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# Decompressive Craniectomy and Hinged Craniotomy for Traumatic Brain Injury: Experience in Two Centers in a Middle-Income Country

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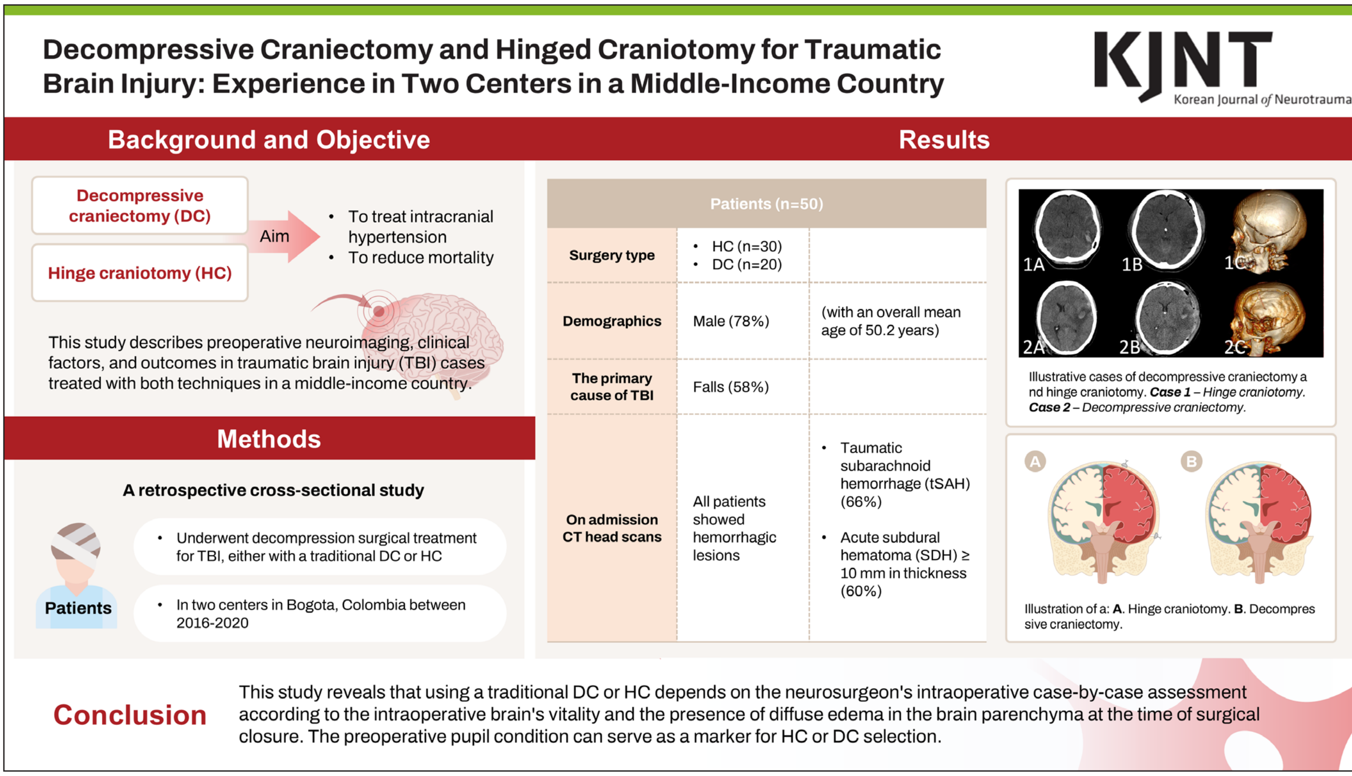
**Conflict of Interest**
The authors have no financial conflicts of interest.

