

Optimal Decompressive Craniectomy Operation Time For Traumatic Brain Injury With The Clinical Development: A Meta-Analysis

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ABSTRACT

Introduction: Traumatic Brain Injury (TBI) is a major health issue, often leading to death or long-term disability. Decompressive craniectomy (DC) is a surgical procedure used to reduce intracranial pressure (ICP) in severe cases, but the best timing for this surgery remains unclear.

Methods: This study is a meta-analysis following PRISMA guidelines. Research was collected from seven databases, focusing on studies comparing early (<24 hours) and late (>24 hours) DC. Data on patient characteristics, CT scan results, treatment timing, and outcomes were analyzed.

Results: Out of 2,571 studies, 23 met the inclusion criteria. The analysis showed that early DC significantly reduces ICP and improves survival rates ($p=0.0003$). However, some studies reported higher mortality and complications with early surgery.

Discussion: While early DC generally improves survival, its impact on long-term recovery is uncertain. Differences in study methods and patient conditions make it difficult to determine the best approach. More high-quality research is needed to confirm these findings.

Conclusion: Early DC may help save lives in severe TBI cases, but its effect on recovery remains unclear. Further studies are needed to determine the best timing for this procedure.

Keywords: Traumatic Brain Injury, Decompressive Craniectomy, Intracranial Pressure, Neurosurgery, Meta-Analysis

INTRODUCTION

Traumatic Brain Injury (TBI) is a major global health issue, affecting approximately 1.4 million individuals annually, with mortality rates reaching 15-20% in the 5–35 age group. In the United Kingdom, nearly 1.4 million people experience TBI each year, with about 3,500 requiring intensive care unit (ICU) admission. Severe cases often result in pre-hospital fatalities, where 90% of pre-hospital deaths are attributed to head trauma. Survivors frequently experience neurophysiological impairments, affecting work and social activities. Males are two to three times more likely to suffer from TBI than females. The primary causes of TBI include road traffic accidents (50%), falls (20–25%), and violent incidents or recreational activities (15–25%). Asia reports an incidence rate of 160 per 100,000 annually, with an associated mortality rate of 20 per 100,000 per year. However, comprehensive epidemiological data on TBI in Indonesia is lacking.^{1,2}

TBI-related neurological dysfunction and mortality result from direct brain trauma, prolonged coma, infected skull fractures, hydrocephalus from subarachnoid hemorrhage, and increased intracranial pressure (ICP). Brain injuries are classified as focal (e.g., epidural hematoma, subdural hematoma, contusions) or diffuse (e.g., concussion, diffuse axonal injury). High-impact trauma often causes a combination of both, leading to cerebral edema and intracranial hypertension, which may not manifest immediately.^{2,3}

Clinically, TBI severity is assessed using the Glasgow Coma Scale (GCS), categorizing cases as severe (GCS 3–8), moderate (GCS 9–13), or mild (GCS 14–15). However, neurosurgeons are increasingly relying on neuroimaging techniques such as computed tomography (CT), CT angiography, and magnetic resonance imaging (MRI) for precise diagnosis and prognosis.^{4,5,6,7}

Decompressive craniectomy (DC) is a potential treatment for refractory intracranial hypertension, following European and American Brain Injury Consortium guidelines. Standard medical management includes head elevation, sedation, analgesia, neuromuscular paralysis, ventricular drainage, pharmacological blood pressure control, osmotherapy, moderate hypocapnia, and

therapeutic hypothermia ($>34^{\circ}\text{C}$). DC provides immediate ICP relief in cases of diffuse cerebral edema, neurological deterioration, and persistent ICP >30 mmHg with cerebral perfusion pressure (CPP) <45 mmHg. While traditionally considered a last resort, emerging evidence suggests early DC may enhance patient outcomes by reducing secondary brain injury.^{8,9,10}

The efficacy and safety of DC remain debated due to limited randomized controlled trials (RCTs). Further research is needed to determine the optimal timing and impact of DC, particularly in resource-limited settings where access to advanced procedures remains a challenge.¹¹

METHODS

This study employs a meta-analysis design, systematically reviewing relevant research that meets predefined inclusion criteria to address a specific research question (RQ). Literature searches were conducted following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines.

The exclusion criteria included studies not published in English or Indonesian and studies with incomplete results that could not be supplemented. Online literature searches utilized seven databases: Cochrane Library, Medline, Embase, Web of Science, Google Scholar, Scopus, and PubMed. Keywords were selected using MeSH (Medical Subject Headings) and Boolean operators, including "decompression craniectomy," "intracranial pressure," and "traumatic brain injury." Literature was systematically reviewed using PRISMA, which consists of four evidence-based phases: identification, screening, eligibility, and inclusion. PRISMA serves as a guideline for authors, reviewers, and editors in evaluating journal quality.

