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Early cranioplasty versus traditional cranioplasty enhances surgical outcomes in patients with malignant cerebral infarction after decompressive craniectomy

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Abstract

Background A growing cohort of malignant cerebral infarction (MCI) patients after decompressive craniectomy (DC) required cranioplasty (CP). However, few studies have reported the effect of CP on functional improvements in post-DC MCI patients. The aim of this study was to determine whether early CP for post-DC MCI patients enhances surgical outcomes and alters overall complication rate.

Methods 86 post-DC MCI patients after CP were divided into the early CP cohort and the traditional CP cohort according to the time span from DC to CP. Complications, NIHSS, mBI, mRS, and CRS-r were assessed, and early CP and traditional CP were defined as occurring less than or more than 3 months after DC.

Results Complications were observed in 9 patients (24.32%) in the early CP cohort and 14 patients (28.57%) in the traditional CP cohort ($p > 0.05$). NIHSS, mRS, mBI, and CRS-r between pre-operation and post-operation did significantly differ ($p < 0.05$). Between the two cohorts, operative time, intraoperative blood loss, post-operative parameters (NIHSS, mBI and mRS), ΔNIHSS, and ΔmBI did significantly differ ($p < 0.05$), while post-operative CRS-r did not significantly differ ($p > 0.05$). There was a linear relationship between ΔNIHSS and the time span from DC to CP ($r = 0.505$, $p < 0.0001$), and there was a linear relationship between ΔBI and the time span from DC to CP ($r = -0.568$, $p < 0.0001$).

Conclusions Our study demonstrated that, first, CP has a favorable effect on improving neurological function, ability to perform daily living, and consciousness in post-DC MCI patients; second, early CP does not alter the overall complication rate and is as safe as traditional CP; third, compared to traditional CP, early CP reduces operative time and intraoperative blood loss, promotes improvements in neurological function and ability to perform daily living, and enhances these improvements.

Keywords Cranioplasty, Decompressive craniectomy, Malignant cerebral infarction, Surgical outcomes, Time span from DC to CP

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Introduction

Malignant cerebral infarction (MCI) is a severe cerebrovascular disease in neurology that is characterized by acute onset, high disability, and high mortality [1]. It is caused by blockage of the middle cerebral artery, anterior cerebral artery, internal carotid artery, or cerebral cortex branches. Patients who received conservative treatment had a mortality rate of up to 78%. In contrast, patients who received decompressive craniectomy (DC) treatment had lower 6-month mortality rate and comparable or better functional outcomes than those who received conservative treatment [2]. Early DC is an effective method for relieving increased intracranial pressure, improving patient outcomes, and significantly reducing the mortality rate in patients with malignant cerebral infarction [3–5]. Currently, DC is the main treatment for malignant cerebral infarction. However, DC can cause large skull defects, which will result in a lack of adequate skull support for brain tissues; thus, the brain tissue will be subjected to atmospheric pressure, resulting in a reduction of the blood flow to the focal brain tissues and disruption of the dynamics of the cerebrospinal fluid, which will lead to a variety of neurological dysfunctions, such as "syndrome of the trephined" or "sinking skin flap syndrome", thus delaying neurological recovery [6, 7]. All of these shortcomings have resulted in a growing cohort of MIC patients who subsequently require a reconstructive cranioplasty (CP).

Cranioplasty (CP) is a surgical procedure commonly performed on patients who have undergone DC. This procedure may affect patients' physical, psychological, neurological, and cognitive functions. CP is an important surgical method for restoring the normal anatomy of the cranial cavity and repairing skull defects. It not only achieves cosmetic purposes but also promotes brain fusion, enhances neurological function, improves quality of life, mood, cerebral blood flow, and clinical symptoms and neurological dysfunction [8]. Although CP is frequently regarded as a technically simple procedure, it is associated with a high incidence of complications, ranging from 16 to 35%. These complications include intracranial hematoma, seizure, cerebral edema, and poor wound healing [9, 10]. The timing of CP is a popular research topic that is closely related to complications and patients' quality of life after DC. Due to risk factors such as intracranial infection, subcutaneous effusion, poor wound healing, and cerebral edema, CP is traditionally recommended for 3 months to more than 6 months after DC [11].

The clinical reality is that the timing of cranioplasty varies widely between treatment centers and is usually guided by the patient's clinical condition after DC and by the individual neurosurgeon's clinical experience rather than by evidence-based data. Objective data should be used to guide the timing of CP to ensure consistency and improve patient outcomes. However, the appropriateness of traditional CP timing is questioned by many neurosurgeons due to severe scalp adhesion to subcutaneous tissues and the dura mater, difficulty in intraoperative separation, increased blood loss, and postoperative hydrocephalus. Currently, there is no consensus on the optimal timing of CP. Numerous studies have shown that 3 months after DC as the defining time, early CP ($<=3$ months from DC) has a similar or lower risk of postoperative complications and contributes to neurological function and neuropsychological recovery compared with traditional CP (>3 months from DC) [13–14]. Growing evidence in support of early CP has led some surgeons to elect to perform CP at an earlier date. The Chinese Expert Consensus on Traumatic Cranioplasty (2016) suggests that early cranioplasty is advocated if there are no contraindications to surgery or if the condition permits.

