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Original Research Article

Outcomes and Predictors of Early versus Late Decompressive Craniectomy Following Traumatic Brain Injury

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Abstract:

Background: The timing of decompressive craniectomy (DC) in managing traumatic brain injury (TBI) remains a contentious issue, with debates surrounding the outcomes and predictors of early versus late intervention.

Methods: This observational, prospective cohort study included patients undergoing DC for TBI at a tertiary care center. Patients were divided into early (within 24 hours post-injury) and late (after 24 hours post-injury) DC groups. Data on demographics, mode of injury, pre- and post-operative Glasgow Coma Scale (GCS) scores, presence of mass effect, midline shift, time to surgery, and Glasgow Outcome Scale Extended (GOSE) scores at discharge were collected and analyzed.

Results: A total of 174 patients were studied, with 87 in each group. No significant difference was observed in age distribution (p=0.41) or gender (p=1.0). Mode of injury significantly influenced the timing of DC, with falls more common in late DC (51.72% vs. 17.24%, p<.0001). The late DC group had higher pre-operative GCS scores (9.32 ± 3.91 vs. 5.83 ± 2.45, p<.0001). Mass effect was present in all early DC patients but in only 19.54% of late DC patients (p<.0001). The mean time to surgery was significantly shorter in the early DC group (9.2 ± 2.88 hours vs. 64.17 ± 29.62 hours, p<.0001). The late DC group showed a higher percentage of favorable GOSE scores at discharge (47.13% vs. 10.34%, p<.0001).

Conclusion: The study suggests that while early DC is crucial for patients with significant mass effect and midline shift, late DC can result in comparable or better outcomes for patients with higher initial GCS scores or different modes of injury. The decision on the timing of DC should be individualized based on clinical presentation and injury characteristics.

Keywords: Traumatic brain injury, Decompressive craniectomy, Early intervention, Late intervention, Outcomes, Predictors.

Introduction

Traumatic brain injury (TBI) remains a significant cause of morbidity and mortality worldwide, presenting a complex challenge for healthcare systems. Among the surgical interventions for managing severe TBI, decompressive craniectomy (DC) is a critical procedure aimed at relieving elevated intracranial pressure (ICP) when medical management fails. This procedure involves the removal of a section of the skull to allow a swelling brain room to expand without being squeezed. Despite its potentially life-saving role, the timing of DC, whether early (within 24 hours of injury) or late (after 24 hours), remains a subject of ongoing debate and investigation. The decision-making process is nuanced, influenced by a myriad of patient-specific factors and injury characteristics, necessitating a comprehensive understanding of the outcomes and predictors associated with each approach.

Recent studies have demonstrated varied outcomes associated with the timing of decompressive craniectomy, reflecting the complexity of TBI management. Early DC is posited to potentially reduce the duration of intracranial hypertension, thereby minimizing secondary brain injury [1]. Conversely, late DC is often considered in patients who do not initially exhibit signs of severe brain swelling or elevated ICP, or in those whose conditions deteriorate despite maximal medical therapy [2]. The decision between early and late DC involves a delicate balance between the benefits of preventing secondary brain injury and the risks of unnecessary surgery or delayed intervention.

Research focusing on the predictors of outcomes following DC has identified several key factors, including patient age, initial Glasgow Coma Scale (GCS) score, the presence of pupillary abnormalities, the timing of surgery, and the extent of brain shift on imaging [3]. Age, for instance, has been consistently shown to be a crucial determinant of outcomes, with younger patients generally faring better after DC [4]. The GCS score at admission serves as a valuable predictor of recovery, with higher scores associated with more favorable outcomes [5].

The impact of the timing of DC on patient outcomes has been a focal point of recent research, with studies yielding mixed results. Some have found early DC to be associated with better functional outcomes and reduced mortality [6], while others argue that the benefits of early DC may not be universally applicable, highlighting the need for individualized decision-making [7]. The variability in outcomes underscores the importance of identifying reliable predictors that can guide clinical decisions regarding the optimal timing for DC.

Complications associated with DC, such as infection, hydrocephalus, and subdural hygroma, also play a critical role in determining the overall success of the intervention [8]. Understanding the risk factors for these complications is essential for optimizing patient care and improving prognosis.

The debate over early versus late DC underscores the need for a nuanced approach to TBI management, one that considers a constellation of clinical variables and leverages predictive models to inform surgical timing. As the body of evidence grows, so does the potential for developing more refined guidelines that can aid clinicians in making informed decisions tailored to individual patient profiles.

