# The Evolving Concept of Damage Control in Neurotrauma: Application of Military Protocols in Civilian Settings with Limited Resources

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■ OBJECTIVE: **The aim of the present review was to describe the evolution of the damage control concept in neurotrauma, including the surgical technique and medical postoperative care, from the lessons learned from civilian and military neurosurgeons who have applied the concept regularly in practice at military hospitals and civilian institutions in areas with limited resources.**

■ METHODS: **The present narrative review was based on the experience of a group of neurosurgeons who participated in the development of the concept from their practice working in military theaters and low-resources settings with an important burden of blunt and penetrating cranial neurotrauma.**

■ RESULTS: **Damage control surgery in neurotrauma has been described as a sequential therapeutic strategy that supports physiological restoration before anatomical repair in patients with critical injuries. The application of the concept has evolved since the early definitions in 1998. Current strategies have been supported by military neurosurgery experience, and the concept has been applied in civilian settings with limited resources.**

■ CONCLUSION: **Damage control in neurotrauma is a therapeutic option for severe traumatic brain injury management in austere environments. To apply the concept while using an appropriate approach, lessons must be learned from experienced neurosurgeons who use this technique regularly.**

## INTRODUCTION

Trauma has increased significantly in the past several decades all around the world. Traumatic brain injury (TBI) has an enormous effect socioeconomically and results in

**Key words**
- Damage control
- Global surgery
- Low resources
- Military neurotrauma
- Neurotrauma
- Severe TBI

**Abbreviations and Acronyms**
**CT**: Computed tomography
**DCNt**: Damage control in neurotrauma
**GCS**: Glasgow coma scale
**ICP**: Intracranial pressure
**TBI**: Traumatic brain injury

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**Table 1.** Criteria for Damage Control Surgery in Neurotrauma Proposed in 2001

| Inclusion Criteria |
|---|
| Age <50 years |
| GCS score <9 after emergency room resuscitation (Sa+$O_2$ >90% and systolic blood pressure >90 mm Hg) and after pharmacologic sedation or paralytic agent has been metabolized if used (short-action agent in rapid sequence induction institutional protocols) |
| Isolated, non-penetrating head injury, without other associated trauma (e.g., abdominal, thoracic, or extremity injuries) |
| CT finding compatible with diffuse injury, Marshall grade III or IV (volume and width of lesion and midline shift measured using CT scan software and correlated with the ABC method for the width and [A/2]-B method for the midline shift) |
| Evolution <12 hours after the event |
| Meeting none of the criteria for brain death |

GCS, Glasgow coma scale; $SaO_2$, oxygen saturation; CT, computed tomography; A, greatest hemorrhage diameter in axial plane; B, hemorrhage diameter at 90° to A in axial plane; C, originally as number of CT slices with hemorrhage multiplied by slice thickness but craniocaudal diameter of hemorrhage can be substituted if multiplanar formats are available.
Data from Rubiano et al.[15]

great mortality and morbidity, especially in low- and middle-income countries, where trauma remains one of the leading causes of death.[1,2] Ideally all patients with severe TBI requiring advanced medical or surgical intervention will be transferred to a major trauma center with specialized neurosurgical and neurocritical care. However, in a vast majority of noncapital cities in middle- and low-income countries, rural areas, and military frontlines, these patients will face different conditions, with the possibility of prolonged transfer times before reaching these specialized centers.[3-5] An emerging concept, based on surgical experience from military scenarios and rural trauma surgeons, has supported the development of the damage control approach in neurotrauma. In the present study, we have explored the concept of damage control in neurotrauma (DCNt), including decision-making suggestions for its application and techniques and learned lessons from experienced neurosurgeons who regularly use this approach.

## Damage Control Surgery Concept

Damage control surgery has been described as a sequential therapeutic strategy that supports physiological restoration before anatomical repair in patients with critical injuries.[6] It was first described by Rotondo et al.[7] in 1993 as an abbreviated abdominal surgery, performed in critically injured patients to avoid the lethal triad of acidosis, coagulopathy, and hypothermia.[8] This concept has been considered an important advancement in surgical techniques and has become an essential component of modern trauma care. The damage control concept has been applied globally in general surgery and orthopedics, with a fundamental shift from the traditional surgical focus of anatomical restoration to focus on physiological restoration with the aiming of saving lives.[9,10] The original concept described the performance of limited surgical intervention as quickly as possible in critically injured patients, using all measures necessary to stop hemorrhage and avoid prolonged surgical procedures. After the procedure, patients should be transferred to intensive care for secondary resuscitation until their condition allows for final reconstructive surgery.[11] Damage control resuscitation, with early correction of hypotension, hypothermia, and coagulopathy in patients with severe trauma should also accompany damage control neurosurgery.

## Damage Control in Neurosurgery

Damage control as a term in neurosurgery was introduced in 1998 by Rinker et al.[12] Rinker was a rural trauma surgeon from United States, who advocated for emergency craniotomy training for rural surgeons to enable them to treat patients with severe TBI in environments in which neurosurgeons were not immediately available.[12] In 2001, the same term, but applied to early cranial decompression for neurotrauma patients treated in areas with low neuromonitoring resources, was proposed by Rubiano[13,14] in Bogotá, Colombia. This approach using the phrase "damage control" has been used since 2001 at Simon Bolivar Hospital, a public university hospital in the north side of Bogotá, Colombia. With the limitations regarding intensive care unit bed availability

**Figure 1.** The standard trauma incision, bicoronal incision, modified hemispherectomy incision, and C-shape incision can be performed as initial incisions in the damage control in neurotrauma approach.