However, the functional effects of CP in patients with cerebral damage caused by MIC after DC may differ from those in patients with cerebral damage due to other causes after DC, and few studies have reported the effect of early CP on functional improvement in patients with MCI after DC. Therefore, we aimed to determine whether early CP for post-DC MCI patients enhances surgical outcomes and alters the overall complication rate.

Methods

Patients and ethics

This was a single-center, retrospective cohort study gathering information on 86 MCI patients who had undergone DC with subsequent CP in Xi'an Gaoxin Hospital from January 2016 to June 2023. The patients were divided into two cohorts according to the time span from DC to CP. In our study, we defined early CP as occurring within 3 months post-DC, whereas traditional CP was defined as occurring after 3 months post-DC. In this study, CP procedures were performed by the same team neurosurgeons in the neurosurgery department of Xi'an Gaoxin Hospital. This study was reviewed and approved by the Xi'an Gaoxin Hospital Ethics Board. Patient data collected from the electronic medical records were maintained in compliance. This study did not involve direct contact with patients. Therefore, individual patient consent was not required for the duration of our study. The study complied with the ethical standards set out in the 1964 Declaration of Helsinki.

Inclusion and exclusion criteria

The inclusion criteria were (1) an age of 40 to 70 years; (2) unilateral DC performed between 24 and 96 h after the onset of MCI; (3) without hydrocephalus before CP; (4) 1-month post-operative follow-up; (5) no swelling of

brain tissue; and (6) wound healed well without infection. The exclusion criteria were (1) any underlying disease, including other cardiovascular and cerebrovascular diseases, liver or kidney dysfunction, coagulation disorders, or intracranial infections, affecting the prognosis; (2) an age of < 40 or > 70 years; (3) death within 3 months after CP; (4) more than CP after DC; and (5) bilateral DC. The inclusion and exclusion criteria were the same for both cohorts.

Data collection

The data were collected from electronic medical records. The primary outcomes studied were complications, neurological function, consciousness, and ability to perform daily living. The modified Barthel Index scale (mBI, ranging from 0 (worst) to 100 (best)) was applied to assess function in activities of daily living (ADL). The modified Rankin scale (mRS) was used to assess the ability to live independently. The National Institute of Health Stroke scale (NIHSS, ranging from 0 to 42) was used to assess neurological function. The coma remission scale-revised (CRS-r, ranging from 0 (worst) to 23 (best)) was used to quantify levels of consciousness. The relevant data were collected from all enrolled patients with MCI who had undergone CP after DC: age, sex, site of DC, skull defect area, Glasgow coma scale (GCS) score at admission, pre-operative and post-operative NIHSS, pre-operative and post-operative mRS, pre-operative and post-operative mBI, pre-operative and post-operative CRS-r, CP material (polyetheretherketone (PEEK) and titanium), operative time, intraoperative blood loss, time span from DC to CP, and complications (intracranial hematoma, intracranial infection, poor wound healing, subcutaneous effusion, hydrocephalus, dural tear, and seizure). Poor wound healing included wound infection, wound dehiscence, and scalp necrosis. The diagnosis of hydrocephalus was established according to computed tomography (CT) findings and clinical course. Pre-operative parameters were recorded at admission and post-operative parameters were recorded at 1 month after CP.

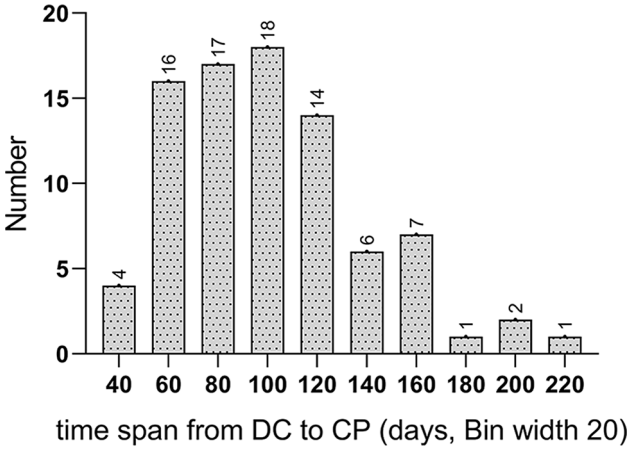

Fig. 1 Frequency distribution of the time span from DC to CP

Statistical analysis

SPSS software (version 22.0; IBM, Armonk, NY, USA) was used for data entry and statistical analyses, and GraphPad Prism 9.0 was used for image processing. Variables were tested for data distribution (Kolmogorow-Smirnow test) and the appropriate parametric or non-parametric test were used for comparison of means or medians (Student's unpaired t test, Mann–Whitney U test) and correlation analysis (Spearman-Rho or Pearson). The quantitative data are presented as the mean ± standard deviation, whereas the qualitative data are presented in terms of frequency or percentage (%), and comparisons between cohorts were performed using Chi-square. Repeated measure two-way ANOVA was used to compare NIHSS, mRS, mBI, and CRS-r between the two cohorts. Statistical significance was set at $p < 0.05$. significance. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, $^{****}p < 0.0001$, ns (not significant). $p > 0.05$.

