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Original Article

The Role of CT Perfusion in Predicting the Neuropsychological Outcome of Patients with Mild and Moderate Traumatic Brain Injury

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Abstract

Objective Patients with traumatic brain injury (TBI) often continue to have symptoms of neuropsychological dysfunction. Studies have demonstrated cerebral perfusion (CP) deficits following TBI. There is limited literature on the association between CP and neuropsychological outcomes following TBI. This study aimed to analyze the correlation between neuropsychological outcome and CP in patients with mild to moderate TBI.

Materials and Methods Patients with mild to moderate TBI and computed tomography (CT) scan suggestive of diffuse axonal injury underwent CT perfusion scan within 48 hours of injury. All patients were evaluated with various neuropsychological tests at 3 months of follow-up. The correlation between CP and neuropsychological outcome was assessed.

Results Forty patients (21 with TBI mild and 19 with moderate TBI) were enrolled. Among 21 patients with mild head injury, 14 (66.7%) showed evidence of hypoperfusion in the right frontal lobe and 12 (57.1%) in the right parietal lobe. Among 19 patients with moderate head injury, 12 (63.1%) patients showed hypoperfusion in the right frontal lobe and 7 (36.8%) in the right parietal lobe. CP in the bilateral frontal and left temporal lobe white matters showed a statistically significant negative correlation with the number of mistakes committed in the Stroop A, B, and C tests. Perfusion in the left temporal white matter showed a negative correlation with the trail making test (parts A and B) and a positive correlation with the animal fluency test. The right parietal and left frontal lobes also showed a positive correlation with the AFT.

Conclusion We found a significant correlation between CP of the white matter of different lobes during the acute phase of TBI and neuropsychological performance at 3 months after TBI.

Keywords
- cerebral perfusion
- CT perfusion
- mild head injury
- moderate head injury
- neuropsychological outcome
- traumatic brain injury

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Introduction

Traumatic brain injury (TBI) has been a major public health problem worldwide and is associated with significant morbidities and mortalities. Nearly 1.6 million people sustain TBI every year in India, with an annual incidence of 160/100,000.[1] TBI has been classified as mild, moderate, and severe based on the Glasgow Coma Scale (GCS) score at admission. Mild TBI, being the most common, accounts for 60 to 80% of all TBI cases, whereas moderate and severe TBIs account for 10 to 30 and 5 to 15%, respectively.[1,2] Mild TBI also has better neurological outcomes compared with moderate and severe TBIs. Patients with mild TBI are often expected to recover completely within 3 months. However, it is not uncommon to find mild TBI patients with persistent symptoms.[3] The prevalence of persistent symptoms among mild TBI patients can vary from 7 to 33%.[4] Such symptoms often encompass various domains of neuropsychological function, including memory, emotion, executive functions, attention, and fluency.[5–7] Over 20% of patients can present with impairment of complex attention and memory function at 12 months of follow-up after mild TBI.[8] Neuropsychological impairment can lead to poor functional outcomes following TBI and impose an economic burden on the family and society. Hence, early detection of impaired neuropsychological functions and timely rehabilitation are essential. Neuropsychological impairment following mild TBI is often subtle and depends on the timing of assessment after injury and the methodology used in the evaluation.

TBI can result in impaired cerebral perfusion, with studies showing a triphasic response pattern of cerebral blood flow (CBF).[9] Cerebral perfusion parameters, as measured by a computed tomography perfusion (CTP) scan, can be used to predict the functional outcome of severe TBI.[10,11] However, there is limited literature on the association between cerebral perfusion and neuropsychological outcomes following TBI.[12,13] In this study, we have tried to analyze the neuropsychological outcome in relation to regional cerebral perfusion in patients with mild to moderate TBI.