The determination of the optimal timing for decompressive craniectomy following traumatic brain injury remains a complex, multifaceted decision-making process. The outcomes and predictors of early versus late DC are influenced by a variety of factors, including patient demographics, injury characteristics, and clinical presentation. Ongoing research and advanced predictive models are essential for enhancing our understanding of these dynamics, ultimately leading to improved patient outcomes.

Aim:

To compare the outcomes of early versus late decompressive craniectomy in patients with moderate to severe traumatic brain injury (TBI) and identify predictors of better recovery based on demographic, clinical, and treatment variables.

Materials and Methods

The study was meticulously designed to ensure comprehensiveness and scientific rigor, adhering to ethical standards set forth by the institutional review board.

Study Design and Setting

The research adopted an observational, prospective cohort design. It was conducted at the Medical College Hospital (MCH), Thiruvananthapuram, specifically within the wards and Intensive Care Unit (ICU) under the Department of Neurosurgery.

Study Period and Population

The initial phase of decompressive craniectomies was conducted from July 2020 to December 2020, with a follow-up duration extending to March 2021. The study population encompassed all patients undergoing decompressive craniectomy at the Govt Medical College, Trivandrum, for traumatic brain injury, admitted within 24 hours of injury.

Sample Size Calculation

To calculate the sample size, data from the study by Cianchi et al. on late decompressive craniectomy in traumatic brain injury and its outcomes at 6 months using the Glasgow Outcome Scale (GOS) published in the Journal of Trauma Management and Outcomes, 2012 edition, was utilized. The formula applied was:

$$N=(Z(1-\alpha/2)+Z(1-\beta))^2\times(S_1^2+S_2^2)/(\mu1-\mu2)^2$$

Substituting the values for a 95% confidence level and a power of 80%, the calculated sample size was 123 in each group.

Inclusion and Exclusion Criteria

Inclusion Criteria: Patients aged 18-70 years diagnosed with moderate to severe traumatic brain injury, admitted within 24 hours of injury.

Exclusion Criteria:

- Age below 18 or above 70 years.
- Prior neurological condition with residual disability.
- Polytraumas.
- Primary brainstem injuries on initial CT.
- Refusal to participate in the study.
- GCS 3 with bilaterally non-reactive pupils and absent brainstem reflexes.
- Diffuse brain injury.

Data Collection Procedures

Data collection commenced after obtaining written informed consent from participants or their deputies. A predefined proforma facilitated the collection of data at presentation, during the post-operative period, and throughout serial follow-ups. This data included demographic details, clinical and imaging variables, and was systematically entered into a Microsoft Excel sheet for analysis. The neurological outcome was assessed using the Extended Glasgow Outcome Scale (GOS-E) at discharge, one month, and three months post-discharge.

Methodology

Patients diagnosed with severe traumatic brain injury were managed according to the institute's protocol, which aligns with state guidelines and the Brain Trauma Foundation guidelines. The management included immediate surgery or initial conservative treatment. Surgical patients underwent standard decompressive craniectomy with specific dimensions and procedures for bone flap preservation and post-operative care. Conservative management involved meticulous ICU care with a focus on maintaining physiological parameters within therapeutic ranges and addressing potential complications.

Statistical Analysis

Data were presented as counts, percentages, means ± standard deviations, or medians with interquartile ranges as appropriate. The Kolmogorov-Smirnov test assessed data normality. Non-parametric tests were applied for non-normally distributed data. The Mann-Whitney Test, Kruskal-Wallis test, Wilcoxon signed-rank test, Chi-Square test, and Fisher's exact test were utilized for analysis as applicable. Statistical Package for Social Sciences (SPSS) version 21.0 facilitated data analysis, with p-values less than 0.05 denoting statistical significance.

Ethical Considerations

The study received approval from the institutional ethical committee. Informed consent was obtained from all participants, ensuring the confidentiality and integrity of participant data throughout the research process.

Results

The study compared outcomes and predictors of early versus late decompressive craniectomy following traumatic brain injury, analyzing various parameters including age, gender, mode of injury, Glasgow Coma Scale (GCS) scores over time, presence of mass effect, midline shift measurements, time interval to surgery, and Glasgow Outcome Scale Extended (GOSE) at discharge.

Age Comparison

The age distribution across the early and late decompressive craniectomy groups showed no significant difference (p=0.41, Mann-Whitney test). In the early group, the mean age was 46.74 ± 12.64 years, while in the late group, it was 47.88 ± 15.59 years. The age categories revealed a wide range from under 20 to over 50 years, with the largest proportion of patients in both groups being over 50 years of age, constituting 39.53% of the early group and 47.67% of the late group.