Results

Patient and surgical parameters

In this study, 86 MCI patients who had undergone CP after DC were divided into the early CP cohort and the traditional CP cohort according to the time span from DC to CP. The time span from DC to CP ranged from 40 to 213 days and was mainly distributed between 60 and 120 days (Fig. 1). The median interval of the time span from DC to CP was 69 days (range 40–87) in the early CP cohort versus 119 days (range 92–213) in the traditional CP cohort. The early CP cohort comprised 37 patients, and the traditional CP cohort comprised 49 patients. Table 1 summarizes the main surgical-demographic parameters at baseline. Operative time in the early CP cohort (149.4 ± 30.64 min) was 19 min shorter than that in the traditional CP cohort (168 ± 19.90 min), which was a statistically significant difference ($p = 0.001$). Intraoperative blood loss in the early CP cohort (120 (99, 180) mL) was 20 mL less than that in the traditional CP cohort (160 (114.5, 215) mL), which was a statistically significant difference ($p = 0.046$). There were no significant differences in the other clinical-demographic parameters ($p > 0.05$).

Complications of CP

Complications of CP included intracranial hematoma, intracranial infection, wound infection, wound dehiscence, scalp necrosis, subcutaneous effusion, hydrocephalus, dural tear, and seizure. Overall, complications were observed in 23 patients (26.74%). Complications were observed in 9 patients (24.32%) in the early CP cohort and 14 patients (28.57%) in the traditional CP cohort. Two patients had multiple complications in the early CP

Table 1 Demographics and surgical parameters

Variables	Early CP ($n=37$)	Traditional CP ($n=49$)	Total ($n=86$)	χ^2/t/U	*p*
Age (years)	57.51 ± 6.58	57.14 ± 6.08	57.30 ± 6.26	0.270	0.788
Sex (male/female)	20/17	23/26	43/43	0.653	0.514
Site of DC (left/right)	18/19	22/27	40/46	0.345	0.730
Operative time (minutes)	149.4 ± 30.64	168 ± 19.90	160 ± 26.59	3.405	0.001
Intraoperative blood loss (mL)	120(99,180)	160(114.5,215)	147.5(106.5,201.5)	678	0.046
Skull defect area (cm^2)	127.9 ± 17.51	130.3 ± 16.78	129.3 ± 17.04	0.653	0.515
CP materials (PEEK/Titanium)	8/29	12/37	20/66	0.312	0.755
GCS at admission	10(8,12)	10(8,13)	10(8,13)	899	0.950
Pre-operative NIHSS	21.76 ± 8.97	20.78 ± 7.97	21.20 ± 8.38	0.536	0.594
Pre-operative mRS	4.38 ± 0.55	4.35 ± 0.63	4.36 ± 0.59	0.242	0.809
Pre-operative CRS-r	13.70 ± 5.75	14.45 ± 5.84	14.13 ± 5.78	0.591	0.556
Pre-operative mBI	23.38 ± 17.51	30.67 ± 18.52	27.53 ± 18.35	1.852	0.068

DC: decompressive craniectomy

CP: cranioplasty

mBI: modified Barthel Index

mRS: modified Rankin scale

NIHSS: National Institute of Health Stroke scale

CRS-r: coma remission scale-revised

GCS: Glasgow coma scale

PEEK: polyetheretherketone

Table 2 Comparison of complications between the two cohorts

Parameter	Early CP ($n=37$)	Traditional CP ($n=49$)	χ^2	*p*
Intracranial hematoma	2(5.41%)	1(2.04%)	0.842	0.400
Intracranial infection	0	0		
Subcutaneous effusion	2(5.41%)	7(14.29%)	1.332	0.183
Wound infection	2(5.41%)	4(8.16%)	0.497	0.619
Wound dehiscence	0	2(4.08%)	1.243	0.214
Scalp necrosis	0	2(4.08%)	1.243	0.214
Hydrocephalus	2(5.41%)	2(4.08%)	0.289	0.773
Dural tear	2(5.41%)	6(12.24%)	1.081	0.280
Seizure	2(5.41%)	3(6.12%)	0.141	0.888
Overall complications rate	9(24.32%)	14(28.57%)	0.441	0.660

cohort and ten patients had multiple complications in the traditional CP in the traditional CP cohort. Intracranial hematoma (5.41% early CP, 2.04% traditional CP); subcutaneous effusion (5.41% early CP, 14.29% traditional CP); wound infection (5.41% early CP, 8.16% traditional CP); wound dehiscence (0% early CP, 4.08% traditional CP); scalp necrosis (0% early CP, 4.08% traditional CP); hydrocephalus (5.41% early CP, 4.08% traditional CP); dural tear (5.41% early CP, 12.24% traditional CP); seizure (5.41% early CP, 6.12% traditional CP); and overall complication rate (24.32% early CP, 28.57% traditional CP). These differences were not statistically significant ($p>0.05$; Table 2).