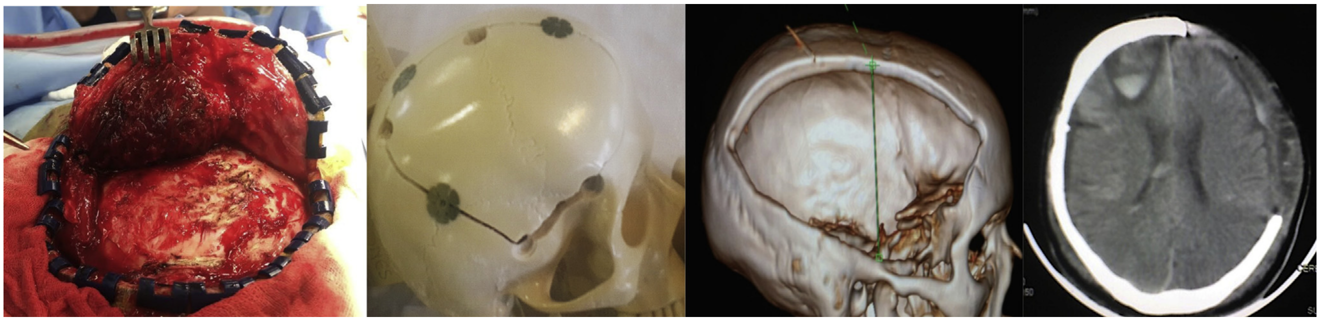

**Figure 2.** The standard trauma incision allows for craniectomy with bone flaps ~10–12 cm in diameter. Resection of anterior frontal and posterior temporoparietal bone sections can be restricted owing to the limited exposure.

and lack of advanced neuromonitoring tools, early (<12 hours) primary decompressive craniectomy began to be performed in patients with severe TBI who had met specific inclusion criteria (Table 1).

In 2003, the first review of patients treated using this damage control approach was submitted to an international neurosurgical journal. The reviewers criticized the use of this term, suggesting that it was used by "general surgeons and trauma surgeons" and was not applicable to the field of neurosurgery. In 2004, the *Injury* journal published a special edition dedicated to damage control surgery. A specific study on damage control neurosurgery was reported by Rosenfeld,[16] a military neurosurgeon from Australia. He described the concept of damage control neurosurgery as an abbreviated urgent neurosurgical procedure performed in the injured patient to help to prevent secondary brain injury, assist in stabilizing the patient, and improve patient survival and outcome.[16] The process was described as an urgent surgical procedure performed by the neurosurgeon or a generalist in a remote, rural, or military environment. In 2009, after several rejections from neurosurgery journals because of the "damage control term," the report from the Bogotá group was published after changing the title to "Early Decompressive Craniectomy."[15] In 2010, a special issue on military neurosurgery published by *Neurosurgical Focus* again introduced the term "damage control" to describe neurotrauma surgical procedures performed by military surgeons in Iraq. Two studies were reported by Bell et al.,[17] from the team of Dr. Rocco Armonda, a military neurosurgeon from the Uniformed Services University of Health Sciences. They described the use of early decompressive craniectomy to treat severe penetrating and closed head injuries during wartime.[17] In the same issue, Teff[18] described "damage control" neurosurgery courses that were supported by military surgeons in Iraq and Afghanistan during the conflict years. Teff[18] reported that decompressive craniectomy has defined the era of damage control in wartime neurosurgery. In these courses, military surgeons taught non-neurosurgeons how to perform aggressive decompression in far forward combat support hospitals before transferring the patient to definitive care.[18] This experience from Iraq, which improved the classic decompression technique, introducing the modified "Kempe" incision to achieve greater access for a wider craniectomy and could be easily advanced to a bilateral procedure, required for extensive bilateral severe injuries, especially blast cerebral injuries.[19] Recently, the concept has been applied in civilian scenarios and has been reported by groups from several regions worldwide, including Eastern Europe and Latin America.[20,21]

## DCNt Approach

The DCNt approach includes urgent abridged neurosurgery for critically ill patients with TBI. The DCNt approach aims to limit

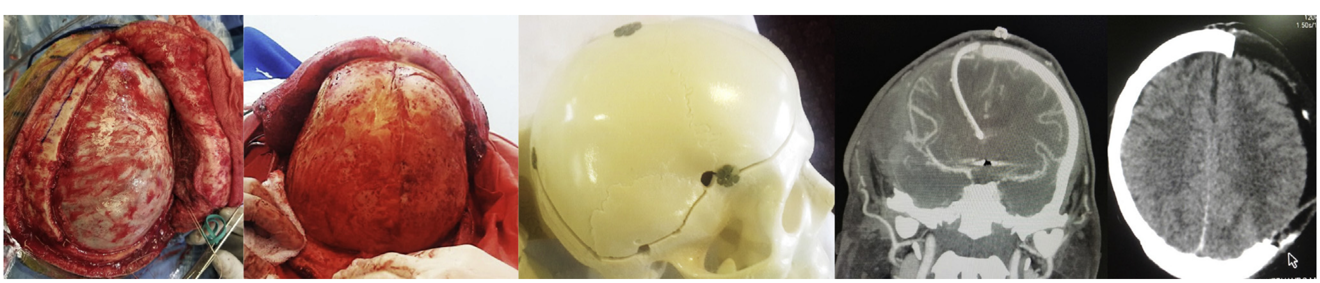

**Figure 3.** The C-shape and Kempe incisions allow for craniectomy with bone flaps ~15–17 cm in diameter. These unilateral or bilateral incisions increase the bone exposure and allow for larger flaps.

