Review article

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Decompressive craniectomy in traumatic brain injury: Quo Vadis?

Intracranial hypertension is the leading cause of mortality in patients with cranial injury. Currently the traumatic brain injury is a public health problem worldwide. Decompressive craniectomy emerges as a treatment strategy for patients with refractory intracranial hypertension. The completed surgery requires careful surgical technique and exquisite. We present a review of the literature about the technique.

Key words: *neurotrauma, traumatic brain injury, decompressive craniectomy.*

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HISTORY OF DECOMPRESSIVE CRANIECTOMY

The decompressive craniectomy (DC) as a procedure was first described by Annandale in 1894 [1, 2]. In the last part of the XIX century, almost all neurosurgery pioneers had been performed craniectomies as a palliative measure for patients with intractable tumors, but Kocher in 1901, was the first one to propose the palliative decompressive craniotomy for patients with raised intracranial pressure following traumatic brain injury (TBI) [3]. The collaboration of Kocher with Harvey Cushing resulted in the proposition of the use of DC for the treatment of other brain disorders such as vascular malformations and brain tumors, through subtemporal and suboccipital decompressions [4, 5]. Cushing in 1908 [6] published the subtemporal decompressive operations for the intracranial complications associated with bursting fractures of the skull.

The procedure described by Annandale gained popularity in the early 1970's, but due to poor clinical outcomes, quickly fall into discredit [1, 2], and was almost abandoned when experimental evidence [7] suggested that decompression worsen cerebral oedema. In 1968, Clark et al, reported 2 cases with 100% of lethality [8]. In 1971, Kjellberg et al [9], reported 73 cases, using large bifrontal craniectomy with 18% of surveillance. Venes and Collins, in 1975, reported in a retrospective analysis of 13 patients who had bifrontal decompressive craniectomy for the management of posttraumatic cerebral edema, a significant decrease in expected mortality, but severe morbidity in the survivors, and only one patient returned to the pretrauma level of neurological function [10].

However, throughout the 1980's its popularity returned. Pereira et al in 1977, present the results observed with large bifrontal decompressive craniotomy performed on 12 patients with severe cerebral oedema, a 50% surveillance and 41.6% of excellent neurological and mental improvement [11]. In 1980, Gerl and Tavan report that extensive bilateral craniectomy with opening of the dura offers the possibility of rapid reduction of intracranial pressure. In this study, with 30 patients shows a 70% of mortality, and a 20% of the cases with full recovery [12]. In 1990, Gaab et al [13], with a prospective study design with 37 patients <40 years old, they performed 19 bifrontal craniotomies and 18 hemicraniotomies, and report 5 deaths, all others achieved full social rehabilitation or remained moderately disabled; they established as best predictor of a favorable outcome an initial posttraumatic Glasgow coma scale (GCS) ≥7.

In addition to these promising clinical results, new data suggested that complications of TBI may be reduced following early decompression [14-17].

TRAUMATIC BRAIN INJURY (TBI): A CRITICAL PUBLIC HEALTH PROBLEM

Morbidity and mortality, due to injuries, is being recognized as a major public health and a development problem. It ranks among the leading causes of death and occurs in all regions, affecting people in all age and income groups [18]. TBI is a major public health concern worldwide, according to the predictions, neurotrauma will account an increasing number of deaths worldwide by 2020 [19].

The Centers for Disease Control and Prevention (CDC) has defined TBI as an injury to the head arising from blunt or penetrating trauma or from acceleration/deceleration forces associated with one or more of the following: decreased level of consciousness, amnesia, objective neurological or neuropsychological abnormality(ies), skull fracture(s), diagnosed intracranial lesion(s), or head injury listed as a cause of death in the death certificate [20, 21].

The CDC has estimated that every year, during 2002–2006, on average 1.7 million persons had a TBI alone or a TBI associated with other injuries and/or medical conditions [21]. TBI is associated with mortality rates as high as 30% and also with high morbidity [22, 23]. There is a significant percentage of TBI related deaths that occur relatively late, these are secondary to multiple organ failure and infectious complications, such as pneumonia [22, 24, 25].

