Brain Impairment (2023), **24**, 721–731
doi:10.1017/BrImp.2023.2

CAMBRIDGE UNIVERSITY PRESS

ORIGINAL ARTICLE

Functional improvements associated with cranioplasty after stroke and traumatic brain injury: a cohort study

F. Coelho[1], G.S. Noleto[1]*, D.J.F. Solla[1], P.N. Martins[2], A.F. Andrade[1], M.J. Teixeira[1], W.S. Paiva[1] and R. Anghinah[1]

[1]Department of Neurology, University of São Paulo Medical School, São Paulo, Brazil and [2]Faculty of Medicine, Juiz de Fora Medical School, Juiz DE Fora, Brazil
*Corresponding author. Email: gustavosnoleto@yahoo.com.br

(Received 24 October 2021; revised 23 December 2022; accepted 16 January 2023)

Abstract

Objective: Decompressive craniectomy is part of the acute management of several neurosurgical illnesses, and is commonly followed by cranioplasty. Data are still scarce on the functional and cognitive outcomes following cranioplasty. We aim to evaluate these outcomes in patients who underwent cranioplasty following traumatic brain injury (TBI) or stroke.

Methods: In this prospective cohort, we assessed 1-month and 6-month neuropsychological and functional outcomes in TBI and stroke patients who underwent cranioplasty at a Brazilian tertiary center. The primary outcome was the change in the Digits Test at 1 and 6 months after cranioplasty. Repeated measures general linear models were employed to assess the patients' evolution and interactions with baseline characteristics. Effect size was estimated by the partial η^2.

Results: A total of 20 TBI and 14 stroke patients were included (mean age 42 ± 14 years; 52.9% male; average schooling 9.5 ± 3.8 years; 91.2% right-handed). We found significant improvements in the Digits Tests up to 6 months after cranioplasty ($p = 0.004$, partial $\eta^2 = 0.183$), as well as in attention, episodic memory, verbal fluency, working memory, inhibitory control, visuoconstructive and visuospatial abilities (partial η^2 0.106–0.305). We found no interaction between the cranioplasty effect and age, sex or schooling. Patients submitted to cranioplasty earlier (<1 year) after injury had better outcomes.

Conclusion: Cognitive and functional outcomes improved after cranioplasty following decompressive craniectomy for stroke or TBI. This effect was consistent regardless of age, sex, or education level and persisted after 6 months. Some degree of spontaneous improvement might have contributed to the results.

Keywords: Decompressive craniectomy; cognition; brain injuries; traumatic; cerebrovascular disease; stroke; neuropsychological tests

Introduction

The oldest document in the History of Neuropsychology was not written, but an archaeological record. Since antiquity, man has sought to understand the relationships between the brain, behavior and cognition, and craniotomy emerged as an instrumental procedure for comprehending the anatomical features of our brain. Today, decompressive craniectomy (DC) is used as a treatment for refractory intracranial hypertension that involves extracting part of the skull to release the swelling and relief intracranial hypertension. Harvey Cushing was the first to describe the procedure. This technique and its variants have been used for decades for treating stroke, traumatic brain injury (TBI) and other distinct pathologies (Cushing, 1905).

Despite the decrease in mortality associated with this surgical technique, morbidity is still high among patients undergoing DC (Amorim et al., 2012; Cushing, 1905; Kjellberg & Prieto, 1971;

Kondziolka & Fazl, 1988). Many patients have early and late problems, namely hernia on the edge of the craniectomy (51%), resulting in brain damage (6 to 58%) (Honeybul, 2010), subdural hygroma (16 to 62%), (Honeybul, 2010; Jiang et al., 2005; Stiver, 2009) Hydrocephalus (2 to 29%), (Chibbaro & Tacconi, 2007; Flint et al., 2008) motor impairment (Chibbaro & Tacconi, 2007; Flint et al., 2008; Yang et al., 2003) infections (Yang et al., 2003), and sinking skin flap syndrome (26%) (Ashayeri et al., 2016; Stiver, 2009).

Patients with major cranial defects ($>100\ cm^2$) are particularly at risk for sinking skin flap syndrome, characterized by headaches, dizziness, changes in mood and behavior, seizures, fatigue, motor deficits, and language problems (2008b; Grant & Norcross, 1939, Stiver et al., 2008a; Yamaura & Makino, 1977).

Little is known about the pathophysiological mechanisms of this syndrome. Some authors believe in the hypotheses of abnormal cerebral pulsatility (Grantham & Landis, 1948), atmospheric pressure effect through the bone defect (Farrington, 1945; Stula, 1985; Tabaddor & LaMorgese, 1976; Yamaura & Makino, 1977), changes in the cerebrospinal fluid dynamics and venous drainage (Fodstad et al., 1984; Langfitt, 1969; Royall et al., 1992; Segal et al., 1994), as well as changes in blood flow and brain metabolism (Erdogan, 2003; Isago et al., 2004; Kemmling et al., 2010; Kuo et al., 2004; Maeshima et al., 2005; Richaud et al., 1985; Sakamoto et al., 2006; Stiver et al., 2008b; Suzuki et al., 1993; Winkler et al., 2000; Yoshida et al., 1996).

Cranioplasty is a secondary procedure after DC to restore cranial bone morphology, traditionally recommended for esthetic purposes and brain protection. Of note, some published case reports and clinical series have suggested functional improvements in neurological deficits, cognition and cerebral hemodynamics after cranioplasty (Chieregato, 2006; Lezak, 1995; Nakamura et al., 1980; Ng & Dan, 1997; PV, 2015; Schiffer et al., 1997; Sujit Kumar et al., 2004). However, little is known about these potential neuropsychological changes after cranioplasty. This study aims to assess patients' changes in cognition following cranioplasty after DC.