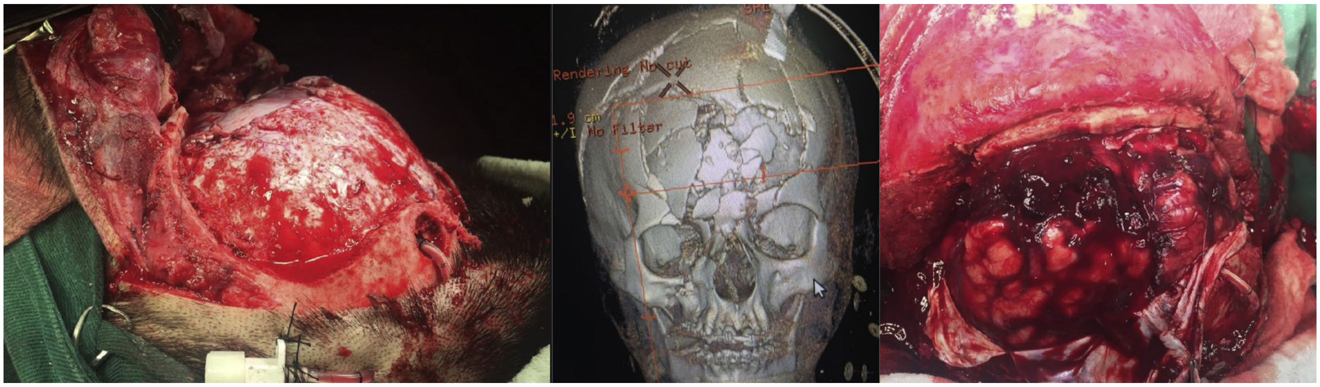


**Figure 4.** The bifrontal approach is recommended for bifrontal contusions, although not regularly used as a damage control in neurotrauma technique.

secondary brain injury, stabilize the patient to enable safe transfer, and improve patient outcome. In DCNt, the principles applied include the early use of hyperosmolar therapy (hypertonic saline or mannitol), arrest of intracranial bleeding, and evacuation of intracranial hematomas (including craniotomies performed with burr holes, rongeurs, and Gigli saw). In addition, the DCNt approach aims to limit contamination of compound wounds by early surgical debridement, alleviation of intracranial hypertension, prevention or arrest of cerebral and cerebellar herniation (coning), decompression of the brain stem, and restoration of anatomical continuity when possible. Dural closure is optional and is dependent on the patient's hemodynamic condition and/or the available resources. Recently, a randomized control trial performed by Brazilian neurosurgeons to study these techniques in a civilian setting demonstrated no differences in patients with and without the use of dural watertight closure in these environments.[22] The study compared patients who had or not received watertight dural closure after unilateral decompressive craniectomy. They reported no significant differences between the 2 groups in age, Glasgow coma scale (GCS) score at surgery, Glasgow outcome scale score, and postoperative follow-up period in days. A total of 9 surgical complications developed (5 in the control group and 4 in the test group), with no significant differences between the 2 groups.[22]

The DCNt approach aims to prevent the deleterious cascade of expanding intracranial hematomas and/or cerebral edema that occurs after TBI and can eventually exceed the capability of the autoregulatory mechanisms. This deleterious cascade results in exponential increases in intracranial pressure (ICP), which worsens secondary brain injury, potentially leading to tentorial and foramen magnum herniation. Prevention of this cascade can be achieved through early surgical intervention using decompressive craniectomy.

Recent military conflicts, most notably in Iraq and Afghanistan, have led to a significant increase in the numbers of both military and civilian individuals with severe penetrating and closed head trauma. Traditional approaches to the treatment of patients with severe TBI at the frontline have largely consisted of conservative measures and subsequent transfer to larger, often overseas, military hospitals for continued expectant management and potential surgical intervention. However, during recent conflicts, a significant shift in the paradigm has occurred toward early frontline

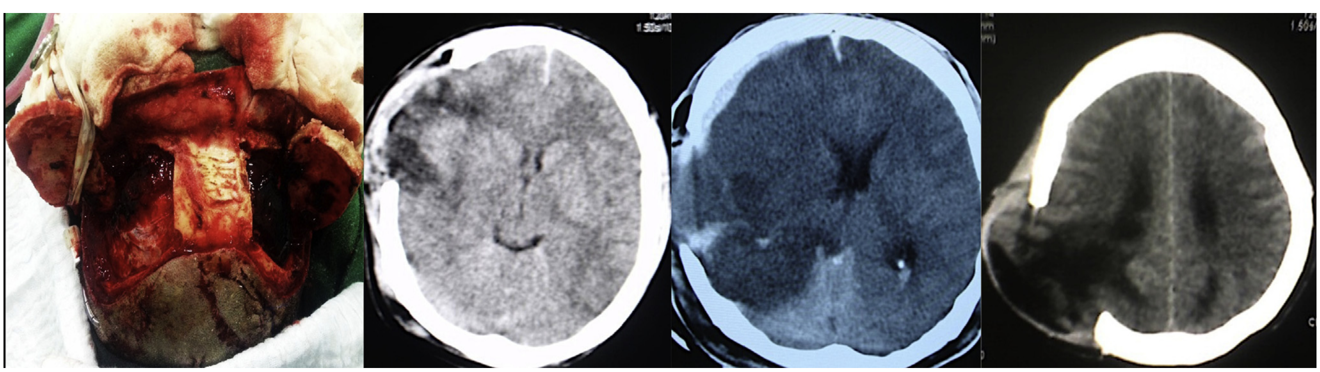

**Figure 5.** Small decompressions increase the risk of complications and affect the recovery process for patients with severe traumatic brain injury. Common complications include cortical infarct, venous bleeding, fungus cerebri, and hygroma.