TBI is the most common cause of death and disability in children and young adults [26]. In the United States, this kind of injury generate 235.000 hospitalizations, 50000 deaths, and permanent disability in 99000 [26]. The economic burden for TBI alone in the United States in 2000 was estimated in $110 billion derived from direct (e.g. medical) and indirect (e.g. lost productivity) costs [27].

One of the main characteristic of TBI is that patients without a severe TBI, can experience subsequent mental and/or medical problems [28, 29]. The acute consequences of TBI are just only a half of the complete problem, the long-term repercussions of TBI are substantial especially among adolescents and young adults, whose brains continue to mature and develop [30]. Approximately 293,000 persons with ages between 15 to 24 years old, sought emergency department treatment for TBI in the United States in 2010 [31].

People who sustain TBI during or before adolescence can have a limited return to pre-trauma academic or work activities that aggravates the economic and physical consequences derived from the treatment and the rehabilitation. Furthermore, they may have diminished attainment of personal milestone [32-34].

When all the costs of severe TBI are considered, aggressive treatment is a cost-effective option, even for older patients [35].

INTRACRANIAL HYPERTENSION (ICH)

Morbidity and mortality related to brain injury mostly results of brain edema, In neurotrauma, brain edema leads to an elevation in intracranial pressure (ICP), altering physiologic parameters like the cerebral perfusion pressure (CPP) and then brain oxygenation [36]. Edema formation plays a role to the resulting pathology following TBI [37], is a secondary injury caused by a cascade of mechanisms initiated at the moment of injury. In the pathophysiology of the primary and secondary lesions in TBI are the targets to prevent and wane the progression of brain damage.

Intracranial hypertension is a frequent complication of severe TBI [38-40]. Close than 70% of brain injured patients will present ICH [41-44]. TBI is the most common cause of intracranial hypertension [45]. ICH is the most frequent cause of death and disability following severe TBI [46-48]. ICH (defined as ICP ?20 mmHg) is a known independent risk factor for poor neurological outcomes [49].

ICP is determined by the volume of its contents: brain, blood and cerebrospinal fluid (CSF). As stated by Monroe-Kelly doctrine [50, 51], «the sum of the intracranial volumes of blood, brain, CSF and other components is constant and that an in increase in any one of these must be offset by an equal decrease in another» [52], so the skull is a rigid structure, inextensible, in order to maintain a constant blood pressure, the volumes inside the cranium should be constant. Any increase or an additional volume (e.g., haematomas, oedema, hyperemia), will carry an increase in the ICP, and must result in a decrease in the others. Alterations in brain autoregulation, blood flow, and brain edema, persists are consequences of raised ICP.

TBI patients with refractory ICH, have worst outcomes, and more likely to development herniation syndromes [53, 54]. A CPP lesser than 60-70mmHg is associated with diminished oxygenation and altered metabolism in brain parenchyma [55].

The raised ICP results in «spatial compensation», i.e., extrusion of CSF and blood (mainly venous) from the intracranial cavity. CSF has a key role in spatial compensation because it can be expelled to the spinal theca, the reservoir [56, 57]. In the intracranium can be stored 150mL of new volume without a significant increasing of the ICP, this occurs because the venous blood can be derived to the general circulation [50]. Should be remembered that CSF shift is time- and age-dependent variable. Older people can accommodate more of the expanding new volume due to the additional space created by cerebral atrophy, conversely, young people get symptomatically faster, due to the lack of space.

Among deleterious effects of increased ICP is the shift of brain parenchyma resulting in structural damage to the brain and to herniation syndromes. The latter can result in compression on the brainstem causing bradycardia and hypertension and, if untreated, respiratory depression and death [58-60].

In the context of raised ICP, the cerebral perfusion pressure (i.e., difference between ICP and mean arterial blood pressure) generally decrease, contributing to sacrifice cerebral blood flow and generating ischemia and neuronal death, but reduced CPP is associated with the hypoxic/ischemic injury regardless of the ICP [45, 61].