## ABSTRACT

**Objective:** The goal of a decompressive craniectomy (DC) or a hinge craniotomy (HC), is to treat intracranial hypertension and reduce mortality. Traditionally, the decompression procedure has been performed with cranial bone removal. However, decompression and repositioning the cranial bone, named HC, has been presented as an alternative for certain cases. Our objective is to describe the neuroradiological and clinical preoperative factors and outcomes in traumatic brain injury (TBI) cases treated with both techniques in 2 centers in a Middle-Income country.
**Methods:** This is a retrospective cross-sectional study of adult patients who underwent decompression surgical treatment for TBI, either with a traditional DC or HC, in 2 centers in Bogotá, Colombia between 2016–2020.
**Results:** This study involved 30 cases that underwent HC and 20 that underwent DC. 78% were male with an overall mean age of 50.2 years. 66% cases had traumatic subarachnoid hemorrhage (tSAH) and 60% had evidence of acute subdural hematoma ≥10 mm in thickness. The overall mortality rate during hospitalization was 20%. Preoperative pupil impairment differences between the 2 groups were statistically significant ($p$=0.026).
**Conclusion:** This study reveals that using a traditional DC or HC depends on the neurosurgeon's intraoperative case-by-case assessment according to the intraoperative brain's vitality and the presence of diffuse edema in the brain parenchyma at the time of surgical closure. Each case requires an individualized evaluation before and during surgery. The preoperative pupil condition can serve as a marker for HC or DC selection.

**Keywords:** Decompressive craniectomy; Craniotomy; Intracranial hypertension; Developing countries; Brain injuries, traumatic

## GRAPHICAL ABSTRACT




**Informed Consent**
The requirement to obtain informed patient consent was waived due to the methodological nature of the article, which is a descriptive cross-sectional study.

**Ethics Approval**
This study received Institutional Ethics Board approval and Institutional Review Board of the Fundación Universitaria de Ciencias de la Salud.

## INTRODUCTION

Traumatic brain injury (TBI) remains one of the most prevalent causes of neurosurgical diseases.[6, 10] The risk of severe neurological sequelae or death due to TBI remains one of the main concerns in public health.[18] However, advances in modern neurosurgery have allowed mortality to decrease from 80% in the 1940s to up to 20% nowadays in the best-case scenarios.[13] According to the National Trauma Data Bank, surgical management with craniotomy is performed in 3.6% of all patients with TBI.[1] The TBI therapeutic approach includes multiple steps in care and the neurosurgical treatment becomes important for severe intracranial hypertension through decompression. Decompressive craniectomy (DC) is a procedure in which a large fragment of the cranial vault is removed to reduce intracranial pressure (ICP).[24] Frontotemporoparietal DC (not less than 12×15 cm or 15 cm in diameter) improves mortality and results in favorable outcomes in some cases.[7] Two different options have been documented for cranial decompression: 1) DC and 2) hinge craniotomy (HC). The HC involves an initial decompression with a posterior repositioning of the bone to allow a degree of decompression while retaining the bone flap in situ, in a ‘floating’ or ‘hinged’ fashion.[2,23]

The optimal surgical approach for cranial decompression, DC or HC, is still under discussion. Complications associated with bone removal in DC have been widely described, such as the expansion of contralateral lesions, infections, hydrocephalus, and trephination syndrome.[1,13] However, a partially insufficient ICP decrease has also been discussed with the use of an HC.[23,28] In this study, we aimed to describe the experience and clinical outcomes of patients treated with both techniques in two centers in a middle-income country.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## MATERIALS AND METHODS

This descriptive cross-sectional study included patients with TBI with an admission non-enhanced computed tomography (CT) scan of the head who underwent neurosurgical treatment with either DC or HC at Hospital de San José, Bogotá, Colombia, and Hospital Infantil Universitario de San José, Bogotá, Colombia, between January 2016 and June 2020. Patients aged ≥18 years who were admitted to the emergency department with TBI and who underwent surgical treatment for primary decompression were included in the study. Clinical and radiological data were collected from the electronic medical records. On admission, patients were classified based on the Glasgow Coma Scale (GCS) as follows: mild (GCS 14–15), moderate (GCS 9–13), and severe (GCS ≤8). Decompression neurosurgery was conducted on all patients when the GCS was ≤8.

