A Narrative Review of the Bifrontal Decompressive Craniotomy in Clinical Practice

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Abstract

The bifrontal approach, pioneered by Kjellberg in 1971, remains one of the few anterior approaches to the skull, yet no unified review of its historical and modern use currently exists. A literature search was conducted using PubMed, focusing on adult studies involving bifrontal decompressive craniotomy (DC). Bifrontal DC is indicated for severe traumatic brain injury with frontal lesions, elevated intracranial pressure refractory to medical x management, and certain cases of cerebrovascular accidents. Randomized trials, including DECRA and RESCUEicp, have demonstrated the procedure's efficacy in reducing mortality and intracranial pressure, though long-term neurological outcomes remain mixed. Military neurosurgeons have reported success with early bifrontal craniectomy in combat trauma, and civilian studies highlight its utility in managing traumatic bifrontal contusions. Surgeon preference and individual skill were frequently cited as deciding factors in the approach selected. Despite its versatility, poor rates of upper recovery have been reported, along with high rates of cerebrospinal fluid (CSF) leaks and wound complications. Despite its drawbacks, the bifrontal approach remains a viable option in the neurosurgeon's toolbox, allowing wide exposure and straightforward surgical planning, thus minimizing retraction injury. Future research and clarification could be directed towards the management of the superior sagittal sinus laceration and optimized placement of the posterior burr holes.

Introduction

Dr. Raymond Kjellberg published his bifrontal approach to DC in 1971 (1). While decompressive cranial openings have been traced back to ancient human history (2, 3), his bi-hemispheric decompression technique was argued to be a more physiological approach and improve upon the unilateral decompression due to its reduced retraction injury and ability to simultaneously decompress both hemispheres. The bifrontal craniotomy positions the patient in a neutral supine position, with minimal head rotation, which increases the visibility of midline structures and can be ideal for frontal midline masses. Kjellberg's initial investigation had high mortality (82%), and since then, there have only been a few studies on the use and implementation of the Kjellberg procedure (1).

Methods

To evaluate the use of bifrontal craniotomy in clinical practice, PubMed was searched using the terms ("Bifrontal craniectom*" OR "Bifrontal Craniotom*") on Dec. 15, 2024, yielding 364 results. Search results were screened to exclude case reports, abstracts, and gray literature. Adult investigations were included in cases where patients received bifrontal DC or craniotomy, including retrospective, prospective, clinical trials, and case-controlled analyses. Reviews were included in the discussion if they presented novel shifts in thinking on the application of the bifrontal approach. Snowballing was utilized to identify seminal works within the field of neurosurgery that were not otherwise captured by the primary literature search.

Discussion

Clinical Indications

Current clinical guidelines endorse a limited therapeutic application of the bifrontal approach. The Brain Trauma Foundation (BTF) suggests DC for severe traumatic brain injury (TBI) cases (Glasgow Coma Scale [GCS] <9) with acute subdural hematomas (aSDH) and/or diffuse hematoma burden (4). Bifrontal DC is reserved for bilateral frontal lesions. Primary prophylactic DC is considered when elevated ICP is expected postoperatively. Secondary therapeutic DC use can be for patients with cerebrovascular accident

(CVA) or who have refractory post-traumatic cerebral edema after initial medical management has failed. The bifrontal DC is also indicated for cases of epidural hematoma (EDH) and penetrating head injuries affecting the frontal lobes.

The understanding of TBI severity is rapidly changing, including the recent new CBI-M criteria, consisting of 4 pillars: clinical, biomarkers, imaging, and modifiers (5). Emerging evidence suggests patient-specific factors also influence DC outcomes. Apolipoprotein ε4 genotype has been associated with increased risk of poor neurological recovery following TBI, though specific data for its implications on DC remain limited (6). Additionally, emerging research on inflammatory biomarkers such as S100 and GFAP levels may predict which patients are most likely to benefit from early surgical intervention versus medical management (7). Age-related differences in brain elasticity and cerebrospinal fluid dynamics also influence the effectiveness of decompressive procedures, with younger patients typically demonstrating better tolerance for the procedure (8).

A 2008 review identified 3 chief areas of clinical use for DC: TBI, malignant middle cerebral artery (MCA) infarction, and traumatic subarachnoid hemorrhage (SAH) (9). The investigation found DC anecdotally valuable for treating increased intracranial pressure unresponsive to conventional treatment modalities. Notably, the investigators favored an individualized approach depending on the surgeon's expertise, given the lack of clear evidence at the time supporting the use of DC in TBI pathologies.