Material and methods

Study design and settings

A cohort study was conducted from February 2015 to July 2017 in a single tertiary academic center with three repetitive assessments: the first up to 30 days before cranioplasty and then after one and six months following cranioplasty.

Clinical and surgical management were performed at the discretion of the attending teams according to national and local guidelines. The cranioplasty was performed as in routine practice, with autologous bone as the first choice or methyl methacrylate polymer. Patients underwent general anesthesia, lying supine and with cephalic lateralization contralateral to the craniectomy.

After trichotomy and rigorous asepsis with chlorhexidine, the existing incision was reopened with careful separation of the cutaneous flap from the dura mater. The temporal muscle was also isolated and separated from the dura mater whenever possible. Autologous bone was replaced with a nylon 2.0 fixation when possible. When not possible, we used methyl methacrylate prostheses molded during the procedure. In all cases, we made 4 to 8 fixations from the dura mater to the bone or prosthesis with using Prolene to reduce dead space and bring the dura mater as close as possible to its original position. A drain under the galea was routinely placed and maintained with a vacuum for 24 h. Patients were discharged around the fifth postoperative day and the stitches were removed around the fourteenth postoperative day.

This study was approved by the local institutional ethics committee (Comissão de Ética Para Análise de Projetos de Pesquisa do HCFMUSP number 13023, protocol 00119/10).

https://doi.org/10.1017/BrImp.2023.2 Published online by Cambridge University Press

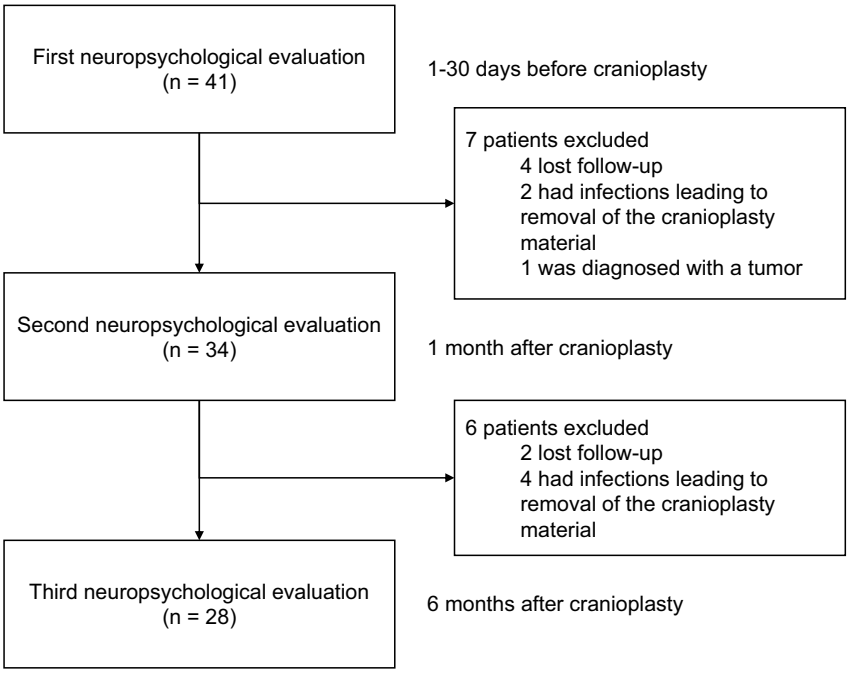

Figure 1. Fluxogram of patients evaluation.

Participants

Patients were eligible if previously submitted to DC due to malignant ischemic stroke or TBI with cerebral edema causing deviation of the midline structures >5 mm and aged between 17 and 65 years old. Exclusion criteria were less than 3 years of schooling and inability to understand and follow the instructions during the evaluations.

Patients were consecutively enrolled and assessed for eligibility criteria at the neurorehabilitation outpatient clinic. They were followed up for 6 months after the recruitment. There was no control group.

Variables and data sources/measurement

An experienced neuropsychologist (FC) performed the neuropsychological assessments (Fig. 1). Instruments used were: Colorful Trail Test I and II (Trial Making Test standardized version for the Brazilian population), Digit Tests, Logical Memory Tests, Visual Reproduction (all them Subtests of Wechsler Memory Scale), 'Rey Auditory Verbal Learning Test' (RAVLT), Phonemic and Semantic Verbal Fluence Test, Arithmetics, Numbers Sequences Test, Letters Sequences Test (all subtests of WAIS-III), Stroop Test (Victoria version), Cubes Test (subtest of WAIS-III) and Rey Complex Figure Copying. For depression and anxiety symptoms, we used the Beck Depression and Anxiety Inventories (BDI and BAI, respectively). In addition, the Pfeffer questionnaire (Functional Activities Questionnaire – FAQ) was used to verify the ability to perform activities of daily living.

The primary outcome was the change from baseline in the Digits Tests after 1 and 6 months.