The preoperative pupil condition was categorized into 2 groups: unilateral or bilateral mydriasis or without impairment. Follow-up was performed during the first year after the procedure when data were available, and information was extracted from outpatient follow-ups. This study was approved by the Institutional Ethics Board and Institutional Review Board of the Fundación Universitaria de Ciencias de la Salud, and the requirement to obtain informed patient consent was waived due to the methodological retrospective nature of the study. This study complies with the Declaration of Helsinki

### Statistical analysis

The absolute and relative frequencies of the categorical variables are described. Means with standard deviations, and interquartile ranges were calculated according to the distribution of the variables. The $\chi^2$ test, Mann-Whitney U test, and t-test were performed according to the distribution of variables. Statistical significance was set at $p<0.05$. significant. The statistical software package STATA v.15® (StataCorp LLC, College Station, TX, USA) was used for data analysis.

### Surgical procedure

An external ventricular drain (EVD) is used for ICP monitoring in all cases. If possible, EVD was placed contralaterally when decompression was performed unilaterally. For unilateral decompression, a reverse question mark or an L.G. Kempe incision was made. A detailed stepwise description of both incisions performed at our institution has been published previously.[24] After the scalp is incised, it is reflected anteriorly as a myocutaneous flap of the scalp and temporalis muscle. Four to five burr holes were routinely used. Frontotemporoparietal decompression was intended to achieve a 12×15 cm or 15 cm diameter craniotomy (**FIGURE 1**). Additional removal of the inferior aspect of the temporal bone was performed until it reached the floor of the middle fossa to achieve satisfactory basal decompression (**FIGURE 2**). Based on preoperative clinical and neuroradiological assessments as well as intraoperative findings, the decision to perform a DC or HC was based on the neurosurgeon's preference. This decision was influenced by the vitality of the brain and the presence of diffuse edema in the brain parenchyma at the time of surgical closure. If the brain appeared excessively contused, lacked pulsatility, or was tense, DC was performed.

If the bone flap is in good condition (e.g., without comminute fractures), it is preserved in a special freezer under −30°C for further cranioplasty. Otherwise, the bone was repositioned without fixation using Vicryl 1-0 (**FIGURE 1**). Given the need to release pressure, a dural patch was placed and fixed with Vicryl 4-0 without water-tight closure. The remaining closure procedure was routinely performed. The patients were then transferred to the intensive care unit (ICU) afterward for complementary medical treatment.