Gender Distribution

Gender distribution was evenly matched between the two groups, with 80.46% males and 19.54% females in each group, leading to a p-value of 1 (Chi-square test), indicating no significant difference in gender distribution between early and late decompressive craniectomy groups.

Mode of Injury

The mode of injury significantly influenced the timing of decompressive craniectomy. Falls were more common in the late decompression group (51.72%), whereas road traffic accidents (RTA) predominated in the early decompression group (82.76%), resulting in a highly significant difference (p<.0001, Chi-square test).

Glasgow Coma Scale Scores

Pre-operative GCS scores were significantly higher in the late decompression group (9.32 ± 3.91) compared to the early decompression group (5.83 ± 2.45), with a p-value of <.0001 (Mann-Whitney test). Post-operative GCS scores showed gradual improvement over days in both groups, but the late decompression group consistently had higher scores from day 1 to day 7, all with significant p-values of <.0001 when comparing early and late groups each day (Mann-Whitney test). Intra-group comparisons also revealed significant improvements over time within each group (Wilcoxon Signed Ranks Test).

Presence of Mass Effect

All patients in the early decompression group showed positive mass effect, whereas 80.46% in the late group did not exhibit a mass effect at the time of surgery, marking a significant difference (p<.0001, Fisher's exact test).

Midline Shift Measurements

The extent of midline shift also differed significantly between groups. The early decompression group had a larger proportion of patients with a midline shift of >8mm (36.78%) compared to the late group (4.60%), with a significant p-value of <.0001 (Fisher's exact test). The mean midline shift in the early group was 8.44 ± 1.85 mm, significantly greater than in the late group (4.85 ± 2.07 mm, p<.0001, Mann-Whitney test).

Time Interval to Surgery

The time from injury to surgery was markedly different between groups. The early decompression group had surgery within 0-16 hours for the majority (98.85%), while all patients in the late decompression group underwent surgery after 24 hours. The mean time to surgery was 9.2 ± 2.88 hours in the early group and 64.17 ± 29.62 hours in the late group, with a highly significant p-value of <.0001 (Mann-Whitney test).

Glasgow Outcome Scale Extended (GOSE) at Discharge

The GOSE at discharge showed that 47.13% of patients in the late decompression group had favorable outcomes (GOSE 5 to 8), compared to only 10.34% in the early decompression group, resulting in a significant difference (p<.0001, Chi-square test). The mean GOSE score was higher in the late decompression group (4.07 ± 2.36) than in the early group (2.92 ± 1.43), with a p-value of 0.037 (Mann-Whitney test).

In summary, the timing of decompressive craniectomy following traumatic brain injury significantly affected outcomes, with the late decompression group generally faring better in terms of pre-operative and post-operative GCS scores, mode of injury, presence of mass effect, midline shift, and GOSE scores at discharge.

Table 1: Comparison of age between early and late decompressive craniectomy groups.

Age(years)	Early(n=86)	Late(n=86)	Total	P value
<=20	3 (3.49%)	4 (4.65%)	7 (4.07%)	0.062*
21-30	7 (8.14%)	10 (11.63%)	17 (9.88%)	
31-40	15 (17.44%)	20 (23.26%)	35 (20.35%)	
41-50	27 (31.40%)	11 (12.79%)	38 (22.09%)	
>50	34 (39.53%)	41 (47.67%)	75 (43.60%)	
Mean ± SD	46.74 ± 12.64	47.88 ± 15.59	47.31 ± 14.16	0.41‡
Median(25th-75th percentile)	48(39.25-55)	50(37-61.5)	49.5(37.75-59.25)	
Range	16-70	14-70	14-70	

‡ Mann Whitney test, * Fisher's exact test

Table 2: Comparison of gender distribution between the two groups.

Gender	Early(n=87)	Late(n=87)	Total	P value
Female	17 (19.54%)	17 (19.54%)	34 (19.54%)	1†
Male	70 (80.46%)	70 (80.46%)	140 (80.46%)	
Total	87 (100%)	87 (100%)	174 (100%)	

† Chi square test

Table 3:Mode of injury and its impact on the timing of decompressive craniectomy.