Materials and Method

Patients admitted to our trauma emergency center with mild and moderate head injury between May 2022 and December 2023 were screened based on the inclusion and exclusion criteria. The inclusion criteria were (1) patients with mild (GCS 13–15 and duration of loss of consciousness <30 minutes) and moderate (GCS 9–12) TBI; (2) patients whose initial CT scan is normal or showing minimal cortical subarachnoid hemorrhage (SAH), minimal intraventricular hemorrhage, or punctate contusions in deep white matter (suggestive of diffuse axonal injury [DAI]); (3) age greater than 15 years. We excluded the patients with a history of neurological or psychiatric disease, mental retardation, addiction to alcohol or psychoactive drugs, history of allergy to contrast agents, or CT scan showing acute SDH or EDH requiring surgical evacuation, contusions greater than 1 cm in size, SAH in the sylvian fissures, and suprasellar and basal cisterns from the study. Those who met the inclusion criteria were prospectively included in this study. Written informed consent was taken from the patients or immediate relatives (first-degree). Our Institute Ethical Committee approved the study protocol (354/IEC/PGM/2022). All selected patients underwent a CTP within 48 hours of injury.

CT Perfusion Protocol

CTP was done using a 128-slice dual-source SOMATOM Definition Flash CT scanner (Siemens Medical Systems, Erlangen, Germany). A plain CT scan was taken initially to rule out any significant intracranial findings, following which 60 mL of iohexol (nonionic low osmolar iodinated contrast) was injected over 30 seconds (at a rate of 4 mL/s for the initial 10 seconds followed by 1 mL/s for 20 seconds) followed by 20 mL of saline flush. After contrast injection, the system initiated a series of scans, including the entire brain, which were acquired continuously for 40 seconds. The radiation parameters were kept at around 80 kVp and 120 mAs. Following the acquisition of the dynamic contrast scan, the dataset was viewed on the Siemens workstation through syngo.via software (Siemens Healthineers, Erlangen, Germany) with CT Neuroperfusion viewing protocol. The software analyzed the sets of dynamic postcontrast series and adjusted the dataset for motion correction, segmentation, and vessel definition. The software then generated color-coded image sets with separate sets for different parameters. Each set of color-coded brain images was assessed for CBF, cerebral blood volume (CBV), and mean transit time (MTT). For this, regions of interest (ROIs) of 1 to 1.5 cm were drawn in the brain parenchyma. Two ROIs were drawn in the frontal, parietal, occipital, and temporal lobes. The total number of ROI was 16. The values obtained were analyzed for perfusion abnormality based on the absolute values. The values were then compared with the contralateral side of the brain and correlated with clinical outcomes.

The CBF, CBV, and MTT values for bilateral frontal, parietal, temporal, and occipital lobes were calculated from CTP. The CBF was divided into hypoperfusion, normal perfusion, and hyperperfusion for each lobe bilaterally. Similarly, the MTT was divided for each lobe into low transit time, normal transit time, and increased transit time. Increased MTT values suggest slow cerebral perfusion, while decreased MTT means increased cerebral perfusion.

The patients were managed as per the institute's protocol for mild and moderate head injury. All the patients underwent neuropsychological assessment at 3 months of follow-up using the digit span test, trail making test (TMT), Stroop test, and animal fluency test (AFT). The mean score for each test was calculated and compared between different groups based on the cerebral perfusion parameters calculated from CTP. Neurological outcome was assessed for all patients using the extended Glasgow Outcome Scale (GOSE) at 3 months of follow-up.