Secondary outcomes included the Logical Memory Tests, Visual Reproduction, RAVLT, each subtest of WAIS-III (Arithmetic, Numbers Sequences, Letter Sequences), Rey Complex Figure Copying, BDI, BAI and FAQ.

https://doi.org/10.1017/BrImp.2023.2 Published online by Cambridge University Press

Table 1. Baseline data

Baseline	Total ($n = 34$)	TBI ($n = 20$)	Cerebrovascular disease ($n = 14$)
Age, mean ± SD	42.0 ± 14.2	40.0 ± 14.5	44.7 ± 13.7
Male	18 (52.9%)	12 (60.0%)	6 (43.9%)
Schooling years, mean ± SD	9.5 ± 3.8	9.2 ± 3.8	9.7 ± 4.1
Right manual dexterity	31 (91.2%)	20 (100%)	11 (78.6%)
Months from craniectomy to cranioplasty, median (IQR)	22.5 [7.0–45.0]	29.0 [11.5–51.5]	14.5 [7.0–36.0]
Type of injury			
Diffuse injury		13 (65.0%)	
Acute Subdural Hematoma		5 (25.0%)	–
Epidural Hematoma		2 (10.0%)	–
Subarachnoid Hemorrhage		–	6 (42.8%)
Stroke		–	6 (42.8%)
Intracerebral Hemorrhage		–	2 (14.3%)

IQR, Interquartile range; SD, standard deviation; TBI, traumatic brain injury.

Study size

The obtained convenience sample for the study (one group, three repeated measures) was satisfactory for the detection of an effect size f equal to 0.25 or higher with 0.8 power and alpha 0.05.

Statistical methods

For descriptive purposes, categorical variables were presented through relative and absolute frequencies. Continuous variables were normally distributed and were presented as mean and standard deviations.

Repeated measures general linear models were employed to assess the patients' evolution and interactions with baseline characteristics when appropriate. When the sphericity assumption was not met, the Greenhouse-Geisser or Huynh-Feldt correction was applied, as indicated. Effect size was estimated by the partial η^2.

All tests were two-sided and final p values under 0.05 were considered statistically significant. All analyses were conducted with the software SPSS (IBM Corp. SPSS Statistics para Windows, version 24.0. Armonk, NY).

Results

Participants

A total of 41 patients were initially included in the study, of which 13 were excluded (6 lost follow-up, 6 had infections leading to the removal of the cranioplasty material and one was diagnosed with a tumor) (Fig. 1). The 34 patients who attended the second evaluation were included in the analysis. Demographic and clinical data are described in Table 1.

Twenty out of 34 participants sustained a TBI (58,8%), of which 12 were male (60%). Mean age was 40.0 ± 14.5 years old (range 17–64), average schooling time 9.2 ± 3.8 years (range 4–18 years)

https://doi.org/10.1017/BrImp.2023.2 Published online by Cambridge University Press

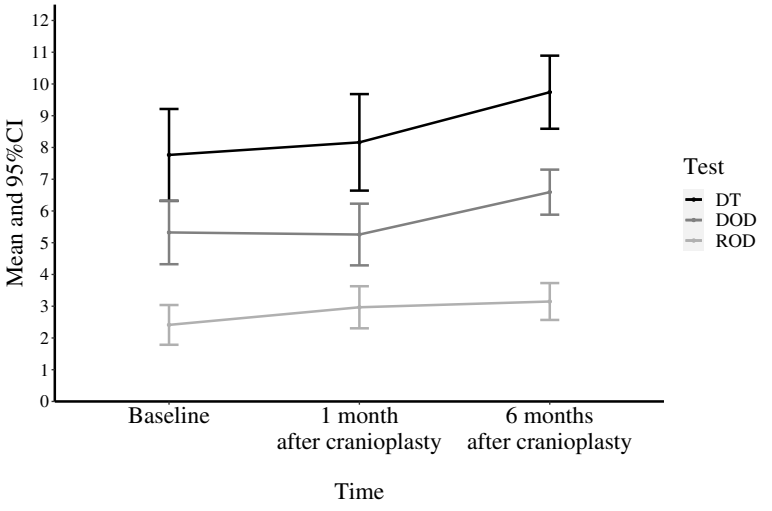

Figure 2. Digit Tests performance over time.

and the median time from injury was 22.5 months (range 2–240 months). Diffuse injury was DC's most common underlying indication (Table 1). Participants submitted to DC with cerebrovascular diseases were 14 out of 34 patients (41.2%). In this group, 8 were female (57.1%), the mean age was 44.7 ± 13.7 years old (range 27–65), average schooling was 9.7 ± 4.1 years (range 3–16) and the average time to cranioplasty was 28.6 months. Spontaneous aneurysmal subarachnoid hemorrhage and stroke comprised 6 patients (42.8%) each one, whilst intraparenchymal spontaneous hemorrhage comprised 2 (14.3%) out of 14 patients (Table 1).

There were significant cognitive improvements on hearing-verbal attention, episodic memory, verbal fluency, constructive visual and visuospatial function ($p < 0.05$). Digit tests (total, direct order and reverse order) significantly improved after 1 and 6 months following cranioplasty (Table 2, Fig. 2).

There were interactions between DT evolution and etiology ($p = 0.010$) (Fig. 3), ROD evolution and etiology ($p = 0.004$) (Fig. 3), and A1-A5 evolution and etiology ($p = 0.037$). Time since diagnosis had interactions with DT ($p = 0.018$) (Fig. 4), DOD ($p = 0.035$), and A4, A5, and A7 ($p =$ 0,022; 0,040 and 0,041, respectively).

Memory process evaluations through Logical Memory Tests ($p = 0.002$ and $p < 0.001$), Visual Reproduction ($p = 0.022$ and $p = 0.025$), (Table 2, Figure S1) and most of the parameters of 'Rey Auditory Verbal Learning Test' (RAVLT) had a significant improvement (Table 2, Figure S2). Language functions also showed significant differences on Phonemic Verbal Fluence Test ($p = 0.01$) and Semantic Verbal Fluence Test ($p = 0.002$) (Table 2, Figure S3).