Neurological function and consciousness

In the early CP cohort, CRS-r was significantly different between post-operation and pre-operation ($p<0.0001$; Fig. 2 left). In the traditional CP cohort, CRS-r was significantly different between post-operation and pre-operation ($p<0.01$; Fig. 2 left). Between the two cohorts, pre-operative and post-operative CRS-r did not significantly differ ($p>0.05$; Fig. 2 right). In the early CP cohort, NIHSS was significantly different between post-operation and pre-operation ($p<0.0001$; Fig. 3A). In the traditional CP cohort, NIHSS was significantly different between post-operation and pre-operation ($p<0.001$; Fig. 3A). Between the two cohorts, pre-operative NIHSS did not significantly differ ($p>0.05$; Fig. 3B), post-operative NIHSS did significantly differ ($p<0.05$; Fig. 3B), and ΔNIHSS did significantly differ ($p<0.0001$; Fig. 3C). The distribution of ΔNIHSS in the early CP cohort was a median of -8 (25% percentile – 11, 75% percentile – 4), and that in the traditional CP cohort was a median of -2 (25% percentile – 3, 75% percentile – 1).

Ability to perform daily living

In the two cohorts, mRS was significantly different between post-operation and pre-operation ($p<0.0001$; Fig. 4A). Between the two cohorts, pre-operative mRS did not significantly differ ($p>0.05$; Fig. 4B), post-operative mRS did significantly differ ($p<0.05$; Fig. 4B).In the early CP cohort, mRSs were generally less than or equal to 3, and there was a linear relationship and positive correlation between the time span from DC to CP and mRS ($r=0.350$, $p=0.034$; Fig. 4C), while in the traditional CP group, mRSs were mainly greater than or equal to 3, and there was a linear relationship and positive correlation between the time span from DC to CP

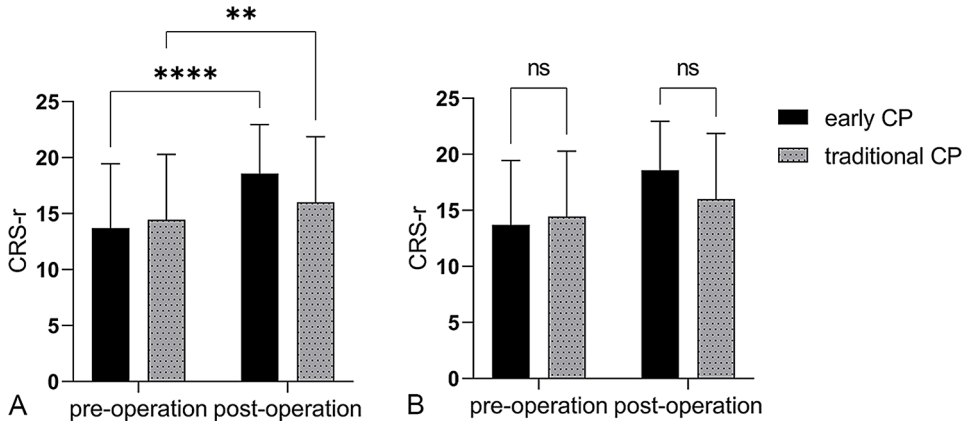

Fig. 2 Comparison of CRS-r in the two cohorts. (left) Comparison of CRS-r between post-operation and pre-operation in the two cohorts. (right) Comparison of post-operative and pre-operative CRS-r between the two cohorts