THE NEUROSURGICAL TECHNIQUE [62]

There are two kinds of craniectomies: hemicraniectomies and bilateral craniectomies.

When making the surgical plan there are some factors to be considered: location, hemisphere, size of the decompression, dural technique, the bone flap, etc. The CT scan will offer large determination of the location (frontal, temporal, parietal, occipital), and hemisphere (uni/bilateral). Some indications for decompressive hemicraniectomy are the unilateral lesions, such as unilateral swelling, contusions, extradural or subdural hemorrhage, midline shift [63], generally is required bifrontal decompression for diffuse cerebral edema with no obvious midline shift [63].

When the decision has been taken, should try at maximum to do bone removal as large as possible, has been recommended that the size of the decompression be, at a minimum, 14 cm (anteroposterior) by 12 cm (superoinferior) if the intention is to perform a frontotemporoparietal craniectomy [64].

The ideal technique implies the removal of bone in the entire supratentorial hemicranium. One of the most important landmarks for this procedure is the root of the zygoma, it allows the identification the floor of the temporal fossa. Also are important landmarks: the asterion (confluence of the lamboid, occipitomastoid, and temporoparietal sutures, indicates the area of transition between the transverse and sigmoid sinuses), the keyhole (identifies the pterion and indicates the location of the frontal, temporal, and orbital cavities), the inion, the glabella, and the midline (delineates the course of the superior sagittal sinus). When the patient's head is placed in the headholder, it is ideal that the sagittal plane of the head be 0-15° horizontal to the floor [65].

Skin incisions for decompressive hemicraniectomy

Because the objective is the exposure of the entire hemicranium, there are two incisions that allow this goal to be achieved.

1. Large reverse question mark frontotemporoparietal incision

This incision is quick and easy, but has the potential risk of flap ischemia and dehiscence of the wound. It begins at the widow's peak, continues posteriorly along the midline to the inion, it then turns sharply to the ear parallel to a line extending from the inion to the root of the zygoma [66]. The incision should skirt the superior and anterior portions of the ear as closely as possible and extend 1 cm below the root of the zygoma. With this incision the hemicranium is exposed at the midline, along the line of the transverse sinus. Also permits a great temporal fossa exposition. Skirting the ear avoids the superficial temporal artery; it ensures a good blood flow to the skin flap [67]. Now, the periostium can be incised using an electrocautery knife, and then, the cutaneous flap can be reflected. The temporalis muscle can be reflected in two ways [67]:

– Reflect the skin anteriorly as a separate layer of muscle, this facilitate the temporalis muscle reflection.

– Reflect the muscular and the cutaneous flaps together, as a single piece. This permit to conserve the original muscle position in the absence of an underlying attachment to the bone and preserve cosmesis.

2. L.G. Kempe modified incision or midline sagittal incision with «T-bar»:

With this incision there is a better blood flow to the skin flaps, and so, lesser dehiscence risk, especially in the posterior portion of the incision, the weakness of the previously described incision [67]. The scalp is incised in the midline from the widow's peak to the inion, after this, is created a limb to the incision, forming the «T-bar» from 1-2cm anterior to the tragus, extending superiorly, 1cm behind the coronal suture until find the midline sagittal incision [65-67]

Skin incisions for bilateral decompressive craniectomies

Bilateral craniectomies are especially useful in cases of bilateral frontal contusions or generalized cerebral edema without focal lesion [65]. Can be performed in two ways:

1. Perform two hemicraniectomies as previously described:

This will result in the midline a strip of bone 2 – 3cm wide, for covering the superior sagittal sinus. Can be used either the midline sagittal incision with «T-bar» or the large reverse question mark frontotemporoparietal incision [67].

2. Kjellberg type

In this, is made a standard bicoronal incision, beginning 1-2cm anterior to the tragus, going superiorly behind the coronal suture until finding the opposite root of the zygoma, also ending 2cm anterior to the tragus [66]. The flap resulting is reflected anteriorly and inferiorly exposing the frontal and anterior temporal lobes [67].