Mode of injury	Early(n=87)	Late(n=87)	Total	P value
Fall	15 (17.24%)	45 (51.72%)	60 (34.48%)	<.0001†
RTA	72 (82.76%)	42 (48.28%)	114 (65.52%)	
Total	87 (100%)	87 (100%)	174 (100%)	

† Chi square test

Table 4: Pre-operative and post-operative Glasgow Coma Scale (GCS) scores across different time points

Glasgow Coma Scale	Early	Late	Total	P value
Pre-operative				
Mean ± SD	5.83 ± 2.45	9.32 ± 3.91	7.57 ± 3.69	<.0001‡
Median(25th-75th percentile)	7(3-8)	8(6-13)	7(4-9.75)	
Range	3-10	3-14	3-14	
Post-operative day 1				
Mean ± SD	3 ± 0	3 ± 0	3 ± 0	1‡
Median(25th-75th percentile)	3(3-3)	3(3-3)	3(3-3)	
Range	3-3	3-3	3-3	
Intra group p value	<0.0001¶	<0.0001¶	-	-
Post-operative day 2				
Mean ± SD	5.85 ± 2.18	7.87 ± 2.38	6.84 ± 2.49	<.0001‡
Median(25th-75th percentile)	6(4-8)	8.5(7-10)	7(5-9)	
Range	3-10	3-10	3-10	
Intra group p value	0.815¶	0.0001¶	-	-
Post-operative day 3				
Mean ± SD	6.84 ± 2.86	9.13 ± 2.77	7.93 ± 3.03	<.0001‡
Median(25th-75th percentile)	6(5-9)	10(7-11)	8(5-11)	
Range	3-14	4-14	3-14	
Intra group p value	0.016¶	0.661¶	-	-
Post-operative day 4				
Mean ± SD	6.9 ± 3.03	9.13 ± 2.77	7.99 ± 3.1	<.0001‡
Median(25th-75th percentile)	6(4-9)	10(7-11)	8(5-11)	
Range	3-14	4-14	3-14	
Intra group p value	0.009¶	0.661¶	-	-
Post-operative day 5				
Mean ± SD	7.56 ± 3.08	10.13 ± 3.63	8.81 ± 3.59	<.0001‡
Median(25th-75th percentile)	7(5-11)	11(7-14)	8(6-11)	
Range	3-14	4-14	3-14	
Intra group p value	0.0001¶	0.052¶	-	-
Post-operative day 6				
Mean ± SD	7.65 ± 3.11	10.34 ± 3.67	8.96 ± 3.64	<.0001‡
Median(25th-75th percentile)	7(5-11)	11(7-14)	8.5(6-12)	
Range	3-14	4-14	3-14	
Intra group p value	<0.0001¶	0.015¶	-	-
Post-operative day 7				
Mean ± SD	7.65 ± 3.11	10.45 ± 3.71	9.02 ± 3.68	<.0001‡
Median(25th-75th percentile)	7(5-11)	11(7-14)	8.5(6-12.75)	
Range	3-14	4-14	3-14	
Intra group p value	<0.0001¶	0.015¶	-	-
At discharge				
Mean ± SD	8.6 ± 3.12	10.95 ± 4.08	9.79 ± 3.82	<.0001‡
Median(25th-75th percentile)	8(6-12)	13(7-15)	10(7-14)	
Range	4-15	4-15	4-15	
Intra group p value	<0.0001¶	0.001¶	-	-

‡ Mann Whitney test, ¶ Wilcoxon Signed Ranks Test

Table 5: Presence of mass effect and its association with the timing of surgery.

Mass effect	Early(n=87)	Late(n=87)	Total	P value
Negative	0 (0%)	70 (80.46%)	70 (40.23%)	<.0001*
Positive	87 (100%)	17 (19.54%)	104 (59.77%)	
Total	87 (100%)	87 (100%)	174 (100%)	

*** Fisher's exact test**

Table 6: Midline shift measurements and their implications on the outcomes.

Midline shift(mm)	Early(n=87)	Late(n=87)	Total	P value
<=8	55 (63.22%)	83 (95.40%)	138 (79.31%)	<.0001*
>8	32 (36.78%)	4 (4.60%)	36 (20.69%)	
Mean ± SD	8.44 ± 1.85	4.85 ± 2.07	6.64 ± 2.66	<.0001‡
Median(25th-75th percentile)	8(7-9)	4(3-7)	7(4-8)	
Range	5-15	1-10	1-15	

‡ Mann Whitney test, * Fisher's exact test

Table 7:The impact of the time interval to surgery on patient outcomes.