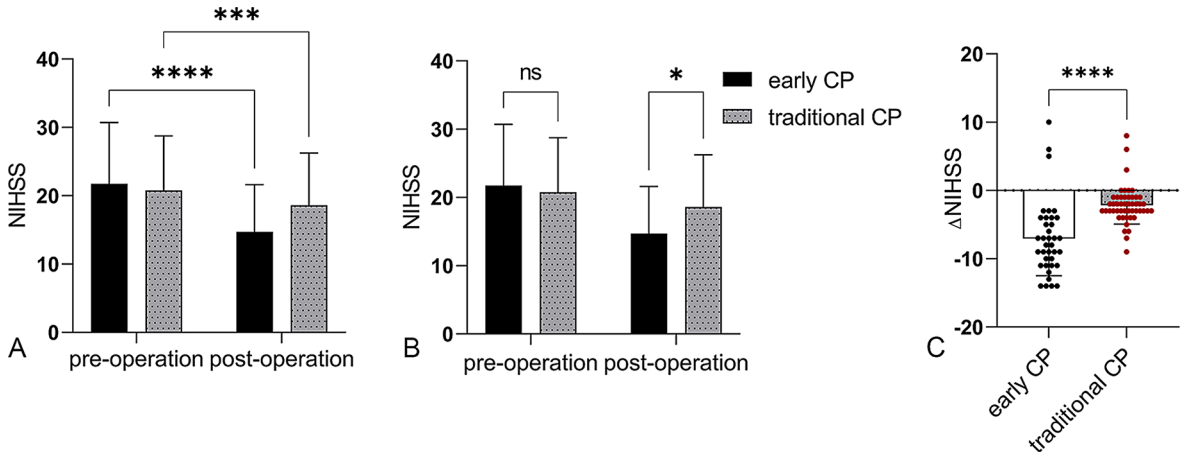

Fig. 3 Comparison of NIHSS and ΔNIHSS in the two cohorts. ΔNIHSS = post-operative NIHSS– pre-operative NIHSS. Dots represent subjects in the study. (**A**) Comparison of NIHSS between post-operation and pre-operation in the two cohorts. (**B**) Comparison of post-operative and pre-operative NIHSS between the two cohorts. (**C**) Comparison of ΔNIHSS between the two cohorts and scatter plot of ΔNIHSS in the two cohorts

and mRS ($r = 0.393$, $p = 0.005$; Fig. 4C).In the two cohorts, mBI was significantly different between post-operation and pre-operation ($p < 0.0001$; Fig. 5A). Between the two cohorts, pre-operative mBI did not significantly differ ($p > 0.05$; Fig. 5B), post-operative mBI did significantly differ ($p < 0.05$; Fig. 5B), and ΔmBI did significantly differ ($p < 0.0001$; Fig. 5C). The distribution of ΔmBI in the early CP cohort was a median of 35 (25% percentile 27.5, 75% percentile 48), and that in the traditional CP cohort was a median of 16 (25% percentile 6.5, 75% percentile 25).

Surgical correlations

ΔNIHSS was calculated as the post-operative NIHSS minus the pre-operative NIHSS and indicated the degree of improvement in neurological function for post-DC MCI patients who had undergone CP. A linear relationship was found between ΔNIHSS and the time span from DC to CP ($r = 0.505$, $p < 0.0001$; Fig. 6A). ΔmBI was calculated as the post-operative mBI minus the pre-operative mBI and indicated the degree of improvement in daily living ability for post-DC MCI patients who had undergone CP. A linear relationship was found between ΔBI and the time span from DC to CP (r = -0.568, $p < 0.0001$; Fig. 6B).

Discussion

DC performed within 96 h of symptom onset in MCI patients is expected to improve survival and the ability to perform daily living activities [10]. However, the functional effects of CP performed after DC in patients with brain injury due to cerebral infarction may differ from those in patients with brain injury due to other causes. In addition, there are few reports on the functional effects of CP in MCI patients. Previous studies have focused on analyzing the outcomes of CP, focusing on the timing of CP, either without specific neurological outcomes or using only crude measures such as the Glasgow Outcome Scale (GOS) [15]. This is the largest series of study detailing functional effects and safety of CP following DC in MCI patients.