Making the bone flap for decompressive hemicraniectomy

Superior to the root of the zygoma is made a single bur hole, to delineate the floor of the temporal fossa. The asterion should be exposed by reflecting the soft tissue caudally. Making this maneuver can be visualized the inferior extent of the temporal and occipital lobes [67]. Already made the blur hole is inserted the footplate and the bone flap is turned by extending the beginning of the craniectomy along the line toward the inion. For avoiding the transverse sinus is necessary to stay at least 1-cm rostral to the asterion. The lambdoid suture will be crossed when the bone flap is extended posteriorly, then, the drill bit is turned parallel to and 1-cm medial to the lambdoid suture until reach a point 1 cm from the midline [67].

The drill is then turned parallel to the sagittal sinus, again crossing the lambdoid suture. Drilling continues toward the supraorbital bar. The craniotomy is continued anteriorly by hugging the floor of the frontal fossa as closely as possible, staying as close to the orbital rim as the anatomy allows. Next, the drill is turned posterolaterally toward the keyhole and aimed as close to the pterion as possible. At this point, the drill is removed and re-inserted into the bur hole at the root of the zygoma [67].

The second drill line is created by hugging the floor of the temporal fossa and extending it as far anteriorly as possible toward the temporal tip. The bone flap is removed by levering it using the pterion as fulcrum [67]. Usually the pterion cracks on removal and the dura can be dissected using Rhoton dissectors. Leksell rongeurs are used to remove bone excess, it is necessary to smooth the edges of the bone flap [66, 67].

Making bone flap for bilateral decompressive craniectomies

The bur holes are placed in the keyhole and in the root of the zygoma just below the superior temporal line. This type of craniectomy can be removed as a single piece or a strip of bone can be left over the sagittal sinus for protection, then resulting two bone flaps.

The bilateral frontal and subtemporal craniectomies will be performed, so the firs drill line extends from the zygoma, ascending and crossing the sagittal superior sinus until reach the contralateral zygoma, the a second drill line extends from keyhole to keyhole, crossing 1cm parallel and superior to the orbital rim, then other tow drill lines will be performed, are made from the zygomatic bur hole going anteriorly, hugging the floor of the temporal fossa toward the temporal tip and extending superiorly and anteriorly toward the keyhole [67]. This will result in the exposing of the frontal and anterior temporal lobes. The craniectomy can be enlarged using Leksell rongeur, especialy the subtemporal craniectomy [66].

Dural opening

For this step can be used three different ways of opening the dura with fish-mouth incision, stellate incision, C-shaped fashion incision and cruciate incision [66, 68]. The C-shaped fashion is one of the most used incisions for dural opening, it goes from the temporal tip of the temporal lobe, and curving back about 8 cm crossing the sylvian fissure, and ending in the frontal region [66]. For allow brain swelling can be practiced spoke-wheel relief cuts. The dural flap is reflected anteriorly. Now, the underlying hematomas can be evacuated. Once hemostasis is ensured, the dura leaves can be laid back over the brain surface [67], and a large piece of dural substitute is placed over the opened dura [66].

Dural substitutes and sealants

In dural closure can be used absorbable gelatin sponges like (Gelfoam, Pharmacia and Upjohn, Kalamazoo, MI), dural substitutes and dural sealants. The dura substitutes are designed to be either placed as an onlay over dural defects or sutured into place [69]. These could be autologous tissues, such as pericranium or fascia lata, or artificial dural substitutes mainly derived from bovine tendon (DuraGen, DuraGen Plus [Integra LifeSciences, Plainsboro, New Jersey, USA], DuraMatrix [Stryker, Cambridge, Massachusetts, USA], TissuDura [Baxter Healthcare S.A., Opfikon, Switzerland]), among others derived from fetal bovine skin [69].