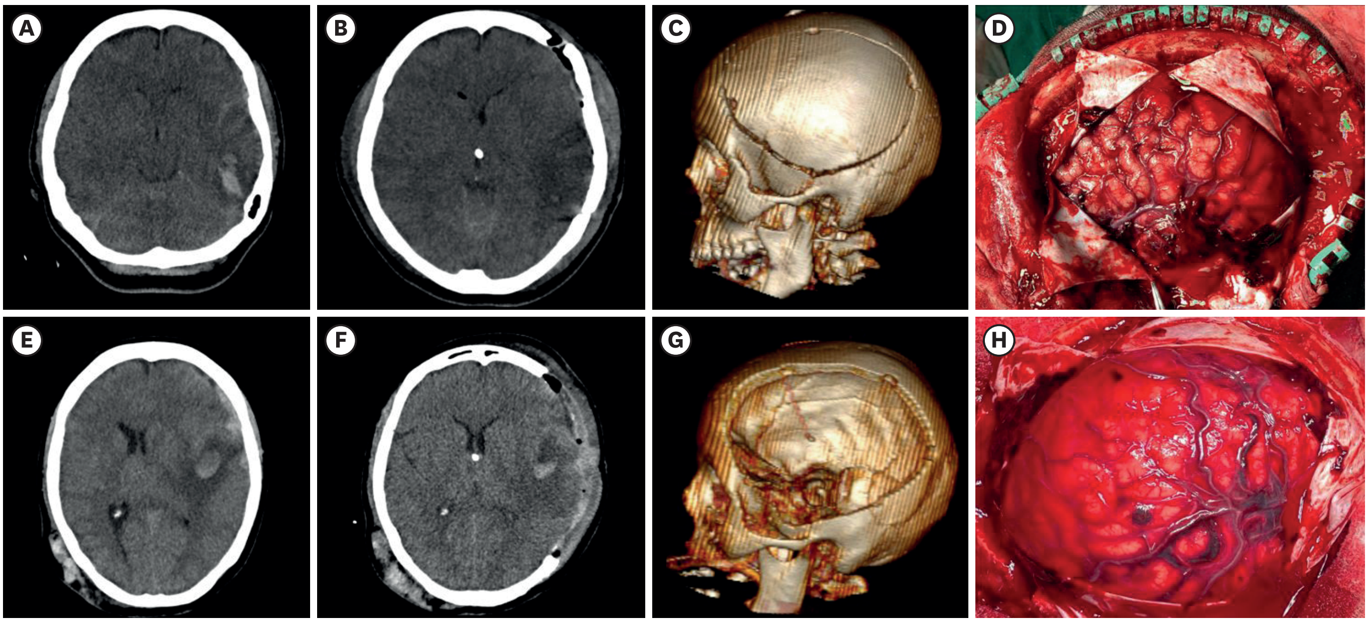


**FIGURE 1.** Illustrative cases of HC and DC.
Case 1. HC. (A) Preoperative CT scan demonstrates a left temporal contusion, traumatic subarachnoid hemorrhage, and diffuse brain edema. (B) Postoperative CT scan demonstrates partial resolution of the hemorrhage as well as a subtle recovery in the ventricular volume. The tip of the ventricular catheter is observed in the third ventricle. Reposition of the bone flap is observed as well. (C) A 3D reconstruction of the postoperative CT scan demonstrates a hinge craniotomy. (D) Intraoperative picture shows mild-to-moderate brain edema associated with a laminar subdural hematoma and hemorrhagic contusions.
Case 2. DC. (E) Preoperative CT scan demonstrates a left fronto-insular contusion associated with severe diffuse brain edema and >5 mm of midline shift to the right. (F) Postoperative CT scan demonstrates partial resolution of the hemorrhage as well as a subtle increase in the ventricular volume. The tip of the ventricular catheter is observed in the third ventricle. Substantial resolution of the midline shift is noted. (G) A 3D reconstruction of the postoperative CT scan demonstrates a large frontotemporoparietal defect after decompression. (H) Intraoperative image demonstrates severe brain edema associated with acute subdural hematoma and traumatic subarachnoid hemorrhage.
HC: hinge craniotomy, DC: decompressive craniectomy, CT: computed tomography, 3D: 3-dimensional.