Digit Span Test

In the digit span test-forward (DST-F), the patient is given a number span and asked to repeat it. If done correctly, the patient must repeat the next sequence. Each span is scored "1" (pass) or "0" (fail). The test is discontinued when the participant fails both trials of the same span length. In the digit span test-backward (DST-B), the patient is instructed to repeat the span backward and scored until the last correct sequence is repeated. The DST evaluates the short-term and working memory of the patients, respectively. A higher score is associated with better working memory.[14]

Trail Making Test

The TMT consists of two parts, A and B. In part A, a page with numbers in circles is shown to the patient. The patient is instructed to connect the numbers by drawing a line between them, with a serial starting from 1 to 25. Part B uses a page with numbers and an alphabet in the circle. The patient is instructed to connect the number (starting from 1) with the alphabet (starting from A) and then to the next number in a series until the last number, 25. The examiner begins timing parts A and B as soon as the instructions are completed and the participant is signaled to start. The total time necessary to complete each trial indicates the visuomotor coordination speed and the executive capacities like attention ability, cognitive flexibility, and working memory.[15]

Stroop Test

Stroop tests A and B use a "color card" (card A) on which there are 100 patches of 3 to 5 different colors and a word card" (card B) on which the names of the colors are printed (in black and white). Stroop C uses a "color-word card" (card C), which prints the names of the colors but is printed in ink of a conflicting color.

The participant's task on card A is simply to utter the names of the colored patches as rapidly as possible, scanning the rows from left to right. On card B, the participant reads aloud the color names as rapidly as possible. On card C, the subject must name the colors of the inks while ignoring the conflicting printed color names. The basic score on each card is the total time (in seconds) the participant takes to utter the 100 names and the number of mistakes he or she committed. This test is used to assess the selective attention and the ability to inhibit cognitive interference.[16]

Animal Fluency Test

It involves the patient naming as many animals as possible within 60 seconds. The clinician records the number of animals named. The AFT is used to assess memory and verbal fluency.[17]

Statistical Analysis

The qualitative data were presented in percentages, and the quantitative data were presented as mean and standard deviation (SD). The data normality was checked by using the Kolmogorov–Smirnov test. In the cases where the data were abnormal, we used nonparametric tests. The variables that were quantitative and not normally distributed were analyzed using the Mann–Whitney *U* test. A comparison of the qualitative variables was done using the chi-squared test. Spearman's correlation coefficient (r) was used to assess the correlation between cerebral perfusion parameters and neuropsychological outcome. SPSS software version 21.0 (IBM) was used for all statistical analyses. A p-value of less than 0.05 was considered statistically significant.

Results

A total of 40 patients were enrolled for this study, out of which 21 (52.5%) patients had mild head injury and 19 (47.5%) had moderate head injury. The mean age of the study group was 34.9 years. Thirty-two (80%) were males, and eight were females (20%). The mechanism of injury was noted for each patient, and the most common mechanism was a road traffic accident, followed by a fall from height, and the least common was assault. Twenty-seven (67.5%) patients had normal findings on the initial CT scan, while 13 (32.5%) patients had positive findings. Specks of contusions were seen in the frontal (6 patients), temporal (2 patients), and parietal lobes (2 patients). CT scans of three patients showed minimal sulcal SAH. ►**Table 1** shows the demographic characteristics of the patients. We did not encounter any complications with CTP, and none experienced adverse reactions to contrast material.

Cerebral Perfusion Parameters

Various degrees of perfusion deficits in terms of CBF and MTT were seen in patients with mild and moderate head injury. In terms of CBF, low CBF was seen more frequently in the frontal lobe, followed by parietal, temporal, and occipital lobes (►**Table 2**). Cerebral perfusion deficit was assessed in relation to the severity of head injury. Out of the total 21

Table 1 Demographic characteristics of all patients

Variables	Frequency (%)
Age (mean ± SD)	34.96 ± 15.1
Sex	
Male	32 (50)
Female	8 (20)
Mode of injury	
RTA	25 (62.5)
Fall	13 (32.5)
Assault	2 (6)
Severity of injury	
Mild	21 (52.5)
Moderate	19 (47.5)
CT finding	
Normal	27 (67.5)
Small frontal contusion	6 (15)
Small temporal contusion	2 (5)
Small parietal contusion	2 (5)
Sulcal SAH	3 (7.5)

Abbreviation: CT, computed tomography; RTA, road traffic accident, SAH, subarachnoid hemorrhage; SD, standard deviation.