Time interval to surgery(in hours)	Early(n=87)	Late(n=87)	Total	P value
0-8 hours	34 (39.08%)	0 (0%)	34 (19.54%)	<.0001*
9-16 hours	52 (59.77%)	0 (0%)	52 (29.89%)	
17-24 hours	1 (1.15%)	0 (0%)	1 (0.57%)	
>24 hours	0 (0%)	87 (100%)	87 (50%)	
Mean ± SD	9.2 ± 2.88	64.17 ± 29.62	36.68 ± 34.64	<.0001‡
Median(25th-75th percentile)	9(7-11)	65(42-75)	22.5(9-64.25)	
Range	3-19	26-179	3-179	

‡ Mann Whitney test, * Fisher's exact test

Table 8: Glasgow Outcome Scale Extended (GOSE) at discharge, comparing outcomes between early and late decompressive craniectomy

GOSE at discharge	Early(n=87)	Late(n=87)	Total	P value
Favourable{5 to 8}	9 (10.34%)	41 (47.13%)	50 (28.74%)	<.0001†
Unfavourable{1 to 4}	78 (89.66%)	46 (52.87%)	124 (71.26%)	
Mean ± SD	2.92 ± 1.43	4.07 ± 2.36	3.49 ± 2.03	0.037‡
Median(25th-75th percentile)	3(2-3)	4(2-6.5)	3(2-5.75)	
Range	1-7	1-7	1-7	

‡ Mann Whitney test, † Chi square test

Discussion

This study adds to the existing body of literature by providing a detailed analysis of various factors that influence the effectiveness of DC in TBI management.

Timing of Decompressive Craniectomy and Outcomes

The significant difference in pre-operative Glasgow Coma Scale (GCS) scores between the early and late DC groups underscores the importance of the injury's initial severity on surgical outcomes. Patients in the late DC group, who had higher pre-operative GCS scores, demonstrated better outcomes post-surgery, which aligns with findings from Honeybul et al. (2011) [9] that suggested patients with less severe injuries at the time of admission tend to have better prognoses after DC. This might reflect the complex interplay between the timing of surgery and the underlying pathophysiological state of the brain following injury.

The mode of injury also played a crucial role in determining the timing of DC, with falls more commonly leading to late decompression and road traffic accidents (RTA) resulting in early decompression. This could be related to the mechanisms of injury and the immediate presentation of symptoms, as RTAs are often associated with high-impact forces leading to immediate severe presentations [10].

Presence of Mass Effect and Midline Shift

The universal presence of mass effect in the early DC group compared to its absence in a significant proportion of the late DC group highlights the urgency and necessity of early intervention in certain cases [11]. Mass effect, indicative of increased intracranial pressure (ICP), necessitates rapid decompression to mitigate secondary brain injury. The extent of midline shift, significantly greater in the early DC group, further emphasizes the severity of brain injury in these patients, necessitating earlier surgical intervention [12].

Time Interval to Surgery

The stark contrast in the time interval to surgery between the two groups, with early DC performed within 16 hours post-injury and late DC performed after 24 hours, raises critical considerations about the 'golden hours' for surgical intervention in TBI. Previous studies, such as the one by Cooper et al. (2011) [13], have highlighted the benefits of early DC in reducing intracranial pressure and improving patient outcomes. However, this study's findings suggest that the benefits of DC, whether early or late, may also depend on other factors, such as the initial severity of the injury and the presence of mass effect or midline shift.

Glasgow Outcome Scale Extended (GOSE) at Discharge

The outcomes measured by the Glasgow Outcome Scale Extended (GOSE) at discharge, indicating more favorable outcomes in the late DC group, challenge the prevailing notion that earlier is always better for all patients. This is consistent with the work by Aarabi et al. (2006) [14], which argued for a more nuanced approach to the timing of DC, taking into account the individual patient's clinical presentation and the evolving nature of their brain injury.

Limitations and Future Directions

While this study provides valuable insights into the outcomes and predictors of early versus late DC following TBI, it is not without limitations. The retrospective design and the single-center setting may limit the generalizability of the findings. Future multicenter, prospective studies are needed to further validate these results and refine guidelines for the timing of decompressive craniectomy.

Conclusion

This study highlights the complex decision-making process involved in determining the timing of decompressive craniectomy for patients with traumatic brain injury. The findings suggest that while early DC is crucial for patients with significant mass effect and midline shift, late DC may offer comparable, if not better, outcomes for certain patients, particularly those with higher initial GCS scores or different modes of injury. These results underscore the need for individualized patient assessments and tailored surgical timing to optimize outcomes for TBI patients.

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