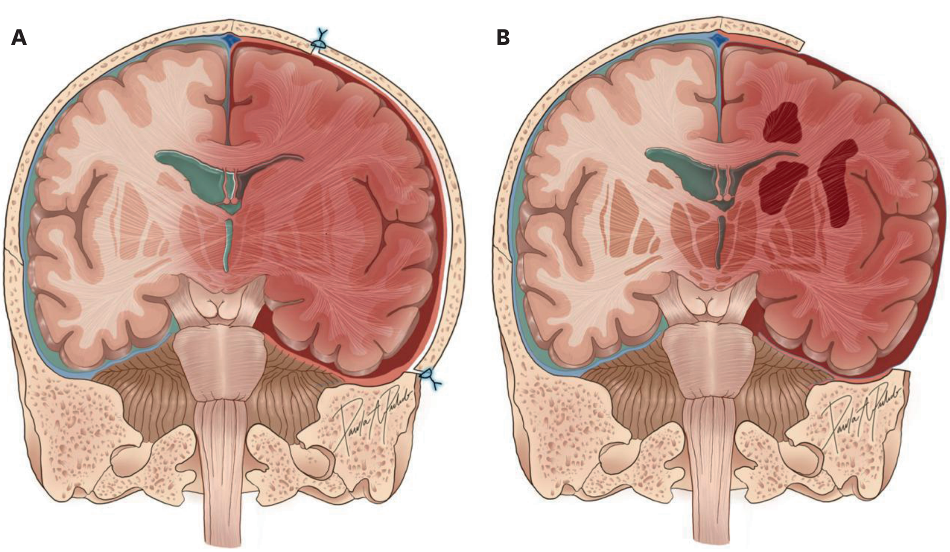


**FIGURE 2.** Illustration of HC and DC.
(A) A HC is demonstrated. A mild-to-moderate brain edema is illustrated. Partial transcranial herniation of the brain is shown. A "floating" bone flap is repositioned and partially sutured to the cranium. (B) A DC is used for severe brain edema is demonstrated. The transcranial herniation of the brain exceeds the cranial vault significantly. Note that in both scenarios a satisfactory basal bone resection is mandatory for adequate decompression.
HC: hinge craniotomy, DC: decompressive craniectomy.


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# RESULTS

### Demographic outcomes

Thirty patients underwent HC, and the remaining 20 underwent traditional DC. Thirty-nine (78.0%) patients were male, and their mean age was 50.2±18.6 years. The mean age in the HC group was 56.8±18.12 years, while that in the DC group was 40.35±14.92 years. Forty-five (90.0%) had closed head injuries. The most frequent TBI mechanism was falls (58%). All patients included in the study had evidence of hemorrhagic lesions on admission CT: 33 (66.0%) cases presented with traumatic subarachnoid hemorrhage (tSAH), 30 cases (60.0%) had evidence of acute subdural hematomas (SDHs) ≥10 mm in thickness, 13 cases (26.0%) had hemorrhagic contusions ≥25 cc of volume, 8 cases (16.0%) had epidural hematomas (EDHs) ≥30 cc of volume, and 7 cases (14.0%) had EDHs <30 cc of volume. Thirty-seven cases (74.0%) had midline shifts on the admission CT scan, of which 28 (56.0%) had a deviation ≥5 mm.

The severity of TBI was categorized as mild in 1 case (2.0%), moderate in 16 (32.0%), and severe in 33 (66.0%) according to the admission GCS score. However, a further decline in the GCS score guided further treatment in those initially considered mild and moderate TBI cases. Notably, pupil changes were observed in 10 (50.0%) patients in the DC group and 6 (20.0%) in the HC group ($p<0.05$) (**TABLE 1**). The mean GCS score at hospital admission was 8.5±3.9 and the mean GCS score was 13.8±1.6 for the alive 40 patients at discharge. All patients were admitted to the ICU with a Richmond Agitation-Sedation Scale of −5. The mean stay in the ICU was 20.7±36.7 days and the mean hospital stay was 28.6±35.7 days.

### Clinical outcomes

None of the patients died during surgery. Of the total number of patients, 10 (20.0%) died during their hospital stay. Five (16.7%) patients in the HC group and 5 (25.0%) in the DC group ($p>0.05$). In total, 26 (52.0%) patients were discharged: 17 (56.7%) from the HC group and 9 (45.0%) from the DC group ($p>0.05$). Two (6.7%) patients from the HC group and 3 (15.0%) from the DC group were discharged to a chronic care unit ($p>0.05$). Four (13.3%) patients from the HC group and 1 (5.0%) from the DC group were discharged for home hospitalization care to complete their rehabilitation process ($p>0.05$). The other 4 patients (2 with HC and 2 with DC) were discharged, but destination data were not available in the clinical records.

Of all cases, 14 (28.0%) presented with nonsurgical infections. In the HC group, there were 4 (13.3%) cases of pneumonia and 2 (6.7%) cases of urinary infections. In the DC group, there were 5 (25.0%) cases of pneumonia, 2 (10.0%) of tracheitis, and 1 (5.0%) of urinary infection. In the HC group, there was 1 (3.3%) of deep vein thrombosis (**TABLE 1**). There were no postoperative intracranial hemorrhages, cerebrospinal fluid leaks, or neurological declines in either group. In the DC group, cranioplasty was performed in 4 patients during follow-up. In the HC group, 1 patient required additional intervention after discharge, which involved the placement of a ventriculoperitoneal shunt. In the DC group, 4 patients underwent cranioplasty during the hospital stay, while an additional patient required reoperation for the drainage of SDH and EDH.