Emergency surgical evacuation is recommended for patients with a GCS of ≤8 and abnormal imaging findings of a SDH greater than 10 mm or midline shift greater than 5 mm on non-contrast Computed Tomography (CT), who also exhibit 1 of 3 other indicators: 1) Neuroworsening with a decrease of 2 points in GCS after admission; 2) Asymmetric or dilated pupils; and 3) Intracranial pressure (ICP) exceeding 20 mmHg (10–13). Military neurosurgeons, drawing from high-volume combat trauma experience, have demonstrated a lower threshold for early DC in ASDH cases (14–16).

Clinical Trials

Since 2000, there have been 3 randomized clinical trials (17–19) on the use and efficacy of decompressive craniectomies (17–19). In all 3 cases, DC was used as a treatment profile for severe TBI (sTBI). These include the DECRA Trial (2011) (17), the RESCUEicp Trial (2016) (18), and the RESCUE-ASDH Trial (2023) (19). Both the DECRA and RESCUEicp trials named the bifrontal craniotomy as one of their therapeutic approaches.

In the DECRA trial (n=155) (17), the comparison between decompressive craniectomy and standard care revealed that patients undergoing craniectomy experienced less time in the intensive care unit (median 11 days DC group vs. 15 days standard care, p-value< 0.001). Furthermore, the DC patients had lower average intracranial pressures (14.4 vs. 19.1, p-value < 0.001) and spent less with intracranial pressures above the 20-mmHg treatment threshold (average 9.2 hrs DC group, vs. 30 hrs standard care, p-value < 0.001). Unfortunately, patients with DC exhibited worse scores on the Glasgow Outcome Scale Extended (GOSE) and had a higher risk of unfavorable outcomes. Mortality was similar in both groups at 6 months (patients with craniectomy (19%) and patients with standard-care group (18%)). The DECRA trial cited inconsistent findings with nonrandomized trials, such as those from 1997 (20), 2001 (21), and the continued use of bifrontal DC for post-traumatic refractory intracranial hypertension. Notably, while these earlier investigations reported increased levels of upper recovery, they did not have a comparison group and had relatively low numbers of subjects (n=35 and n=20).

In 2016, the RESCUEicp trial (n=408) (18) showed significant differences in the GOSE distribution between the surgical and medical intervention groups. At 6 and 12 months, the surgical group exhibited that the decompressive craniectomy group had lower mortality rates, lower severe disability, and upper severe disability when compared to receiving medical care. However, surgical intervention resulted in a higher rate of vegetative states, and the rates of moderate disability and good recovery were similar between the two groups. Surgical treatment for ICP management was randomized between unilateral hemicraniectomy and bifrontal craniectomy. The investigation was pivotal in validating surgical intervention as an option for trauma cases due to the applicability of DC as first-line therapy for TBI and generalizability due to the sample size not demonstrated in previous analyses. In this trial, mortality was reduced by 45% over the medical treatment-only group.

A Cochrane Review of DC for the treatment of refractory high ICP in TBI published in 2019 examined 3 investigations (22) (n=590) to evaluate the utility of DC combined with standard care compared to standard care alone in treating TBI. These were a 2001 report (23) (n=27), the previously discussed DECRA 2011, and the RESCUEicp trial 2016. When meta-analysis techniques were applied, the researchers concluded that DC can reduce mortality in TBI cases. However, the results were inconclusive about the long-term neurological outcomes associated with the use of craniectomies. Furthermore, due to TBI heterogeneity, the investigators were unable to identify clear causes and effects from adverse events along the TBI care trajectories.

Bifrontal Craniectomy in Current Practice: Military Perspectives

Much of the data compiled on bifrontal craniotomy comes from military neurosurgeons who have utilized the bifrontal technique more often than their civilian counterparts (14–16).

As reported in a 2010 analysis (14), of the 28 DCs performed between 2007 and 2009, 7 were bifrontal DCs, as recorded in neurosurgical logs from Afghanistan. Of the cases highlighted, one involved a 14-year-old civilian who was struck by shrapnel and had an associated penetrating head wound. The team reported that the surgical indication was severe bilateral frontal lobe swelling (as seen on CT). They discussed the necessity of making the craniotomy as wide as possible to prevent acute laceration to the herniated portions of the brain on the cut bone edges. After surgery, the patient was neurologically intact but emotionally labile at the 3-month follow-up. The investigators also discussed the advantage of an alternative approach that leaves a strip of bone over the dural sinus to preserve venous flow from the perfused skull. In this case, the surgeons additionally performed a temporal lobectomy to allow for additional brain expansion to prevent secondary brain injury. The clinicians described that bifrontal craniectomy was preferred in various cases with bilateral swelling of either the frontal lobes or the anterior portions of the temporal lobes. Critically, they discussed the value of CT angiograms in diagnosis when MRI is not available, citing upwards of 30% vascular injury in cases of penetrating head injury (24). Notably, the researchers stress that hemodynamic stability was the priority regardless of the early or late decision for DC.

