with 1-cm intervals. The process was repeated in parallel rows of incisions so that each incision in one row was adjacent to an intact dural bridge in the rows on either side. The same course was then performed, but in a direction vertical to the initial incision. This method was believed to be able to increase the tractility of the dura and to allow it to stretch and expand. They performed decompressive craniectomy combined with this technical improvement in six patients, and found that ICP was reduced, by 20-30 mmHg.

After decompressive craniectomy, patients are typically without a cranial flap for several months before cranioplasty, which places them at theoretical risk of injury to the unprotected brain. Moreover, with the skin flap concavity, the hydrodynamic disturbance of CSF circulation and the decrease in cortical perfusion after decompressive craniectomy may also hinder patient recovery.[36-37] A method called "the tucci flap" was suggested by Claudia et al. to resolve this problem.[39] After craniotomy, removal of the intracranial lesion, and duraplasty, the bone flap was replaced and one side of the flap was attached to the cranium by plates. The plates act as a hinge that allows the unattached portion of the bone flap to float out with bone swelling. They performed this method in two patients and reported favorable resolution of ICP elevations. A similar technique was introduced by Kathryn et al., but was called an "*in situ* hinge craniectomy."[40] Their series consisted of 16 patients, and ICP was controlled to normal levels in all patients with this method, sometimes combined with CSF drainage, and no severe surgical complication occurred. Obviously, except for the prevention of potential injury after surgical decompression as mentioned above, this variation of the traditional decompressive craniectomy eliminates the need for a second major cranioplasty, or at least facilitates the process of cranioplasty. In consecutive procedures, most of the patients could undergo cranioplasty under local anesthesia. However, the replaced bone flap would account for a certain amount of space, and the efficacy of decompression would thus be weakened.

Vakis et al. introduced a method to prevent peridural fibrosis after decompressive craniectomy.[41] For the survivors of decompressive craniectomy, development of multiple adhesions among the dura, temporal muscle, and galea would be a problem during subsequent cranioplasty, and would also be a potentially deleterious factor for patient recovery. To prevent adhesions, the authors placed a dural substitute between the dural anasynthesis flap and galea aponeurotica after augmentative duraplasty with temporal muscle. They performed this method in 23 patients who underwent decompressive craniectomy. Compared with a control group consisting of 29 patients who underwent ordinary large decompressive craniectomy, they found that cranioplasty in the patients in their study group was easier, lacked severe secondary complications, required a shorter cranioplasty operating time, and resulted in less intraoperative blood loss.

To increase the space of decompressive craniectomy, Zhang et al. suggested a method of surgical decompression combined with removal of part of the temporal muscle.[42] They resected the temporal muscle above the inferior edge of the bone window formed by the craniectomy. On average, additional space, as large as 26.5 cm^3, was obtained. In their retrospective series, the patients who underwent surgical decompression combined with removal of part of the temporal muscle seemed to have a lower mortality than those who underwent ordinary large decompressive craniectomy. However, survivors developed a higher rate of mastication disability.

The effect of bifrontal decompressive craniectomy with preservation or removal of the bone above the superior sagittal sinus is still undetermined,[3, 17, 43, 44] though it seems that the procedure combined with removal of this bone is being accepted by more institutes. To increase the decompressive effect, simultaneous division of the falx at the floor of the anterior cranial fossa has also been recommended by some authors.[3]

Moreover, except for the technical considerations of this operation, timely decompressive craniectomy before the development of irreversible changes in the injured brain would be equally important for patient outcome.[4, 45-48] With the exception of ICP and clinical signs, PtiO2 monitoring may be another important tool when a timely craniectomy is indicated.[49, 50]

Conclusions

Several types of decompressive craniectomy have been performed for the management of traumatic refractory intracranial hypertension, and the variations in results between studies may be explained by the different methods of surgical decompression. Presently, unilateral fronto-temporoparietal craniectomy/hemisphere craniectomy for lesions or swelling confined to one cerebral hemisphere, and bifrontal craniectomy for diffuse swelling, are recommended for the management of traumatic refractory intracranial hypertension. Different technical improvements in decompressive craniectomy, based on large decompression, have been introduced to increase the decompressive effect, avoid surgical complications, and facilitate subsequent operations and management. Although all of these methods are tentative and experiential, and in most reports the involved patient populations are small, these experiences are valuable. At present, in the absence of definite proof of the efficacy of decompressive craniectomy in the treatment of TBI, such as from multicenter, prospective, randomized, controlled trials, these technical improvements to increase the decompressive effect or avoid potential surgical complications should be considered.

Conflict of Interest

The authors have declared that no conflict of interest exists.

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