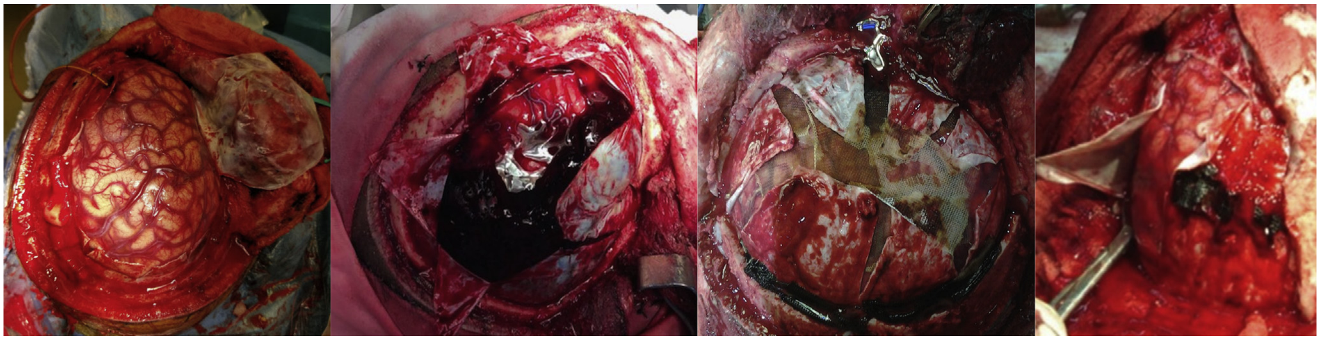

**Figure 6.** A dural incision can be performed using several methods, including the C-shape durotomy, star-shaped incision, and H-shaped incision. Greater cortical surface exposure will be obtained with the C-shape and star-shaped incisions.

decompressive craniectomy, followed by patient overseas transfer.[23-25] One of the key factors leading to the increased use of DCNt in low-resource environments in civilian settings has been the experiences from the military frontline setting, which has an associated risk of prolonged evacuation of patients overseas. Typically, patients with TBI would have been placed on helicopters without direct neurosurgical supervision and transported, potentially for great distances, to far forward surgical facilities with neurosurgical capabilities. This is a similar situation faced by civilian patients in some scenarios, with and without air transport capability. This period of prolonged transportation represents a hazardous phase during which significant cerebral edema and increased ICP can occur, potentiating secondary brain injury. Thus, in settings with a scarcity of intensive care unit capabilities for postoperative care and/or the subsequent need for patient transportation, DCNt provides a method to stabilize the patient and ICP and alleviate the effects of any cerebral swelling that occurs during the early stages of the injury. These aspects have been evaluated recently in resource-poor settings such as Colombia and Nigeria.[26,27] The DCNt approach also enables treatment without the requirement for ICP monitoring, which has often been used in advanced health care settings as a method of determining the necessity for, and timing of, decompression.

## Medical Interventions Used the DCNt Approach

As stated, DCNt is a process directed to the critically ill patient with TBI; however, the medical management provided is also critical for all patients after early decompression. The basic interventions include invasive arterial or central venous catheters, controlled ventilation using a ventilator (if available), urine output catheters, gastric prophylaxis medications, anticonvulsant agents, perioperative antibiotic prophylaxis, antithrombotic prophylaxis after 48 hours, head of bed elevation to 30°–45° to prevent aspiration, and frequent neurological examination. These basic interventions should be a part of postoperative care. These principles have been analyzed in recent consensus and protocol studies in military and civilian high- and low-income settings.[28-30] The patient should be maintained in normothermia and normovolemia, if possible, in accordance with damage control resuscitation principles.[31,32] The use of military resuscitation protocols in low-resource settings has been associated with decreased mortality in patients with severe TBI.[33,34] Hyperosmolar therapy can also be used to lower the ICP. However, no specific recommendation is available to support the use of any specific hyperosmolar agent. Also, every case should be determined individually (e.g., hypertonic saline administration could be hazardous for patients with hypernatremia, and mannitol has a diuretic effect that is undesirable for hypotensive patients). In addition, hypertonic

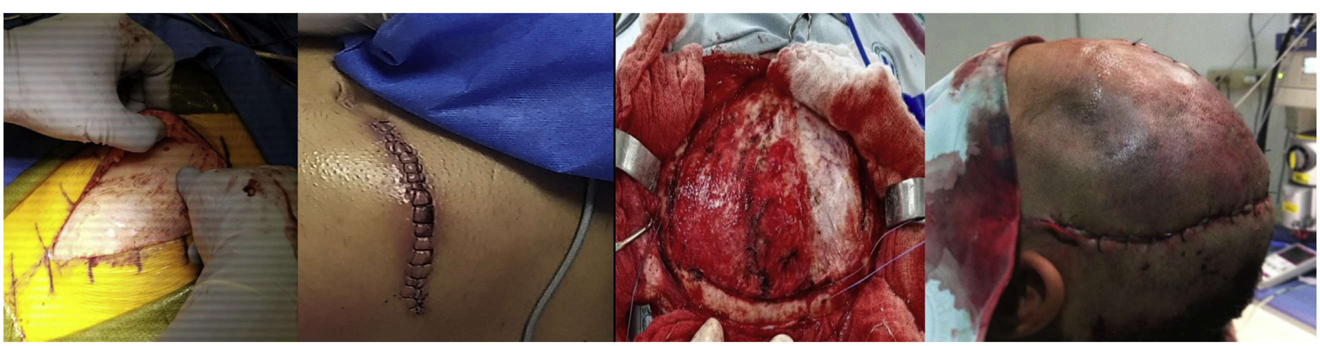

**Figure 7.** The most common bone storage site in damage control in neurotrauma procedures is the subcutaneous tissue in the abdominal wall. Alternatives sites such as the subcutaneous tissue near the craniectomy site can be an option; however, the tension of the sutures will be increased.