In a 2010 investigation (15) of the use of DC for patients transferred to Walter Reed Army Medical Center and National Naval Medical Center in Bethesda, Maryland, records of combined Armed Forces cases from 2003 to 2008 were assessed. In this review of cases, transferred patients were referred for bifrontal DCs in the case of increased ICP during transportation. The team also mentions the challenges associated with an inferior size of cranial opening, in which case the craniotomy should be as wide as possible. Insufficient bone removal resulted in the need for follow-up osteotomies and the initiation of moderate hypothermia to control refractory bouts of intracranial hypertension.

Bifrontal Craniectomy in Current Practice: Civilian Perspectives

More recently, a 2023 report discusses the utility of the bifrontal DC in cases of traumatic bifrontal contusions (TBC) with significant edema (25). In their investigation (n=53), of the 26 patients with TBCs who qualified for early surgical decisions based on current protocols, 24 had bifrontal DCs. Of the 13 who qualified for observation followed by late surgery, 12 had bifrontal DC. The researchers had mixed results due to the unpredictable clinical course of these patients and advocated for a tailored individualized approach to the use of the bifrontal DC. As opposed to the operations used in predominately sTBI described by military neurosurgeons, this team describes the primary subject of their analysis as a victim of low-velocity impact in motor vehicle accidents (MVA) with clinically mild (GCS 15-13) and moderate (GCS 12-9) TBI. For the 13 patients who qualified for late surgery, the most consistent predictor was clinical deterioration (GCS drop of 1–2) and radiographic progression an average of 1.53 days after the initial trauma. The investigators note that the temporality associated with these findings was not statistically significant.

Overall, these findings agreed with a 2011 investigation (26) that earlier surgical decision was associated with better outcomes for the patients who underwent DC for severe post-traumatic cerebral contusions, a phenomenon they dubbed "blossoming of contusions," which was associated with least in part with rapidly deteriorating cognitive status associated with contusions surrounded by rapidly expanding edema. This report also asserts that a low threshold should be set for surgical intervention for patients with

TBC on repeat CT once the overall burden of contusion is greater than 30 ml. For these patients, the average volume of bifrontal contusion expanded from 24 to 43 ml 2 days after surgery. This analysis lacked specific outcome measures other than intrahospital mortality.

As of 2023, the Brain Trauma Foundation (BTF) found only Level II A (moderate-level) evidence (12) for the use of bifrontal DC in severe TBI with diffuse injury without mass lesions, citing the lack of improved outcomes at 6 months as measured by GOSE. The BTF finds DCs valuable only in cases in which ICP elevation values were >20 mmHg for more than 15 minutes within a 1-hour period that are refractory to first-tier therapies. As described in the DECRA and RESCUEicp trials (17, 18), BTF states that the bifrontal DC was found to reduce ICP and minimize the number of days patients spend in the ICU (12).

As of the update to the 4th edition of the BTF guidelines (12), the researchers were aware of the ongoing RESCUE-ASDH trial but not its findings. It is the opinion of this review that the findings of the RESCUE-ASDH trial do not conflict with the 4th edition of the BTF guidelines for management of severe TBI (12). Furthermore, the RESCUE-ASDH trial does not elevate the use of DC from Level IIA evidence.

The Bifrontal Approach in Neuro-oncology

A unique modification of the bifrontal approach can be found in neuro-oncology, which has long been held to be a suitable option for tumor excision dating back to 1958 (27) and later modified in 1971 (28) and then refined as the transbasal approach in 1995 (29). These approaches include surgical resection of frontal mass lesions, most commonly olfactory groove meningiomas (30–38). In these investigations the drawbacks of the bifrontal approach include high rates of cerebrospinal fluid (CSF) leaks, wound infections, and superior sagittal sinus perforation, themes common to the decompressive applications. While the researchers suggest that the bifrontal approach is symmetrical and applicable for sellar masses, the anterior osteotomy with the transbasal approach may be inferior to fully prevent retraction injury (31). In these analyses, bifrontal approaches have a high rate of total excision and low recurrence, which is attributed to the added benefits of a wide exposure (31–33).

Future Directions

The technique continues to be refined, as evidenced by the one-piece transbasal approach described in 2014 (39) and its continued use in neuro-oncology. It has also been proposed that the bifrontal approach could work in educational applications in neurosurgery (40), though the investigations on this application are limited in scope.