Data collection involved identifying relevant studies based on patient characteristics (gender, age, and sample type), diagnostic methods, and outcome analysis. Two reviewers ensured data extraction consistency. This study utilized qualitative data synthesis, specifically the meta-aggregation approach, which summarizes research findings to answer the review question. Extracted data included study design, population demographics, sample size, inclusion/exclusion criteria, age, sex, CT scan findings (MARSHALL classification), decompressive craniectomy timing, medical treatment duration, and long- and short-term outcomes, including mortality rates.

Data extraction was systematically organized in Microsoft Excel and presented in detailed tabular form in the results section.

RESULT

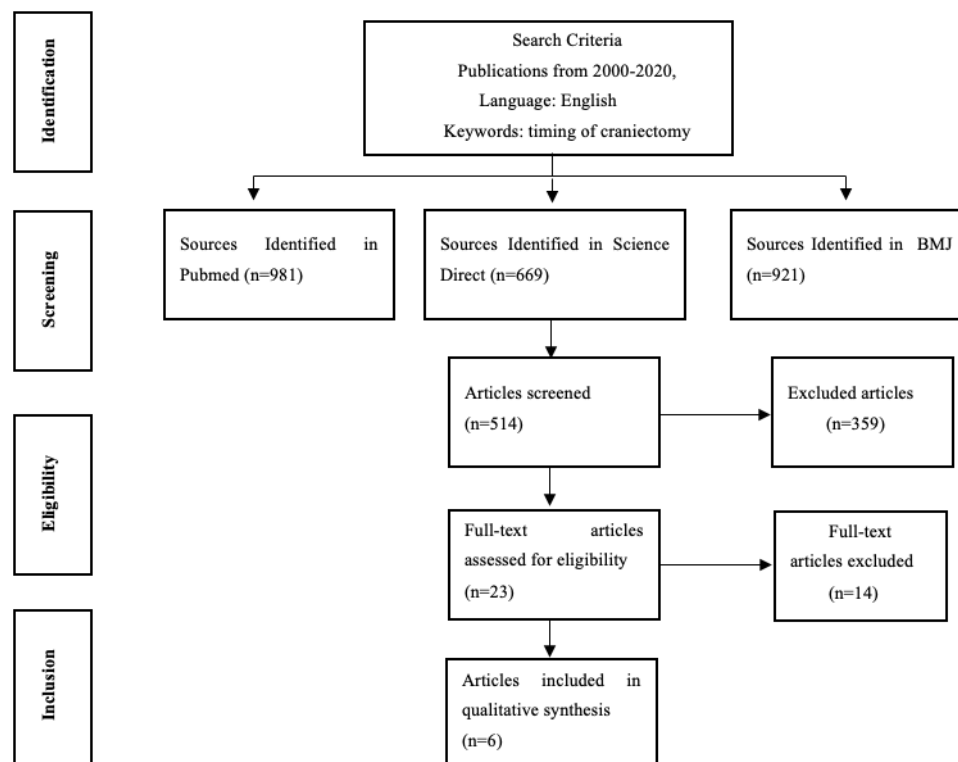


Figure 1. The PRISMA Flow Diagram

The PRISMA flow diagram in Figure 1 presents the literature search process. A total of 2,571 titles were screened from databases such as PubMed, Science Direct, and the British Medical Journal (BMJ). Of these, 2,057 studies were excluded due to duplication, abstract-only content, or non-research articles. A second screening eliminated 359 studies that did not meet the inclusion criteria, leaving 514 articles. Following a full-text review, 14 additional studies were excluded, resulting in 23 studies selected for further analysis.

Table 1 Assessment of Research Quality Based on Jadad Criteria

No	Author	Year	A	B	C	D	E	Total
1	Cooper et al	2011	1	1	0	0	1	3
2	Cianchi et al	2012	1	1	1	0	1	4
3	Hutchinson et al	2016	1	1	1	1	0	4
4	Bagheri et al	2017	1	1	1	0	1	4
5	Shackelford et al	2016	1	1	0	1	0	3
6	Qiu et al	2019	1	1	1	1	0	4

A= randomization was performed; B= randomization was performed correctly; C= *double blinding*; D= blinding was performed correctly; E= explanation provided regarding *withdrawal* and *follow-up*.

Six studies, consisting of three Randomized Controlled Trials (RCTs) and three retrospective cohort studies, met the inclusion criteria and were analyzed through qualitative and quantitative synthesis. The extracted data encompassed study design, randomization methods, treatment settings, blinding, dropout rates, and primary and secondary outcomes. The study population characteristics included sample size, inclusion and exclusion criteria, age, gender, CT scan findings (MARSHALL classification), decompressive craniectomy (DC) timing, and medical treatment duration.