**Figure 8.** Positioning of the head for bilateral procedures includes a fixed neutral position, with placement on a donut roll or horseshoe holder. For unilateral procedures, the patient should be turned laterally, with a tubular roll or pad placed under the contralateral shoulder.

saline will probably not be available in resource-poor settings, although mannitol is more likely to be available. However, mannitol can accumulate in the brain and aggravate the cerebral edema. It should be used sparingly in the postoperative period. If neither mannitol nor hypertonic saline is available, diuretics such as furosemide can be considered, with care regarding blood pressure management and the use of electrolyte tests to avoid the development of hypotension or hyponatremia. Recent studies showing adherence to protocols in settings without the availability for advanced neuromonitoring have advocated for these interventions in TBI management in civilian low-resource settings.[35,36]

## DCNt APPROACH: DECISION-MAKING PROCESS FOR A THREE-PHASE APPROACH

The DCNt approach should be considered for cases of penetrating TBI and cases of closed severe TBI in war zones and low-resource areas. The approach, in accordance with damage control surgery principles, uses a 3-phase process: early surgery, protocol-based postoperative care, and timely cranial reconstruction. Appropriate patient selection for DCNt is required. Finally, floating and hinged cranial bone flaps have a role in resource-poor settings to avoid the need for cranioplasty.

The ethical principles of distributive justice, autonomy, beneficence, and nonmaleficence should be considered when determining the best intervention.[37] Several discussions regarding when to withhold or withdraw care and the intensity of treatment have been reported regarding the differing views from the perspectives of those in high- and low-resource countries. However, these decisions should be determined by the patient and context factors.[38-40] For every patient, the expertise of the local surgeons and the patient's and family's views should be considered within the following principles:

- The principle of justice obliges us to distribute equitably the benefits, risks, costs, and resources (especially in austere environments and military settings).
- The principle of autonomy obliges us to respect the decisions (self-determination) of adults who have decision-making capacity (i.e., patients or their relatives).
- The principle of beneficence is a moral obligation to act for the benefit of others.
- The principle of nonmaleficence obliges us to not inflict harm on others (i.e., not to impose intense treatment on patients without expectations of a good outcome).

The evaluation of parameters to assess the risk of imminent death or critical neurological deterioration is necessary to determine whether to use the DCNt approach. Parameters indicating the risk of imminent death or critical neurological deterioration include lateralizing signs (i.e., dilated pupil, hemiparesis), an

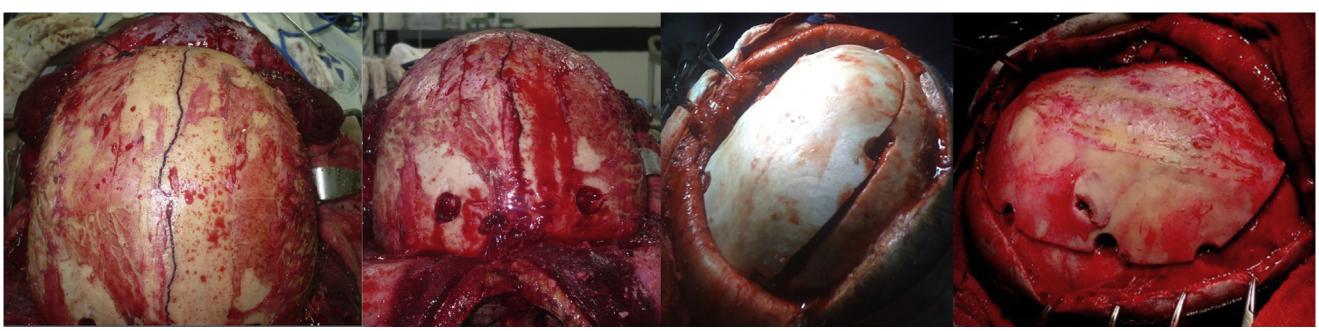

**Figure 9.** Skin flap elevation should be performed with a monopolar scalpel (Bovie [Bovie Medical Corp., Melville, New York, USA]) or periosteal elevator, with ≥3 burr holes, including a frontal one over the frontal sinus, posterior one before the lambdoid suture, and temporal one over the zygomatic region. Variations in these steps depend on resource availability.

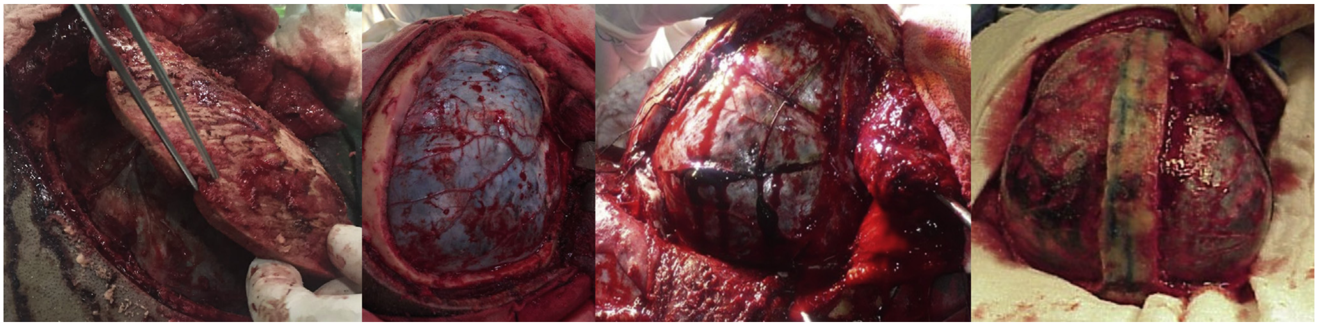

**Figure 10.** Removal of the bone flap requires carefully dissection of the dura mater attachments, with careful attention to the meningeal artery attachments in elderly patients. The lesser wing of the sphenoid bone can be drilled or removed with a rongeur.

acute decrease in the GCS score of >2 points, and/or progressive bradycardia and hypertension. The use of such well-defined criteria can help guide neurosurgeons in austere environments regarding their decisions.[41-43] Specific computed tomography (CT) findings have been associated with worse outcomes since the early classification of the Traumatic Coma Data Bank by Marshall et al.[44] and recent prognosis studies such as the IMPACT (international mission for prognosis and analysis of clinical trials in TBI) study reported by Maas et al.[45] These findings have supported the decision-making processes that have defined the use of a DCNt approach.