# DISCUSSION

The decision to perform traditional DC versus HC is based on the decision of the neurosurgeon, according to the state of vitality of the brain and diffuse edema of the brain parenchyma at the


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**TABLE 1.** Clinical and demographic data

| Characteristics | Total (n=50) | HC (n=30) | DC (n=20) | *p*-value |
|---|---|---|---|---|
| Age (year) | | 56.8±18.12 | 40.35±14.92 | 0.268 |
| Sex | | | | 0.780 |
| Female | 11 (22.0) | 7 (23.3) | 4 (20.0) | |
| Male | 39 (78.0) | 23 (76.7) | 16 (80.0) | |
| Type of trauma | | | | 0.054 |
| Close-head injury | 45 (90.0) | 29 (96.7) | 16 (80.0) | |
| Penetrating injury | 5 (10.0) | 1 (3.3) | 4 (20.0) | |
| Preoperative pupil impairments* | 16 (32.0) | 6 (20.0) | 10 (50.0) | 0.026 |
| Hemorrhagic lesion on admission CT | | | | |
| tSAH | 33 (66.0) | 17 (56.7) | 16 (80.0) | 0.068 |
| Acute SDH (≥10 mm in thickness) | 30 (60.0) | 19 (63.3) | 11 (55.0) | 0.359 |
| EDH (≥30 cc) | 8 (16.0) | 2 (6.7) | 6 (30.0) | 0.075 |
| Hemorrhagic contusion (≥25 cc) | 13 (26.0) | 8 (26.7) | 5 (25.0) | 0.678 |
| Midline shift | | | | 0.895 |
| ≥5 mm | 28 (56.0) | 16 (53.3) | 12 (60.0) | |
| <5 mm | 9 (18.0) | 6 (20.0) | 3 (15.0) | |
| Basal cistern effacement | 30 (60.0) | 16 (53.3) | 14 (70.0) | 0.239 |
| TBI severity at admission | | | | 0.623 |
| Mild | 1 (2.0) | 1 (3.3) | 0 (0.0) | |
| Moderate | 16 (32.0) | 10 (33.3) | 6 (30.0) | |
| Severe | 33 (66.0) | 19 (63.3) | 14 (70.0) | |
| Hospital stay mortality | 10 (20.0) | 5 (16.7) | 5 (25.0) | 0.501 |
| Discharged | 26 (52.0) | 17 (56.7) | 9 (45.0) | |
| Discharged to a chronic care unit | 5 (10.0) | 2 (6.7) | 3 (15.0) | |
| Discharged for home hospitalization care to complete their rehabilitation process | 5 (10.0) | 4 (13.3) | 1 (5.0) | |
| Missing data after discharge | 4 (8.0) | 2 (6.7) | 2 (10.0) | |
| Complications | | | | 0.09 |
| Non-neurosurgical postoperative infections | 14 (28.0) | 6 (20.0) | 8 (40.0) | |
| Pneumonia | 9 (18.0) | 4 (13.3) | 5 (25.0) | |
| Tracheitis | 2 (4.0) | - | 2 (10.0) | |
| Urinary infections | 3 (6.0) | 2 (6.7) | 1 (5.0) | |
| Need for reoperation during the hospital stay | 1 (2.0) | 0 (0.0) | 1 (5.0) | 0.06 |
| Need for further procedure after discharge† | 1 (2.0) | 1 (3.3) | 0 (0.0) | 0.063 |

Values are presented as mean ± standard deviation or number of patients (%).
HC: hinge craniotomy, DC: decompressive craniectomy, CT: computed tomography, tSAH: traumatic subarachnoid hemorrhage, SDH: subdural hematoma, EDH: epidural hematoma, TBI: traumatic brain injury.
*Preoperative pupil impairments were defined as anisocoria or non-reactive pupils.
†Correspondent to a ventriculoperitoneal shunt.