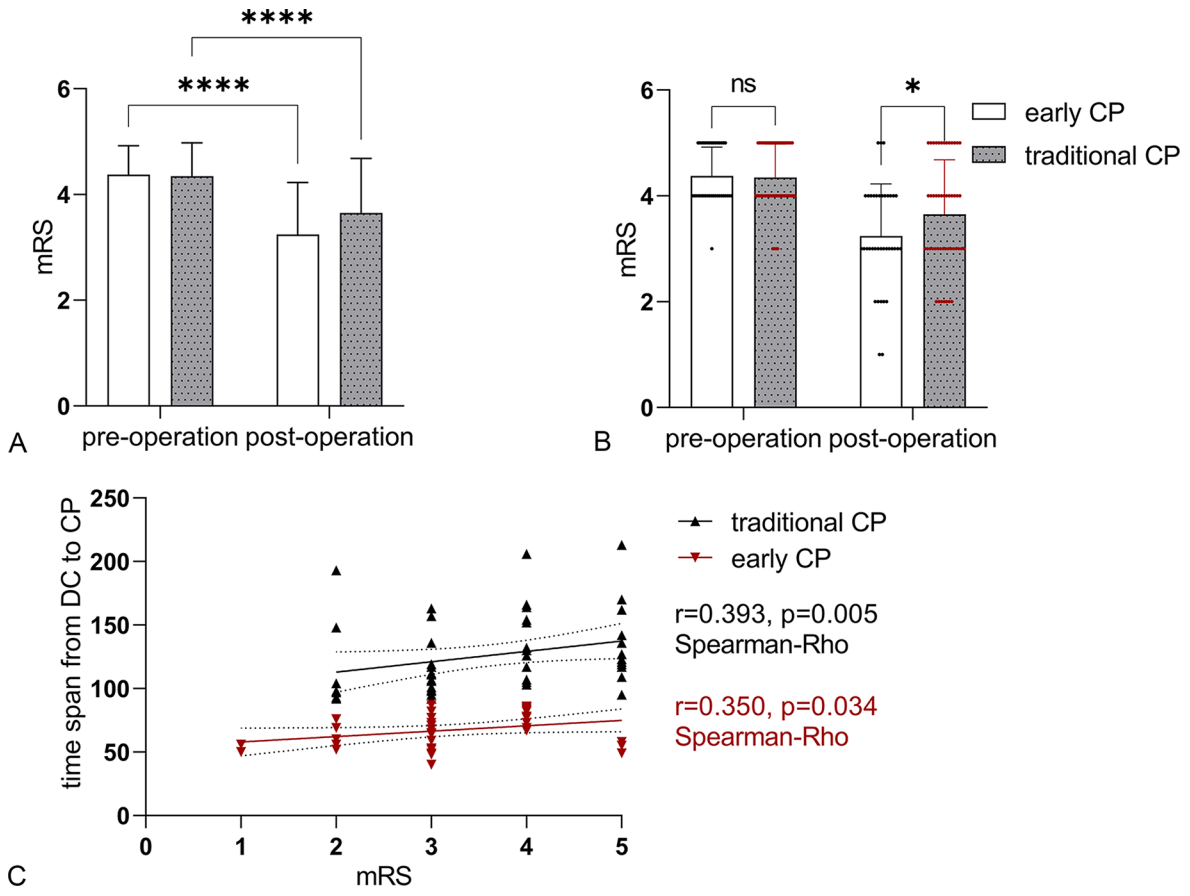

Fig. 4 Comparison of mRS and distribution of the time span from DC to CP on mRS. (**A**) Comparison of mRS between post-operation and pre-operation in the two cohorts. (**B**) Dots represent subjects in the study, Comparison of post-operative and pre-operative mRS between the two cohorts. (**C**) Distribution of the time span from DC to CP on mRS and association of the time span from DC to CP with mRS. ▲ represent subjects of the traditional CP cohort, and ▼ represent subjects of the early CP cohort. Solid lines represent the regression lines generated by combination of subjects in each cohort. Dashed lines represent 95% confidence interval

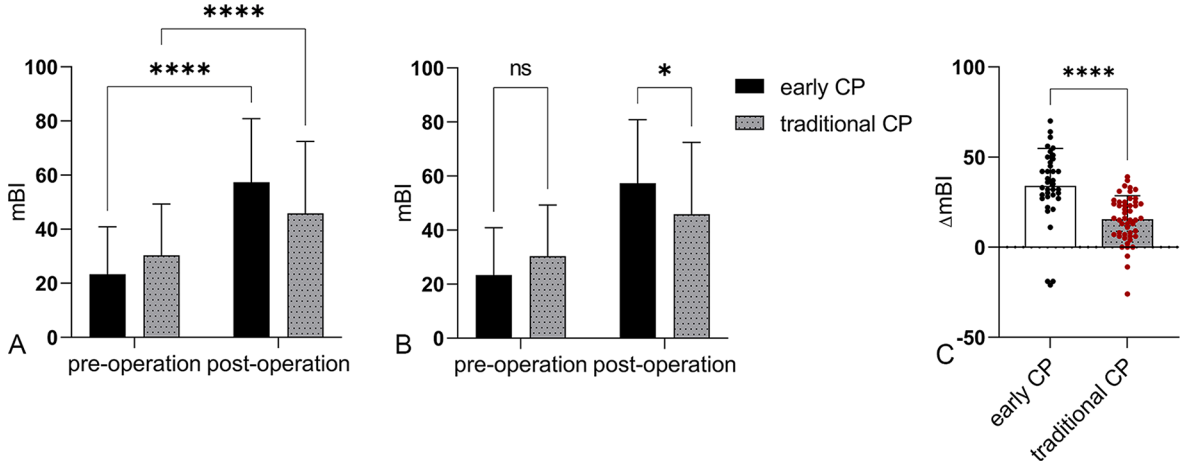

Fig. 5 Comparison of mBI and ΔmBI in the two cohorts. ΔmBI = post-operative mBI– pre-operative mBI. Dots represent subjects in the study. (**A**) Comparison of mBI between post-operation and pre-operation in the two cohorts. (**B**) Comparison of post-operative and pre-operative mRS between the two cohorts. (**C**) Comparison of ΔmBI between the two cohorts and scatter plot of ΔmBI in the two cohorts