With the aim to reinforce primarily repaired dura or as adjuncts to dural substitutes can be used the dural sealants, including DuraSeal (polyethylene glycol hydrogel [Confluent Surgical Inc., Waltham, Massachusetts, USA]), Bioglue (glutaraldehyde, bovine albumin [Cryolife, Kennesaw, Georgia, USA]), Tissucol (human fibrinogen, thrombin, albumin, and animal aprotinin), Tisseel (human fibrinogen, thrombin, and aprotinin [Baxter International Inc., Westlake Village, California, USA]), and Evicel (human fibrinogen and thrombin [Johnson and Johnson Wound Management, Ethicon Inc., Somerville, New Jersey, USA]) [69], Seprafilm (hyaluronate/carboxymethyl cellulose) [70].

Skin closure

The skin is closed over the absorbable gelatin sponge or the dura substitute or sealant using 2-0 Vicryl (Ethicon, Johnson & Johnson Professionals, Inc., Somerville, NJ) stitches for the galea. Typically, staples are used to close the skin.

Craniectomy bone flap management

The craniectomy bone flap can be discarded, be inserted in an abdominal subcutaneous pocket in the left lower quadrant or conserved in a bone bank [66, 67, 71]. The consequences of discard the bone flap are obvious, requires a cranioplasty with intraoperative reconstruction, making expensive the procedure, and sacrificing cosmesis. In some centers are preferred discard it and use 3D methyl methacrylate prosthetic implants [66], especially because over one-half of the patients with severe CNS injury had concomitant systemic infectious processes of some type [66]. When the bone flap is conserved inside the body, it usually remolds the bone edges to some degree. So, keeping the bone frozen in a bone bank is an option with no risks of bone remodeling, and offers great cosmetic outcomes [67].

When the autogenous bone graft is not available for cranioplasty, can be used synthetic materials such as tantalum, silastic, titanium plate, prefabricated acrylic, synthetic bone substitute, and other similar material manufactured for the use of implantation into the body [71].

WHAT IS AND WHAT IS NOT

As has been stated clearly above, DC is a surgical procedure that reduces the secondary damage due to an uncontrolled increase of ICP, but does not heal the primary lesion [72]. Inappropriate techniques for DC, e.g., do not smooth the bony edges; do not try at maximum to do bone removal as large as possible performing wrong approaches like only subtemporal decompression, or only frontotemporal decompression, can generate iatrogenic brain lesion, and even generate brain herniation trough the craniectomy. Do not being faithful to the technique described can result in patient dead or in bad outcomes.

The inconsistent results and the conflicting opinions related to the DC can be due to the substantial variation of its employment. It is imperative that DC must be performed with standardized technical guidelines as proposed by Quinn et al in 2010 [65].

CONCLUSSIONS

The cranial decompression techniques are saving surgeries in expert hands. Neurotrauma surgery is a complex surgery, usually performed by residents and young neurosurgeons. We suggest the use of a checklist during decompressive craniectomy that ensures that the procedure is performed correctly.

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Декомпресивна краніоектомія при черепно-мозковій травмі: Камо грядеши?

Внутрішньочерепна гіпертензія є провідною причиною смертності у потерпілих при черепно-мозковій травмі. У теперішній час травма голови є проблемою охорони здоров’я в усьому світі. Декомпресивна краніоектомія — провідна стратегія лікування пацієнтів з приводу рефрактерної внутрішньочерепної гіпертензії. Виконання краніоектомії вимагає досконалої і ретельної хірургічної техніки. Представляємо огляд літератури з питань техніки виконання краніоектомії.

Ключові слова: *нейротравма, травма голови, декомпресивна краніоектомія.*

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Декомпрессивная краниоэктомия при черепно-мозговой травме: Камо грядеши?

Внутричерепная гипертензия является ведущей причиной смертности пострадавших при черепно-мозговой травме. В настоящее время травма головы является проблемой здравоохранения во всем мире. Декомпрессивная краниоэктомия — ведущая стратегия лечения пациентов по поводу рефрактерной внутричерепной гипертензии. Выполнение краниоэктомии требует совершенной и тщательной хирургической техники. Представляем обзор литературы, посвященный технике выполнения краниоэктомии.

Ключевые слова: *нейротравма, травма головы, декомпрессивная краниоэктомия.*

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