Some of the most common inclusion criteria for the DCNt approach have included the following:

- Age <50–55 years (debated in some-low resources areas where older patients are the usual patients with severe TBI).
- GCS score <9 after emergency room resuscitation (peripheral capillary oxygen saturation >90% and systolic blood pressure >90 mm Hg) and after pharmacologic sedation or muscle relaxants have been metabolized, if used (in some low-resource areas or war zones, patients with a higher GCS score with findings on CT scanning of acute subdural hematoma >1 cm thick or intracranial hemorrhage >50 $cm^3$ can undergo surgery).
- CT findings compatible with diffuse injury of Marshall grade III or IV (with the volume and width of the lesions and the midline shift measured using CT scan software and correlated with the ABC method for width and the [A/2] − B method for the midline shift).
- Interval from injury <12 hours (the timing is still under discussion in some areas; however, a period of 6–24 hours has been described).
- Absence of brain death criteria as evaluated by trained personnel.
- If the patient is very likely to have a poor outcome and is in a vegetative state or would severely disabled if surviving, this should be explained to the family and should help in discussion with the neurosurgeon regarding informed consent.

## SURGICAL TECHNIQUE FOR A DCNt APPROACH

As discussed in our introduction, the historical descriptions of DCNt have included the use of craniotomy with burr holes as a method to temporarily drain the hematoma and decompress the cranial vault, essentially allowing time for transfer of the patient for definitive neurosurgical intervention. However, if one has decided to perform DCNt immediately, the recommendation has been to perform an early wide hemispherical decompressive

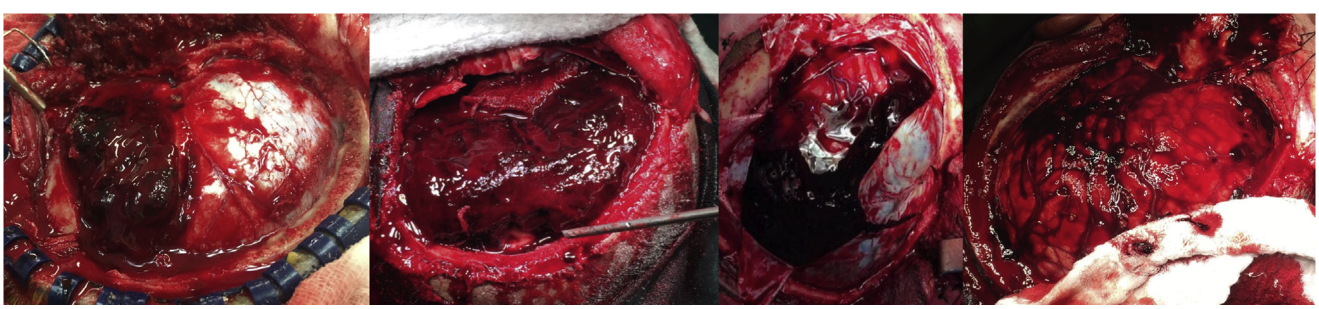

**Figure 11.** Drainage of epidural and subdural collections should be performed. Bleeding control with bipolar forceps and hemostatic agents will allow for a faster procedure, including closure.

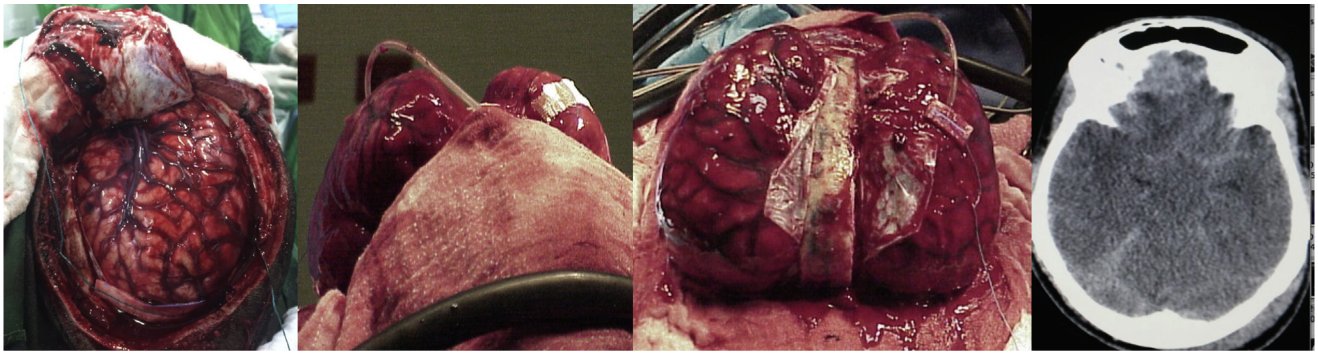

**Figure 12.** Patients with total occlusion of the basal cisterns (brain edema grade III) should undergo closure as soon as possible owing to the technical difficulties in skin flap closure.

craniectomy. Regarding the skin incisions, when undertaking frontotemporoparietal decompression, the standard trauma incision (a question mark shape) or a bicoronal incision (Soutar incision), posterior—auricular incision (C-shape), or modified hemispherectomy T-bar incision (Kempe incision) can be performed (Figure 1). The Kempe T-shaped incision has the advantage that it can preserve the superficial temporal and occipital arteries, reducing the risk of flap necrosis and improving wound healing.

It has been advised that during craniectomy, every effort should be made to make the bone window as large as possible. The decompression area should measure a minimum of 12 cm for the anteroposterior margins by 12 cm for the superoinferior margins when performing frontotemporoparietal craniectomy. This aspect has been evaluated in rural settings in high- and low-resource areas.[46,47] A large decompressive craniectomy has been recommended by international evidence-based guidelines.[48] The modified Kempe, C-shape, and bicoronal incisions allow for an increase in the size of the craniectomy bone flap owing to the greater exposure surface compared with the standard trauma flap incision (Figures 2 and 3). In the presence of a significant anterior cranial fossa injury or bifrontal contusions, a bifrontal craniotomy with sinus cranialization can be an option (Figure 4). The common complications of small decompressions have included venous bleeding, cortical infarct, fungus cerebri, and hygroma (Figure 5). Once the appropriate amount of bone has been removed, dural incisions can be performed using several methods, including the C-shape, star, and H-shape forms (Figure 6).