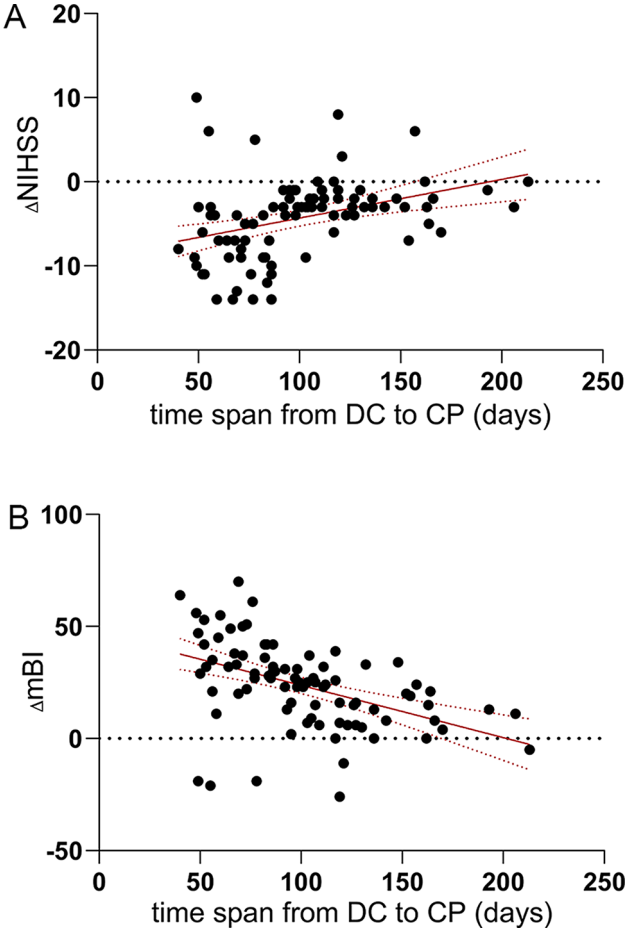

Fig. 6 Scatter plot of surgical correlations. Dots represent subjects in the study. Solid lines represent regression lines generated from all subjects combined. Dashed lines represent 95% confidence interval. (**A**) Association of time span from DC to CP with ΔNIHSS ($r = 0.505$, $p < 0.0001$, Spearman-Rho). (**B**) Association of time span from DC to CP with ΔmBI ($r = -0.568$, $p < 0.0001$, Spearman-Rho)

CP can effectively increase cerebral blood perfusion, correct the metabolic disorders of neuronal cells in the brain, stabilize intracranial pressure, and improve the clinical symptoms of patients; furthermore, CP can accelerate the recovery of brain function and effectively protect the brain tissue of patients. Currently, there are numerous conflicting reports on the timing of CP, with most suggesting that CP is more appropriate for 3 months to more than 6 months after DC, as it can not only reduce the rate of surgical complications, but also enable patients to have a relatively long recovery period. A major complication of DC is the formation of multiple adhesions between the dura mater, temporalis muscle, and dermal flap, which can lead to intraoperative mishaps such as prolonged operative time, excessive blood loss, and unintentional injury to the dura mater and dermis as a result of the technical difficulties encountered during tissue stripping. In this study, operative time was significantly shorter in the early CP cohort than that in the traditional CP cohort, and intraoperative blood loss was significantly less than that in the traditional CP cohort. Previous studies have reported epidural fibrosis formation for at least 4 weeks after laminectomy in rabbits [16]. Although we did not find any published related evidence of epidural fibrosis formation after brain surgery, we demonstrated that epidural fibrosis does not form in large numbers at least 1 month after surgery. Instead, these findings provide a rationale for early cranioplasty, which allows easy anatomical separation of the dura during surgery. Long-term skull defects can lead to skin contracture in the defect area and tight adhesion of subcutaneous tissue to the dura mater, which leads to dura mater rupture during intraoperative separation, increasing the chance of intracranial infection and prolonging the surgical time; additionally, relatively small flaps can be used after large arc cranial reconstruction and shaping, with high skin tension and difficulty in incisional sutures, leading to poor local skin blood supply and resulting in skin ischemia and necrosis. Because the subcutaneous tissue is not very tightly adhered to the dura mater, early cranioplasty is conducive to shortening the operation time, reducing intraoperative bleeding, preventing dura mater damage during peeling, and reducing the chance of intracranial infection formation.

This retrospective study revealed no statistically significant difference in overall complication rates between the early CP cohort and the traditional CP cohort. Among the common complications of cranioplasty, the most serious is infection, especially intracranial infection. Early cranioplasty was associated with a higher rate of infection than late cranioplasty, regardless of the implant material, although these differences were not statistically significant, which was consistent with our findings [12]. In our study, we found no significant difference in infection rates between the two cohorts, despite the high incidence of dural tears in the traditional CP cohort, and no patients with intracranial infections were identified. This result suggested that early CP, performed within 3 months after DC, is a safe surgical intervention, but this option should be chosen with caution in high-risk patients. Furthermore, the time span from DC to CP may not be associated with the risk of infection. Waziri et al. suggested that the risk for hydrocephalus was increased by traditional CP in patients who had undergone DC for stroke [17]. Piedra et al. demonstrated that there was no statistical difference in the rate of hydrocephalus between early CP and traditional CP in 2 separate studies [18, 19]. Our study concurs with these studies and find that the rate of hydrocephalus was low and did not differ significantly between the two cohorts. Only 2 patients developed subcutaneous effusions (5.41%) in the early CP cohort, whereas in the traditional cohort,

follow-up head CT scans revealed subdural effusions in 7 patients (14.29%). There are several possible explanations for this phenomenon. First, atmospheric pressure may have a more deleterious effect on brain tissue when CP is delayed. Second, when early CP is performed, there is less potential dead zone between the CP material and the brain tissue.