Analysis of executive functions (EF) showed significant pre- to postoperative differences on Arithmetic ($p = 0.0050$) and Vitoria Stroop Tests – mean of errors on board III ($p = 0.022$) (WAIS-III Wechsler) used as measures of working memory and inhibitory control respectively. However, the Sequence of Numbers and Letters Test (cognitive flexibility) did not show any significant change ($p = 0.561$) (Table 2). Cubes Test (subtest of WAIS-III) and Rey Complex Figure copying showed significant differences ($p = 0.02$ and 0.04 respectively) (Table 2, Figure S4).

Neither the Pfeffer questionnaire nor the scores expressed through the BDI and BAI showed significant differences over time, and there were no interactions observed between their evolution and age, sex, or education level.

https://doi.org/10.1017/BrImp.2023.2 Published online by Cambridge University Press

Table 2. Primary and secondary outcome measures ($n = 34$)

Test	Before CP	Post-cranioplasty		Partial η^2	p value
		1 month	6 months		
Attention tests					
Total Digits, mean ± SD	7.8 ± 4.1	8.2 ± 4.4	9.7 ± 3.3	0.183	0.004
Direct Order Digits, mean ± SD	5.3 ± 2.9	5.2 ± 2.8	6.6 ± 2.0	0.180	0.005
Reverse Order Digits, mean ± SD	2.4 ± 1.8	3.0 ± 1.9	3.1 ± 1.7	0.108	0.023
Memory tests					
LM I, mean ± SD	11.9 ± 9.2	15.5 ± 8.5	16.8 ± 8.3	0.191	0.002
LM II, mean ± SD	8.7 ± 7.9	12.6 ± 8.1	13.0 ± 7.1	0.217	<0.001
VM I, mean ± SD	22.1 ± 9.8	25.0 ± 9.8	25.7 ± 7.0	0.116	0.022
VM II, mean ± SD	12.8 ± 10.4	16.6 ± 10.0	16.2 ± 8.7	0.106	0.025
RAVLT Results					
A1, mean ± SD	2.9 ± 1.8	3.2 ± 2.1	4.3 ± 2.1	0.242	0.001
A2, mean ± SD	3.7 ± 2.5	4.9 ± 2.6	5.6 ± 2.4	0.275	<0.001
A3, mean ± SD	4.9 ± 3.0	5.5 ± 3.0	5.8 ± 2.5	0.051	0.180
A4, mean ± SD	5.1 ± 3.1	6.0 ± 3.1	6.7 ± 2.6	0.148	0.007
A5, mean ± SD	5.1 ± 3.4	5.9 ± 3.3	7.1 ± 2.5	0.200	0.001
A1 to A5, mean ± SD	21.8 ± 12.4	22.6 ± 15.9	24.1 ± 16.0	0.217	0.576
A7, mean ± SD	2.9 ± 2.7	4.0 ± 3.4	5.1 ± 3.2	0.305	<0.001
Rec., mean ± SD	13.1 ± 16.2	7.9 ± 4.8	8.8 ± 3.4	0.091	0.073
PVF and SVF tests					
PVF (initial F.A.S), mean ± SD	14.8 ± 11.3	15.1 ± 9.9	18.3 ± 7.1	0.131	0.010
SVF (animals), mean ± SD	9.5 ± 5.8	9.0 ± 4.1	11.6 ± 3.6	0.178	0.002
Arithmetic, mean ± SD	6.3 ± 3.2	7.0 ± 2.6	7.8 ± 2.7	0.162	0.005
SNL, mean ± SD	3.7 ± 63.1	3.6 ± 2.9	4.0 ± 2.6	0.017	0.561
VST					
VST-Board I, mean ± SD	25.53 ± 28.43	23.75 ± 19.41	32.58 ± 39.34	0.031	0.33
VST (Error I), mean ± SD	0.79 ± 1.88	0.30 ± 0.65	0.62 ± 1.07	0.042	0.24
VST-Board II, mean ± SD	30.62 ± 27.68	27.93 ± 23.74	28.47 ± 15.62	0.008	0.72
VST-(Error II), mean ± SD	0.68 ± 1.36	0.67 ± 1.19	0.55 ± 1.02	0.006	0.82
VST-Board III, mean ± SD	43.14 ± 34.0	40.33 ± 34.59	46.99 ± 21.99	0.015	0.60
VST-(Error III), mean ± SD	4.23 ± 6.26	2.00 ± 3.95	3.63 ± 5.18	0.110	0.02
Visuoconstructive					
Cubes, mean ± SD	14.6 ± 9.9	16.2 ± 10.3	18.3 ± 9.6	0.112	0.02
RCF, mean ± SD	19.8 ± 11.3	21.3 ± 11.0	25.0 ± 8.9	0.157	0.004

SD: Standard deviation.
LM I. LMII: Logical Memory Tests I and II.
VM I; VM II: Visual Reproduction Tests I and II.
RAVLT: Rey Auditory Verbal Learning Test.
A1: application 1; A2: application 2; A3: application 3; A4: application 4; A5: application 5.
(A1-A5) – Sum of points from applications A1 to A5.
A7 – Late recall; Rec.: memory by recognition.
PVF: phonemic verbal fluency test (initial F.A.S.); SVF – semantic verbal fluency test (animal category).
SNL – Sequence of numbers and letters.
VST – Stroop Test version Victoria.

https://doi.org/10.1017/BrImp.2023.2 Published online by Cambridge University Press