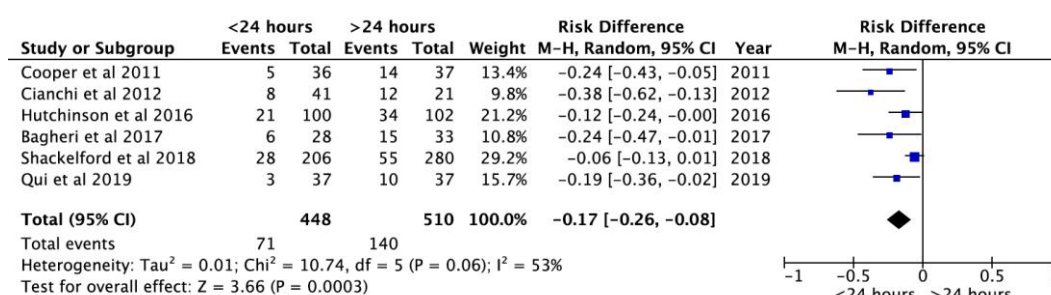


Figure 2. Forest Plot of the Optimal Timing of Decompressive Craniotomy Surgery in Traumatic Brain Injury Patients on Clinical Outcomes

DC is a surgical intervention designed to relieve elevated intracranial pressure (ICP), particularly in cases involving diffuse cerebral swelling and neurological deficits. The meta-analysis comparing early DC (<24 hours, 448 cases) with late DC (>24 hours, 510 cases) demonstrated significantly improved clinical outcomes with early intervention ($p=0.0003$). Statistical analysis confirmed that early DC correlates with better prognoses than late DC, with a confidence interval of -0.26 to -0.08 and a risk difference of -0.17. These findings suggest that the timing of DC plays a crucial role in optimizing patient outcomes.

DISCUSSION

A meta-analysis revealed differing effects of decompressive craniectomy (DC) performed within 24 hours versus after 24 hours on functional outcomes in traumatic brain injury (TBI) patients. However, DC performed within 24 hours significantly reduced mortality rates compared to delayed DC. Due to limitations in existing studies, such as inconsistent outcome measures, lack of blinded randomization, and small sample sizes, future double-blind randomized controlled trials with larger samples are needed to validate these findings.¹²

Some studies contradict the benefits of early DC. Faleiro et al. found higher mortality in patients operated on within six hours (59%) than those operated later (53%). Al-Jishi et al. reported better outcomes and lower mortality with secondary DC (73.1% and 15.4%) compared to primary DC (45.5% and 40.9%).¹³ Similarly, Albanèse et al. found that early decompression resulted in higher mortality (50%) compared to late decompression (20%).¹⁴

Studies highlight varying DC timing strategies. Honeybul et al. observed no functional improvement in patients post-DC, while Hartings et al. linked early surgery with lower intracranial pressure (ICP) and better outcomes.^{15,16} Seelig et al. noted that surgery within four hours had a 30% mortality rate, whereas delays increased mortality to over 90%. Akyuz et al. found that patients undergoing early decompression had better outcomes (44.4% vs. 12.5%, $p = 0.0018$).¹⁷

Meta-analyses by Zhang et al. and Qiu et al. suggest early DC (within 36 hours) may improve Glasgow Coma Scale (GCS) scores and reduce mortality, ICP, and ICU stay duration. However, early DC also increases complications.¹⁰ Qiu et al. reported a 27% one-month mortality rate for unilateral DC compared to 57% in the control group, with better long-term functional outcomes (56.8% vs. 32.4%, $p = 0.035$).¹⁸

Other studies reinforce these findings. Bagheri et al. found that early DC (within 4.5 hours) resulted in favorable outcomes in 54.1% of patients, except in those over 60 years old or with severe brain damage (GCS <5). A large retrospective review of 486 TBI patients linked ultra-early DC (<5.33 hours) with reduced mortality.¹⁹

RCTs such as DECRA and RESCUEICP examined late DC (>24 hours) outcomes. DECRA found that bifrontal DC reduced ICP but worsened functional outcomes, though it was criticized for imbalanced randomization. RESCUEICP largely confirmed DECRA's findings but did not significantly advance understanding of lateral decompression or focal brain injuries.²⁰

Cianchi et al. compared early DC (<24 hours), late DC (>24 hours), and maximal medical management. While hospital mortality and six-month GCS scores were similar, late DC had lower six-month mortality rates than early DC (29% vs. 48.8%, $p = 0.02$). However, retrospective study design limitations exist.²¹

Despite the controversies, DC remains a crucial intervention, typically as a last resort for severe TBI cases. More studies are needed to refine optimal timing and surgical strategies. Unlike stroke management, TBI research suggests that DC following acute brain herniation may still improve survival and functional outcomes. While larger RCTs indicate DC increases survival but also severe disability rates, recent trials suggest earlier DC may improve outcomes and reduce mortality. However, the extent to which early DC benefits TBI patients—whether by preventing herniation or through other mechanisms—remains uncertain. Future research should clarify the role of DC in relation to herniation events and overall patient prognosis.

CONCLUSION

In conclusion, early DC shows potential in improving survival but has uncertain effects on functional recovery. Future large-scale studies are necessary to determine its optimal timing and benefits.

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