CP reduces the risk of additional brain tissue damage when patients undergo rehabilitation without a bone flap. Rehabilitation therapists may also be overly cautious in recovering patients without a bone flap. In this study, we found that CP could improve the consciousness of post-DC MCI patients, which was consistent with the findings of previous studies [20]. Although there was no significant difference in post-operative consciousness between the early CP cohort and the traditional CP cohort, early CP improved patients' consciousness earlier and was able to accelerate the recovery of neurological function and daily living ability in post-DC MCI patients.

The results of this study showed that post-operative NIHSS was significantly lower than pre-operative NIHSS, and between the two cohorts, post-operative NIHSS and ΔNIHSS in the early CP cohort were significantly lower than those in the traditional CP cohort, suggesting that an improvement in neurological function following CP and these improvements may be enhanced by an early CP [14]. Early CP can effectively improve cerebral blood flow regulation and cerebrospinal fluid dynamics and reduce damage to brain tissues due to the short time span from DC to CP. In contrast, traditional CP can lead to many complications, such as subdural effusion, lateral ventricle displacement, and softening of brain tissue in the bone flap area due to prolonged cranial defects, causing severe negative effects on the metabolism of brain tissue; moreover, with prolongation of the time span from DC to CP, oxidative stress, apoptosis, and cerebral edema will occur, causing damage to neuronal cells and further aggravating neurological function [21, 22]. We found that there was a linear relationship between ΔNIHSS and the time span from DC to CP ($r = 0.505$, $p < 0.0001$), which meant that the longer the time span from DC to CP was, the worse the improvement in neurological function was. Early CP has obvious advantages over traditional CP for improving neurological function, improving cognitive function, and improving quality of life. The golden period for neurological function recovery occurs within 3 months after DC [23]. Early CP can restore the normal anatomical structure of the cranium and brain, isolate the effect of atmospheric pressure on brain tissues, and improve the dynamics of the cerebrospinal fluid, thus promoting the recovery of neurological function [24].

This study revealed that, in the two cohorts, mRS and mBI were significantly different between post-operation and pre-operation, and between the two cohorts, ΔmBI and post-operative mRS and mBI were significantly different. It can be seen that CP is associate with direct improvements in ADL (mBI, mRS), i.e. the immediate post-operative surgical scores increase significantly [25], and early CP enhances the improvement in ADL. There was a linear relationship between ΔBI and the time span from DC to CP (r = -0.568, $p < 0.0001$), which meant that the longer the time span from DC to CP was, the worse the improvement in ADL was. Skull defects have adverse effects on the regulation of intracranial pressure, and CP is thought to eliminate these adverse effects. Impaired intracranial pressure regulation has adverse effects on functional improvement during convalescent rehabilitation in MCI patients and impedes functional improvement before CP. Therefore, CP can have favorable effects on post-operative ADL and promote the recovery of daily living ability.

Conclusions

In summary, our study demonstrated that, first, CP has a favorable effect on improving neurological function, ability to perform daily living, and consciousness in post-DC MCI patients; second, early CP does not alter the overall complication rate and is as safe as traditional CP; third, compared to traditional CP, early CP reduces operative time and intraoperative blood loss, promotes improvements in neurological function and ability to perform daily living, and enhances these improvements.

Abbreviations

MCI	Malignant cerebral infarction
DC	Decompressive craniectomy
CP	Cranioplasty
mBI	modified Barthel Index
mRS	modified Rankin scale
ADL	Activities of daily living
NIHSS	National Institute of Health Stroke scale
CRS-r	Coma remission scale-revised
GCS	Glasgow coma scale
GOS	Glasgow Outcome Scale
PEEK	Polyetheretherketone
CT	Computed tomography

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Author contributions

Guarantor of integrity of entire study: HC and ZNY. Study concept/study design: ZNY and HC. Data acquisition: all authors. Data extraction and analysis: ZX and ZY. Manuscript drafting: ZY. Manuscript revision for important intellectual content: all authors. Approval of final version of submitted manuscript: all authors. Statistical analysis: MW and LW. Manuscript editing: all authors. ZY is first authorship. ZNY is corresponding author.HC and ZNY contribute equally.

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Data availability

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study protocol was approved by the Ethics Board of Xi'an Gaoxin Hospital, the Ethics Board of the First Affiliated Hospital of Xi'an Medical University, and the Ethics Board of Xi'an Medical University. This study was retrospective and did not involve direct contact with participants; therefore, the individual consent of participants was not required for the duration of our study.

Consent for publication
Not applicable.

Disclosures
The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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No portion of the paper was presented and published.

Competing interests
The authors declare no competing interests.

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