Preservation of the removed cranial segment, traditionally performed by implantation into the abdomen has resulted in high rates of infection; however, in austere environments, bone banks or bone freezers will usually not be regularly available (Figure 7). The bone should be thoroughly scrubbed and cleaned and debrided if it has been contaminated. The procedure should be performed with the patient under general anesthesia. The patient should then be placed in the supine position, with elevation of the ipsilateral shoulder with a roll. The head of the patient should be turned 0°—15° from the horizontal plane, with placement on a donut cushion or horseshoe base. If the procedure is bilateral, the head should be fixed in the neutral position (Figure 8).

The steps for a DCNt procedure include the following:

1. Shaving of the scalp and marking the midline and relevant surface anatomy.
2. Marking of the incision, beginning at the zygomatic arch, anterior to the tragus, and drawing of a line just above the transverse sinus to the external occipital protuberance. The line should next turn cranially to the vertex, ending at the

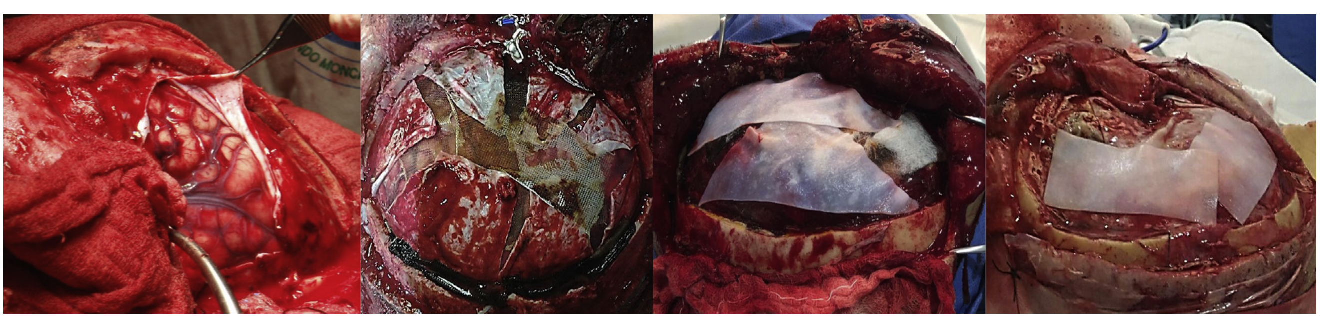

**Figure 13.** Watertight dural closure will not always be possible. Dural substitutes or hemostatic wraps can be useful to create a barrier between the cortical surface and underlying surface of the skin.

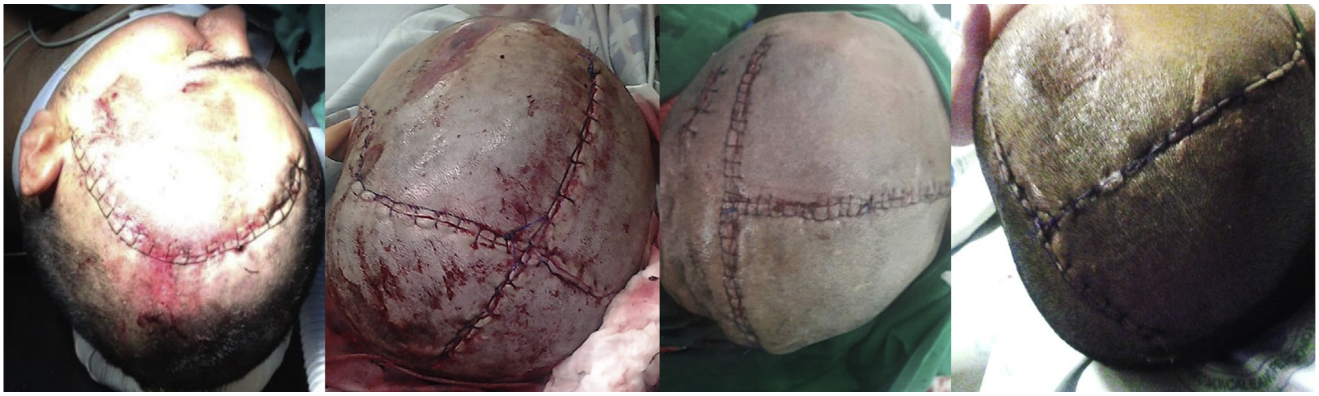

**Figure 14.** Skin closure should be performed as soon as possible. Sutures should be maintained in place for ≥10–12 days. In patients with grade III edema, the sutures should remain in place longer to avoid cerebrospinal fluid leakage.

hairline for a traditional trauma incision; if performing the modified Kempe incision, the line should continue anterior to the tragus in a vertical fashion right over the superior border of the ear until reaching the midline.