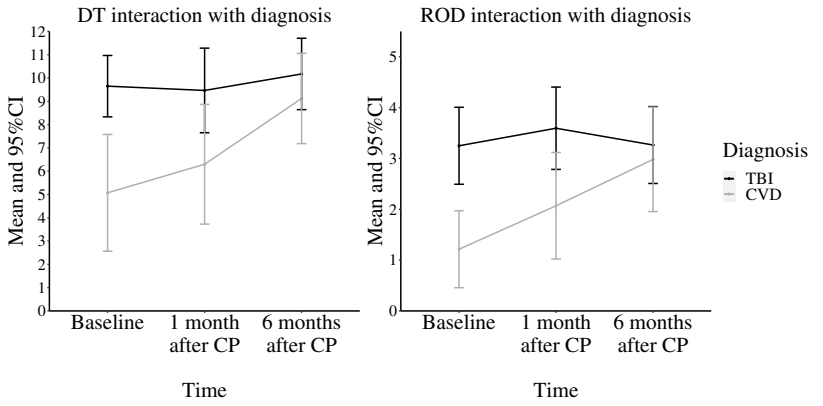

Figure 3. Digit Test (direct and reverse order) behavior according to etiology.

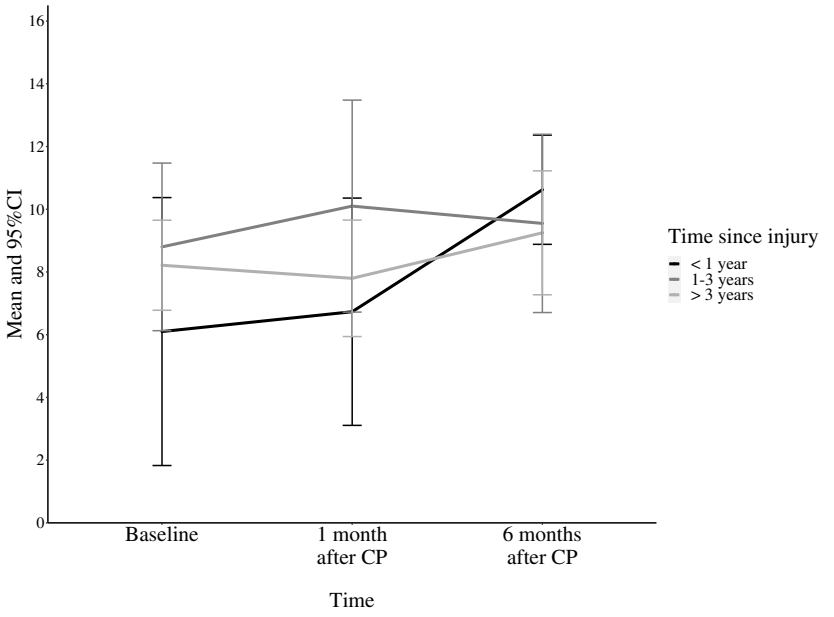

Figure 4. Digit Test (direct and reverse order) behavior according to time from diagnosis.

Discussion

We observed significant improvements in multiple cognitive domains after cranioplasty regardless of age, sex, or education level.

Memory evaluation consists of different components mediated by different neural circuits. These components are mediated by modules of the nervous system that act independent or cooperatively. This system includes long-term memory divided into explicit and implicit (dual system), which proved to be useful to understand functions and deficits in individuals with brain dysfunctions. Declarative or explicit memory refers to the capacity of storage and conscientious evocation of previous experiences and has a functional and anatomical difference from implicit memory. Declarative memory system involves two subsystems: episodic memory (autobiography) and semantic memory.

https://doi.org/10.1017/BrImp.2023.2 Published online by Cambridge University Press

In a comparative analysis of the measures (mean by points of execution) obtained before and after surgery (1 month and 6 months), a significant improvement was observed in the measures A1 (short-term memory) and A7 (spontaneous evocation). The RAVLT test involves descriptive analysis of short-term tasks retention (measure A1), of the learning tests (the acquisition was characterized by the addition of the number of words learned over five tests A1 to A5), spontaneous evocation (measure A7, retention after 20 min) and recognition (measures recognition by memory).

Language processes involve phonological, morphological, syntactic and semantic aspects that allow balance in form, content and use, giving functionality to the language. We used the phonemic verbal fluency test (PVF) and semantic verbal fluency test (SVF, animal category) as our outcome measures for language skills. Pre- and postoperative verbal fluency expected averages (execution points) were compared, and both improved significantly. These results go in line with the previous literature (Coelho et al., 2014; Corallo et al., 2020; Corallo et al., 2017; Di Stefano et al., 2016; Jelcic et al., 2013; Kim et al., 2017) regarding significant improvements in language functionality post-cranioplasty after TBI.

Despite the critical variability in terms of injury time (between DC and cranioplasty) in our series, it did not interact with language recovery, as seen in other studies (Coelho et al., 2014; Jelcic et al., 2013).

Among the cognitive functions investigated in a neuropsychological assessment, EF constitute the least consensual operational definitions in the literature (Jelcic et al., 2013). It is known that, like other psychological procedures, EF are not one-dimensional constructions, being related to different areas in the frontal lobe and functionally connected to other brain regions (Julio-Costa et al., 2018; Malloy-Diniz et al., 2018). Despite the multifactorial nature of EF, which is not fully theorized, there is a relative consensus on the existence of three essential components: inhibition, working memory and cognitive flexibility (Coelho et al., 2014). The scope of this work was restricted to analyzing only these three elements, for pedagogical and objective reasons. Our data showed significant differences ($p < 0.05$) on working memory and inhibitory control, but not in terms of cognitive flexibility, considering pre- to postoperative comparisons.