time of closure during surgery. If the brain appears too contused, not pulsatile, or tense, leaving the bone off as a DC is recommended because it can provide maximal decompression.[3] It is necessary to emphasize that each case is unique and requires an individualized assessment. The data presented in this study complement the published literature on both techniques and can help neurosurgeons make informed and rational decisions on a case-by-case basis regarding which technique to use (**TABLE 2**). Both decompressive techniques in severe TBI have been reported as effective treatments for controlling elevated ICP.[15,18,19,23,27] Post-operative results from Some studies have shown a decrease in ICP and a reduction in midline shift.[20,28] Furthermore, studies comparing HC with DC indicate that HC is at least as effective as DC in this regard.[23] HC and DC are also effective in reducing mortality and length of ICU stay in patients with refractory early or late ICP elevation.[8,16,18,21,23]

HC cannot be considered a substitute for all DCs in TBI patients, but may be considered an alternative for DC in some selected cases. DC has been primarily utilized as a second- or third-line therapy in trials such as Decompressive Craniectomy in Patients with Severe Traumatic Brain Injury (DECRA)[8] and Randomized Evaluation of Surgery with Craniectomy for Uncontrollable


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**TABLE 2.** Advantages of HC and DC

| HC | DC |
|---|---|
| - Allows for brain decompression while maintaining the integrity of the calvarium.<br>- Preserves the cosmetic appearance of the skull, reducing the potential cosmetic deformities.<br>- Potential reduction in infection risk since the bone flap is repositioned and secured back in place.<br>- The repositioned bone flap helps maintain a ICP equilibrium, potentially reducing the risk of the trephined syndrome.<br>- Since the bone flap is repositioned and secured back in place, there may be fewer expenses associated with subsequent cranial repair surgeries. This can result in reduced surgical costs, hospitalization costs, and post-operative care expenditures. | - Allows the brain to swell without being constrained by the skull in a wide manner, providing flexibility in managing brain swelling and allowing for subsequent cranioplasty if necessary.<br>- Secondary DC performed for late refractory ICP elevation is recommended to improve mortality and favorable outcomes.[14]<br>- Secondary DC, performed as a treatment for either early or late refractory ICP elevation, is suggested to reduce ICP and duration of intensive care.[14] |

HC: hinge craniotomy, DC: decompressive craniectomy, ICP: intracranial pressure.

Elevation of Intracranial Pressure (RESCUEicp)[16] in patients with medically uncontrolled elevated ICP. In such situations, it is improbable that the HC would be utilized instead of the DC.[8,16] It is also clear that in many circumstances, after the bone is removed, transcranial herniation of the brain is so severe that repositioning of the bone is almost impossible. Hence, patients who require full craniectomy would not tolerate HC. This must be considered, as it may also limit the analysis of the use of both techniques. Currently, no preoperative radiological prognostic markers are available to determine the extent of transcranial herniation of the brain in centimeters after bone removal. An effective intraoperative method to ascertain this would involve observing whether the transcranial herniation extends beyond the calvarium. In such cases, DC are likely a more suitable option for effectively managing intracranial hypertension.

In our study, while the mortality rate was higher in the DC group (25.0%) than in the HC group (16.7%), the difference was not statistically significant ($p>0.05$). It is crucial to consider that these outcomes can be influenced by preoperative radiological factors. For instance, a midline shift of ≥5 mm at the admission non-enhanced CT scan of the head was observed in 60% of the DC group and 53.3% of the HC group. Additionally, basal cistern effacement was present in 70.0% of the patients in the DC group compared with 53.3% in the HC group. None of these preoperative radiological factors were significantly different between the 2 groups ($p>0.05$). The decision to proceed with decompression neurosurgery, even in cases with a midline shift <5 mm, is influenced by other clinical and neuroradiological factors.

This study provides evidence that HC can serve as an effective intervention for TBI, particularly in cases without severe intraoperative diffuse cerebral edema. Further studies on this topic will provide valuable information for preoperative and intraoperative decision making.