3. A second mark should then be drawn from the midline at the most anterior hair implantation line until the lambdoid suture posterior; these 2 marks should meet at the vertex.
4. Before beginning the incision, one should remember that the superficial temporal artery and facial nerve will be located just 1 cm anterior to the tragus.
5. The incision should be carefully performed across the line, avoiding damage to the superficial temporal artery and facial nerve and controlling any scalp bleeding.
6. Next, the skin flaps and the temporalis muscle should be reflected toward the front and secured by placing a sponge underneath to maintain the blood supply.
7. Drilling of the burr holes is next; depending on the available resources (craniotome or Hudson Brace), one can use a fewer or greater number of burr holes (Figure 9).
8. The burr holes used have most often included a frontal one over the frontal sinus, a posterior one before the lambdoid suture, and a temporal one over the zygomatic region (if the craniectomy is performed using a Gigli saw, more burr holes than just these 3 will be required; however, if a craniotome is available, just 1 burr hole might be required). Bone wax (if available) can be used to control bone venous bleeding (Figure 9).
9. Next, the dura mater should be detached from the skull, all burr hole sites should be connected at epidural level, and additional bone should be removed from the squamous part of the temporal bone and the lower wing of the sphenoid bone using a rongeur (Figure 10).
10. Any epidural collections should be evacuated by tracking the dura mater up to the skull using a durotomy in a stellate, H-, or C-semicircular shape, extending it to the middle cranial fossa to decompress it; bleeding can be controlled using bipolar cautery.
11. At this point, one should be able to visualize the frontal, parietal, and temporal lobes (Figure 11) and perform an inspection, including beneath the cranial edges.

**Figure 15.** Skin recovery after damage control in neurotrauma procedures allows for easy access for the reconstruction process. Integration of the hemostatic wraps with the remaining dural borders will usually occur, creating a barrier between the scalp and muscle and the brain.

12. All subdural clots should be removed, and the bleeding sources should be controlled.
13. Patients with grade III brain edema (total cistern occlusion) should undergo closure as soon as possible to avoid difficulties with the skin flap closure due to tension at the cortical surface (Figure 12).
14. If available, a dural substitute can be used to cover the defect; if not, hemostatic wraps can be used. Gelfoam (Pfizer, New York, New York, USA), Spongostan (Ethicon, Somerville, New Jersey, USA), or Surgicel (Ethicon) can be used to create a barrier between the cortical surface and the muscle or skin if the dura mater cannot be closed fully. In addition, duroplasty with pericranium or other allografts can be performed in accordance with surgeon preference (Figure 13).
15. Finally, one should reflect the scalp flap, control the subcutaneous tissue bleeding, and suture the galea and scalp (Figure 14).

After the procedure, it has been recommended that patients who have undergone DCNt in low-resource areas should be sedated for ≥72 hours, with evaluation of the basic oxygenation, blood pressure, and pupil size and performance of a follow-up CT scan (if available) after 24 hours. If after 72 hours, no midline shift or brain stem compression has been found on the CT scan or new pupil abnormalities have not developed, the patient should be woken up slowly. Cranioplasty can be performed as early as possible once the brain swelling has receded. Integration of the hemostatic wraps to the remaining dural portions will create a surface that allows for dissection to reposition the osseous flap or cranioplasty implant (Figure 15).

### Future of DCNt

In both civilian and military settings, neurosurgeons have successfully been taught to perform DCNt safely and in appropriate circumstances. These acquired neurosurgical skills and knowledge have subsequently been used safely and with life-saving effects in both civilian and military locations. Some discussions have ensued regarding the possibility of including this approach as a possible teaching skill for trauma surgeons, especially in remote locations.[49-51] A further adjunct to undertaking DCNt safely could be the availability of telecommunication between the treating trauma surgeon and the neurosurgeon, whether overseas or at the nearest trauma center with neurosurgical capabilities. With the transfer of CT images, telecommunication will allow the neurosurgeon to be involved in, and assist with, the decisions, in particular, for those patients who require urgent DCNt intervention before transfer. In addition to providing decision-making support, telecommunication can also help to assist the non-neurosurgeon in performing DCNt.[52-54] Dulou et al.[55] described a case in which an on-call neurosurgeon in France established a diagnosis of subdural hematoma in a civilian requiring treatment at an overseas military hospital and then prepared a schematic guide. This guide demonstrated the sites of incision and decompression, enabling the non-neurosurgeons to successfully and safely use a DCNt approach.[55]

The future implementation of neurotrauma registries in low- and middle-income countries will be helpful to our understanding of the effects of this type of intervention in civilian austere environments. Because almost 80% of the trauma procedures performed for severe TBI will be performed in low- and middle-income countries, the collaboration of international institutions will strengthen neurotrauma care systems, with the goal of increasing the availability and adequate care through timely surgical management in remote areas of the world.[56,57] A recent statement of the commitment of the World Federation of Neurosurgical Societies with the World Health Organization to improve the neurosurgical care of patients worldwide is allowing for the concept of global neurosurgery, especially for neurotrauma surgical procedures, the most commonly performed neurosurgical procedure worldwide.[58,59] We understand that most data regarding DCNt concepts have been reported by observational studies within these environments. Sound data from randomized control trials in these specific contexts are lacking, and an urgent necessity exists for increased research of these interventions in the environments in which they will be used most. A recent review of military databases from the Middle East has shown the benefits of early performance (<5.3 hours) of the procedure.[60] More data on the techniques, associated medical management, injury types, and surgical timing are greatly needed. In addition, our study highlights the need to empower and increase clinical research in these environments, because the generalizability and transferability of interventions tested in high-income settings are not always possible.

## CONCLUSION

Damage control in neurotrauma is a concept that needs to be fully understood in the appropriate context. Early cranial decompression as an alternative for the management of severe TBI in austere environments could be an option to treat patients under specific conditions and is especially suited to the conditions in low- and middle-income countries where neuromonitoring is not available. We believe that the use of ethical principles and protocol-guided inclusion criteria, in addition to surgeon expertise and consideration of the local context, will provide a method for the difficult decisions required in these environments. Trained neurosurgeons can safely perform these procedures; however, special conditions will require an integrative approach with the use of novel communication techniques and diagnostic methods. Non-neurosurgeons require specific training if they are to adequately and safely perform decompressive craniectomy. Good quality resuscitative and ongoing medical care are also essential in the DCNt approach. More data obtained using appropriate clinical research methods in these environments are urgently needed.

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