Visuospatial and constructive visual capabilities were evaluated using the Cubes Test (a subtest of WAIS-III) and Rey Complex Figure Copying (RFC), and both improved over time after cranioplasty. Based on these results, both constructive visual activities presented improvements after the bone reconstruction procedure. This significant improvement in visuoconstructive skills evidenced by the RFC test is in accordance with previous findings (Jelcic et al., 2013; Ng & Dan, 1997; Nitrini et al., 2005).

Brain injuries can be responsible for the inability to perform simple or complex activities, when the compromised region is involved with several functions (Nitrini et al., 2005). This functional loss can be assessed with the FAQ and the Pfeffer Questionnaire. Neither showed significant differences in our study.

Some limitations of our study should be noted. The main limitation is the absence of a control group without DC, which would exceed our scope. We cannot exclude the possibility that the observed improvements are partially spontaneous, constituting a part of the natural history of disease rather than an effect of DC. Indeed, we found a significant interaction between the cranioplasty effect and time since DC. Patients with <1 year from the lesion, a period with higher neuroplasticity, showed higher improvements in the primary outcome. Nevertheless, since not all outcomes were affected by time since DC, we believe the cranioplasty has a true effect over cognitive prognosis, although its effect size might have been overestimated in this study due to some spontaneous improvement. The observation that some patients improve even after the first year after injury reinforces our conclusion.

Also, the absence of blinding for the sequential assessments after cranioplasty might have introduced some bias from the evaluator. Third, as factors such as etiology and time to cranioplasty were correlated, we cannot be sure whether interactions owe to the time from craniectomy to

https://doi.org/10.1017/BrImp.2023.2 Published online by Cambridge University Press

cranioplasty or the etiologies themselves. Lastly, being a unicentric study restricted to a convenience sample from the Brazilian public health service, our results might not be fully generalizable to other populations. Finally, one should consider the pathophysiological differences and the heterogeneity of the participants' underlying brain pathologies.

In conclusion, patients who undergo cranioplasty following stroke or TBI seem to have an improved prognosis on auditory verbal attention, episodic memory, verbal fluency, working memory, inhibitory control, visuoconstructive and visuospatial functions. Of note, this effect was consistent regardless of age, sex, or education level and persisted after 6 months. Some degree of spontaneous improvement might have contributed to the results. Patients submitted to cranioplasty earlier after injury presented greater improvements in the primary outcome.

Supplementary materials. For supplementary material for this article, please visit https://doi.org/10.1017/BrImp.2023.2

Acknowledgements. This research was partially funded by the National Council for Scientific and Technological Development (CNPq), Brazil.

Authors Contributions. FC, GS, DJFS, WSP, AFA, MJT and RA contributed to the study design and data collection.
DJFS and PNM performed the statistical analysis.
All authors participated in the writing and revised the final manuscript.

Financial Support. This research was partially funded by the National Council for Scientific and Technological Development (CNPq), Brazil.

Competing interests. Authors have no conflicts of interest to disclose.

Ethical Standard. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

References

Amorim, R. L., Bor-Seng-Shu, E., Gattás, G., Paiva, W., de Andrade, A. F., & Teixeira, M. J. (2012). Decompressive craniectomy and cerebral blood flow regulation in head injured patients: a case studied by perfusion CT. *Journal of Neuroradiology*, *39*(5), 346–349. doi: 10.1016/j.neurad.2012.02.006

Ashayeri, K., M.J., E., Huang, J., Brem, H., & Gordon, C. R. (2016). Syndrome of the trephined: a systematic review. *Neurosurgery*, *79*(4), 525–534. doi: 10.1227/neu.0000000000001366

Chibbaro, S., & Tacconi, L. (2007). Role of decompressive craniectomy in the management of severe head injury with refractory cerebral edema and intractable intracranial pressure. Our experience with 48 cases. *Surgical Neurology*, *68*(6), 632–638. doi: 10.1016/j.surneu.2006.12.046

Chieregato, A. (2006). The syndrome of the sunken skin flap: a neglected potentially reversible phenomenon affecting recovery after decompressive craniotomy. *Intensive Care Medicine*, *32*(10), 1668–1669. doi: 10.1007/s00134-006-0302-7

Coelho, F., Oliveira, A. M., Paiva, W. S., Freire, F. R., Calado, V. T., Amorim, R. L., ..., & Neville, I. S (2014). Comprehensive cognitive and cerebral hemodynamic evaluation after cranioplasty. *Neuropsychiatric Disease and Treatment*, *10*, 695–701. doi: 10.2147/NDT.S52875

Corallo, F., De Cola, M. C., Lo Buono, V., Cammaroto, S., Marra, A., Manuli, A., & Calabrò, R. S. (2020). Recovery of severe aphasia after cranioplasty: considerations on a case study. *Rehabilitation Nursing*, *45*(4), 238–242. doi: 10.1097/rnj.0000000000000212

Corallo, F., De Cola, M. C., Lo Buono, V., Marra, A., De Luca, R., Trinchera, A., ..., & Calabrò, R. S. (2017). Early vs late cranioplasty: what is better? *International Journal of Neuroscience*, *127*(8), 688–693. doi: 10.1080/00207454.2016.1235045

Cushing, H. (1905). The establishment of cerebral hernia as a decompressive measure for inaccessible brain tumors: with the description of intermuscular methods of making the bone defect in temporal and occipital regions. *Surgery Gynecology & Obstetrics*, *1*, 297–314.