Emerging evidence supports DC's feasibility and clinical utility in resource-limited settings. A prospective study from Brazil examining 125 patients undergoing DC showed that 51% of survivors achieved favorable outcomes at 6 months, with lower initial GCS scores and older age being the primary predictors of unfavorable outcomes rather than resource limitations (41). Similarly, a 36-month prospective study from Niger examining 74 DC cases found that despite resource constraints, including >24 hour delays between initial TBI and imaging, the impact of limited resources on patient care was moderate, with 66% survival rates and the conclusion that DC remains a viable intervention in low-resource settings (42). It should be noted the authors primarily use hemicraniectomy with bifrontal approaches accounting for only 4% of cases. A recent global survey of 208 neurosurgeons from 60 countries, including 40 low- and middle-income countries (LMIC), revealed high usage of DC techniques in resource-limited settings, especially in the case of ASDH (43) and in 25% of all patients. From this survey, respondents from LMIC indicated that simplified protocols and alternative surgical techniques, including hinge-craniectomy, may be more advantageous in resource limited settings. The wide exposure offered by bifrontal DC provides distinct advantages in settings where advanced monitoring capabilities are unavailable, allowing for direct visualization of brain swelling and mass effect without relying solely on ICP-monitoring devices. These practical considerations, combined with demonstrated favorable outcomes in resource-constrained environments and the documented adaptation of decompressive techniques to local capabilities, support the continued use of bifrontal DC techniques, even in in resource-limited settings.

We have identified 2 areas that could benefit from additional commentary:

First, an area lacking much commentary is the management of superior sagittal sinus perforation (44). A recent report describes the technique of compartmentalization as a possible alternative to cranialization or obliteration. Notably, the use of the well-vascularized periosteal flap in 6 cases of frontal trauma was not associated with any wound infections or CSF leaks. However, this case series suggests that further investigations are needed to identify the most ideal management for superior sinus laceration. It is vital to discuss optimal intraoperative management techniques for superior sagittal sinus complications, which researchers spanning 50+ years have cited as a chief concern with this approach.

Second, there is no consensus on the optimal placement of the posterior temporal burr holes. Kjellberg (1) himself favored an approach that today resembles the transbasal approach, while military surgeons in acute trauma settings have suggested, in some cases, even 2 temporo-sphenoidal burr holes (15). While novel techniques like 3D brain mapping allow for exceptional visualization of vascular structures when surgical planning is possible (45, 46), neurotrauma frequently requires quick imaging modalities to get the patient to the operating room (24). The development of standardized approaches in DC could lead to improved outcomes and minimize complications when a wide surgical approach is considered.

Several research priorities have been identified from our review of the relevant literature. First, standardized protocols for superior sagittal sinus management require prospective validation, as current techniques remain largely anecdotal and compiled from single-surgeon series. Second, comparative effectiveness research is needed to determine optimal patient selection criteria, particularly regarding timing of intervention and identification of patients most likely to benefit from bifrontal versus unilateral approaches. Third, long-term quality of life analyses beyond 12 months are essential, as recent evidence from the Hutchinson research group suggests that the full impact of TBI outcomes is usually not known for at least 2 years following DC (47). Finally, development of intraoperative guidance systems for optimal bone removal boundaries could standardize the procedure and reduce technique-dependent variability in outcomes.

Conclusion

The utility of the bifrontal DC has been demonstrated by RESCUEicp and DECRA trials for the evacuation of frontal hematoma, recent investigations for traumatic bilateral contusions, certain ruptured cerebral aneurysms resulting in multi-compartment hemorrhage, penetrating head-injury resulting in lobectomy as demonstrated by military reports, and finally as a broad approach for frontal mass lesions in neuro-oncology.

Despite well-documented randomized controlled investigations, our review of the relevant literature demonstrates that the bifrontal approach remains a questionable but versatile approach to frontal trauma. The best example is the RESCUEicp trial, which demonstrated that surgical intervention reduced patient mortality by 45% compared to medical treatment alone. These results are promising and affirm future possibilities in the treatment of cranial pathologies.

Our findings also highlight shifting perspectives on DC over the years, from an emergent rescue operation for patients who otherwise had no chance of survival to a viable alternative to medical management. A common thread across many generations of neurosurgeons is that individual skill and preference for approaches may, in some cases, have clinical preference over demonstrated effectiveness. While there are drawbacks to the bifrontal decompressive craniotomy, the constraints of austere environments continue to force surgeons to keep an open mind to niche surgical approaches.

Disclosures

None.

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