Our study showed that acute SDH with ≥10 mm in thickness was the second most frequent hemorrhagic lesion observed on admission on non-enhanced CT scan of the head. Acute SDH was more frequent compared than in the DC group, with rates of 63.3% and 55.0%, respectively ($p\geq0.05$). However, this finding was not associated with the diffuse edema of the brain parenchyma at the time of surgical closure. This suggests that one would be prepared for a DC or an HC when acute SDH with ≥10 mm in thickness is present.

Pupil impairment, defined as unilateral or bilateral mydriasis in our study, showed statistically significant differences between the 2 groups ($p=0.026$). In the HC group, there were 6 cases (20.0%) with pupil impairments, while in the DC group, there were 10 cases (50.0%). However, pupil impairment was not a decisive factor when performing any of the procedures in our study. Pupil impairment can serve as a clinical parameter for detecting brain swelling as well as elevated ICP and has been identified as a clinically independent predictive factor for both mortality and poor neurological outcomes in TBI cases.[4,11,12,22] This suggests that one possible clinical marker to establish the indication between HC and DC is the condition of the pupils. Furthermore, when there are pupil impairments, this can favor the decision for a DC instead of an HC.[5,9,26] Literature regarding this aspect is scarce, and it is essential to scrutinize these data in future studies.

For patients with severe TBI, we recommend performing the maximum possible decompression, regardless of whether the bone is repositioned. In particular, a large frontotemporoparietal decompression of at least 12×15 cm or 15 cm in diameter is associated with reduced mortality and improved neurologic outcomes compared to a small frontotemporoparietal decompression.[7,17,25] Similarly, HC should be performed with the same dimensions. Additionally, whenever possible, it is advisable to place the bone in a hinged position to avoid the risks associated with further cranioplasty. Finally, the decision on whether to reposition the bone should be made by the neurosurgeon intraoperatively after analyzing the case on an individual basis.[14]

Our study focused only on primary decompression, which may guide further recommendations. Based on our findings, we recommend 1) preparing for a DC or an HC when acute SDH with ≥10 mm in thickness is present, 2) maximizing decompression of at least 12×15 cm or 15 cm in diameter, whether or not bone reposition is performed, and 3) considering an HC in a case-by-case manner according to intraoperative brain's vitality and the presence of diffuse edema in the brain parenchyma at the time of surgical closure.

### Limitations

The retrospective nature of this study and the lack of randomization between groups are major limitations. Additionally, this study lacked a long-term follow-up, and further studies are needed to assess the long-term complications and neurological outcomes in terms of disorders of consciousness and functionality/quality of life. The size of the craniotomies and transcranial brain herniation through the craniotomy during surgery were not evaluated and remain important topics for discussion and further investigation. This study lacked data on the Glasgow Outcome Scale Extended, which made it difficult to compare groups in terms of middle- and long-term outcomes. This study only included patients from 2 institutions in Bogotá, and there is a lack of information about rural areas in Colombia that affect clinical decisions among different regions.

### Future directions

HC likely offers an intermediate option between aggressive medical therapy and traditional DC.[23] Future studies and revisions should compare the efficacy of HC and DC, with clear criteria for the transition from HC to DC in selected cases. Most importantly, this study aimed to compare the long-term functional outcomes, surgical morbidity, and mortality.

## CONCLUSION

This study shows that the decision to perform traditional DC versus HC is based on the intraoperative decision of the neurosurgeon, according to the state of vitality of the brain and diffuse edema of the parenchyma. It is necessary to emphasize that each case is unique


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and requires an individualized intraoperative evaluation. Both DC and HC are effective in controlling elevated ICP, reducing midline shifts, and decreasing mortality and length of ICU stay in patients with TBI. One possible clinical marker for distinguishing between HC and DC is the condition of the pupils. Pupil impairments should favor the decision for a DC. Further research is needed to compare the efficacy of HC and DC in terms of overall survival and long-term neurological outcomes.

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