Di Stefano, C., Rinaldesi, M. L., Quinquinio, C., Ridolfi, C., Vallasciani, M., Sturiale, C., & Piperno, R. (2016). Neuropsychological changes and cranioplasty: a group analysis. *Brain Injury*, *30*(2), 164–171. doi: 10.3109/02699052.2015.1090013

Erdogan, E., Düz, B., Kocaoglu, M., Izci, Y., Sirin, S., & Timurkaynak, E. (2003). The effect of cranioplasty on cerebral hemodynamics: evaluation with transcranial doppler sonography. *Neurology India*, *51*(4), 479–481.

Farrington, P. R. (1945). Closure of a defect of the skull with tantalum. *Rocky Mountain Medical Journal*, *42*, 842–844.

Flint, A. C., Manley, G. T., Gean, A. D., Hemphill, J. C., & Rosenthal, G. (2008). Post-operative expansion of hemorrhagic contusions after unilateral decompressive hemicraniectomy in severe traumatic brain injury. *Journal of Neurotrauma*, *25*(5), 503–512. doi: 10.1089/neu.2007.0442

Fodstad, H., Love, J. A., Ekstedt, J., Fridén, H., & Liliequist, B. (1984). Effect of cranioplasty on cerebrospinal fluid hydrodynamics in patients with the syndrome of the trephined. *Acta Neurochirurgica (Wien)*, *70*(1-2), 21–30. doi: 10.1007/BF01406039

Grant, F. C., & Norcross, N. C. (1939). Repair of cranial defects by cranioplasty. *Annals of Surgery*, *110*(4), 488–512. doi: 10.1097/00000658-193910000-00002

Grantham, E. C., & Landis, H. P. (1948). Cranioplasty and the post-traumatic syndrome. *Journal of Neurosurgery*, *5*(1), 19–22. doi: 10.3171/jns.1948.5.1.0019

Honeybul, S. (2010). Complications of decompressive craniectomy for head injury. *Journal of Clinical Neuroscience*, *17*(4), 430–435. doi: 10.1016/j.jocn.2009.09.007

Isago, T., Nozaki, M., Kikuchi, Y., Honda, T., & Nakazawa, H. (2004). Sinking skin flap syndrome: a case of improved cerebral blood flow after cranioplasty. *Annals of Plastic Surgery*, *53*(3), 288–292. doi: 10.1097/01.sap.0000106433.89983.72

Jelcic, N., Della Puppa, A., Mottaran, R., Cecchin, D., Manara, R., Dam, M., & Cagnin, A. (2013). Case series evidence for improvement of executive functions after late cranioplasty. *Brain Injury*, *27*(13-14), 1723–1726. doi: 10.3109/02699052.2013.844857

Jiang, J. Y., Xu, W., Li, W. P., Xu, W. H., Zhang, J., Bao, Y. H., . . . , & Luo, Q.-Z. (2005). Efficacy of standard trauma craniectomy for refractory intracranial hypertension with severe traumatic brain injury: a multicenter, prospective, randomized controlled study. *Journal of Neurotrauma*, *22*(6), 623–628. doi: 10.1089/neu.2005.22.623

Julio-Costa, A., Moura, R., & Haase, V. (2018). Compêndio de testes neuropsicológicos: atenção, funções executivas e memória, In *In (2a ed.)*. São Paulo: Hogrefe.

Kemmling, A., Duning, T., Lemcke, L., Niederstadt, T., Minnerup, J., Wersching, H., & Marziniak, M. (2010). Case report of MR perfusion imaging in sinking skin flap syndrome: growing evidence for hemodynamic impairment. *BMC Neurology*, *10*(1), 80. doi: 10.1186/1471-2377-10-80

Kim, B. W., Kim, T. U., & Hyun, J. K. (2017). Effects of early cranioplasty on the restoration of cognitive and functional impairments. *Annals of Rehabilitation Medicine*, *41*(3), 354–361. doi: 10.5535/arm.2017.41.3.354

Kjellberg, R. N., & Prieto, A. (1971). Bifrontal decompressive craniotomy for massive cerebral edema. *Journal of Neurosurgery*, *34*(4), 488–493. doi: 10.3171/jns.1971.34.4.0488

Kondziolka, D., & Fazl, M. (1988). Functional recovery after decompressive craniectomy for cerebral infarction. *Neurosurgery*, *23*(2), 143–147. doi: 10.1227/00006123-198808000-00002

Kuo, J. R., Wang, C. C., Chio, C. C., & Cheng, T. J. (2004). Neurological improvement after cranioplasty - analysis by transcranial doppler ultrasonography. *Journal of Clinical Neuroscience*, *11*(5), 486–489. doi: 10.1016/j.jocn.2003.06.005

Langfitt, T. W. (1969). Increased intracranial pressure. *Clinical Neurosurgery*, *16*(Supplement 1), 436–471. doi: 10.1093/neurosurgery/16.cn_suppl_1.436

Lezak, M. (1995). *Neuropsychological Assessment* (3rd edition), Oxford University Press.

Maeshima, S., Kagawa, M., Kishida, Y., Kobayashi, K., Makabe, T., Morita, Y., . . . , & Tsubahara, A. (2005). Unilateral spatial neglect related to a depressed skin flap following decompressive craniectomy. *European Neurology*, *53*(3), 164–168. doi: 10.1159/000086129

Malloy-Diniz, L., Fuentes, D., Mattos, P., & Abreu, N. (2018). *Avaliação Neuropsicológica-2*, Artmed Editora.

Nakamura, T., Takashima, T., Isobe, K., & Yamaura, A. (1980). Rapid neurological alteration associated with concave deformity of the skin flap in a craniectomized patient. Case report. *Neurologia Medico-chirurgica (Tokyo)*, *20*(1), 89–93. doi: 10.2176/nmc.20.89

Ng, D., & Dan, N. G. (1997). Cranioplasty and the syndrome of the trephined. *Journal of Clinical Neuroscience*, *4*(3), 346–348. doi: 10.1016/s0967-5868(97)90103-x

Nitrini, R., Caramelli, P., Bottino, C. M., Damasceno, B. P., Brucki, S. M., Anghinah, R., & Neurologia, A. B.d (2005). [Diagnosis of Alzheimer's disease in Brazil: cognitive and functional evaluation. Recommendations of the Scientific Department of Cognitive Neurology and Aging of the Brazilian Academy of Neurology]. *Arquivos de Neuro-Psiquiatria*, *63*(3A), 720–727. doi: 10.1590/s0004-282x2005000400034

PV, W. (2015). *Alterações cognitivas e de qualidade de vida após cranioplastia para reconstrução de craniectomia descompressiva*. Porto Alegre.: Universidade Federal do Rio Grande do Sul.

Richaud, J., Boetto, S., Guell, A., & Lazorthes, Y. (1985). [Effects of cranioplasty on neurological function and cerebral blood flow]. *Neurochirurgie*, *31*(3), 183–188, (Incidence des crânioplasties sur la fonction neurologique et le débit sanguin cérébral).

Royall, D. R., Mahurin, R. K., & Gray, K. F. (1992). Bedside assessment of executive cognitive impairment: the executive interview. *Journal of the American Geriatrics Society*, *40*(12), 1221–1226. doi: 10.1111/j.1532-5415.1992.tb03646.x

Sakamoto, S., Eguchi, K., Kiura, Y., Arita, K., & Kurisu, K. (2006). CT perfusion imaging in the syndrome of the sinking skin flap before and after cranioplasty. *Clinical Neurology and Neurosurgery*, *108*(6), 583–585. doi: 10.1016/j.clineuro.2005.03.012

Schiffer, J., Gur, R., Nisim, U., & Pollak, L. (1997). Symptomatic patients after craniectomy. *Surgical Neurology*, *47*(3), 231–237. doi: 10.1016/s0090-3019(96)00376-x

Segal, D. H., Oppenheim, J. S., & Murovic, J. A. (1994). Neurological recovery after cranioplasty. *Neurosurgery*, *34*(4), 729–731. doi: 10.1227/00006123-199404000-00024 discussion 731.

Stiver, S. I. (2009). Complications of decompressive craniectomy for traumatic brain injury. *Neurosurgical Focus*, *26*(6), E7. doi: 10.3171/2009.4.FOCUS0965

Stiver, S. I., Wintermark, M., & Manley, G. T. (2008a). Motor trephine syndrome: a mechanistic hypothesis. *Trends in Neurovascular Interventions*, *102*, 273–277. doi: 10.1007/978-3-211-85578-2_51

Stiver, S. I., Wintermark, M., & Manley, G. T. (2008b). Reversible monoparesis following decompressive hemicraniectomy for traumatic brain injury. *Journal of Neurosurgery*, *109*(2), 245–254. doi: 10.3171/JNS/2008/109/8/0245

Stula, D. (1985). [Intracranial pressure measurement in large skull defects]. *Neurochirurgia (Stuttg)*, *28*(4), 164–169. doi: 10.1055/s-2008-1054190

Sujit Kumar, G., Chacko, A. G., & Rajshekhar, V. (2004). Unusual presentation of the "syndrome of the trephined". *Neurology India*, *52*(4), 504–505.

Suzuki, N., Suzuki, S., & Iwabuchi, T. (1993). Neurological improvement after cranioplasty. Analysis by dynamic CT scan. *Acta Neurochirurgica (Wien)*, *122*(1-2), 49–53. doi: 10.1007/BF01446986

Tabaddor, K., & LaMorgese, J. (1976). Complication of a large cranial defect. Case report. *Journal of Neurosurgery*, *44*(4), 506–508. doi: 10.3171/jns.1976.44.4.0506

Winkler, P. A., Stummer, W., Linke, R., Krishnan, K. G., & Tatsch, K. (2000). Influence of cranioplasty on postural blood flow regulation, cerebrovascular reserve capacity, and cerebral glucose metabolism. *Journal of Neurosurgery*, *93*(1), 53–61. doi: 10.3171/jns.2000.93.1.0053

Yamaura, A., & Makino, H. (1977). Neurological deficits in the presence of the sinking skin flap following decompressive craniectomy. *Neurologia Medico-chirurgica (Tokyo)*, *17*(1 Pt 1), 43–53. doi: 10.2176/nmc.17pt1.43

Yang, X. J., Hong, G. L., Su, S. B., & Yang, S. Y. (2003). Complications induced by decompressive craniectomies after traumatic brain injury. *Chinese Journal of Traumatology*, *6*(2), 99–103.

Yoshida, K., Furuse, M., Izawa, A., Iizima, N., Kuchiwaki, H., & Inao, S. (1996). Dynamics of cerebral blood flow and metabolism in patients with cranioplasty as evaluated by 133Xe CT and 31P magnetic resonance spectroscopy. *Journal of Neurology, Neurosurgery & Psychiatry*, *61*(2), 166–171. doi: 10.1136/jnnp.61.2.166

Cite this article: Coelho F, Noleto GS, Solla DJF, Martins PN, Andrade AF, Teixeira MJ, Paiva WS, and Anghinah R (2023). Functional improvements associated with cranioplasty after stroke and traumatic brain injury: a cohort study. *Brain Impairment* **24**, 721–731. https://doi.org/10.1017/BrImp.2023.2