Table 2 Comparison of CBF of the brain in patients with different severity of TBI

Side	Lobe	Number of patients having low CBF		*p*-value
		Mild TBI, $n = 21$ (%)	Moderate TBI, $n = 19$ (%)	
Right side	Frontal	14 (66.7)	12 (63.1)	0.81
	Parietal	12 (57.1)	7 (36.8)	0.19
	Temporal	9 (42.8)	7 (36.8)	0.69
	Occipital	10 (47.6)	7 (36.8)	0.49
Left side	Frontal	13 (61.9)	12 (63.1)	0.93
	Parietal	9 (42.8)	7 (36.8)	0.69
	Temporal	9 (42.8)	7 (36.8)	0.69
	Occipital	7 (33.3)	5 (26.3)	0.62

Abbreviations: CBF, cerebral blood flow; TBI, traumatic brain injury.

patients with a mild head injury, 14 (66.7%) showed evidence of hypoperfusion in the right frontal lobe and 12 (57.1%) in the right parietal lobe. Among 19 patients with a moderate head injury, 12 (63.1%) patients showed hypoperfusion in the right frontal lobe and 7 (36.8%) in the right parietal lobe. Similarly, cerebral perfusion was assessed in each lobe on the left side. The mean CBF value in each lobe was compared between mild and moderate TBI (►**Table 3**). We found no significant difference in the mean CBF between patients with mild and moderate TBI.

The right frontal lobe had decreased MTT in 7 patients and normal MTT in 22 patients. Similarly, the right parietal lobe had low and increased MTT values in 6 and 10 patients, respectively. The left frontal lobe showed decreased MTT in 8 patients, normal NTT in 23 patients, and increased MTT in 7 patients. The left parietal lobe showed low, normal, and increased MTT values in 4, 22, and 11 patients, respectively. ►**Fig. 1** compares the cerebral perfusion based on the MTT values in each lobe on the right and left side.

Cerebral Perfusion and Neuropsychological Outcome

Neuropsychological outcomes were compared between patients with hypoperfusion and those with normal perfusion based on the CBF calculated from CTP. The mean

Table 3 Comparison of mean CBF in each lobe between mild and moderate TBI

	Mild (21)		Moderate (19)		*p*-value
CBF	Mean	SD	Mean	SD	
RFG	72.33	19.953	60.89	32.692	0.09
RFW	30.82	15.108	36.98	23.470	0.32
RPG	72.14	18.429	72.74	24.310	0.93
RPW	33.19	14.617	37.89	19.128	0.38
RTG	66.62	21.418	79.63	34.330	0.15
RTW	41.48	22.576	40.53	16.177	0.88
ROG	75.10	12.969	65.63	20.252	0.08
ROW	40.81	17.515	45.26	17.773	0.43
LFG	71.14	20.291	68.16	35.332	0.74
LFW	36.29	15.761	38.47	22.456	0.72
LPG	69.86	26.407	64.42	18.179	0.45
LPW	38.14	18.200	42.00	17.842	0.50
LTG	60.43	23.638	65.05	36.725	0.63
LTW	45.38	21.278	55.68	51.125	0.4
LOG	69.52	23.598	65.47	19.153	0.55
LOW	43.00	17.297	52.21	19.612	0.12

Abbreviations: CBF, cerebral blood flow; LFG, left frontal gyrus; LFW, left frontal white matter; LOG, left occipital gray matter; LOW, left occipital white matter; LPG, left parietal gyrus; LPW, left parietal white matter; LTG, left temporal gray matter; LTW, left temporal white matter; RFG, right frontal gyrus; RFW, right frontal white matter; ROG, right occipital gray matter; ROW, right occipital white matter; RPG, right parietal gyrus; RPW, right parietal white matter; RTG, right temporal gray matter; RTW, right temporal white matter; SD, standard deviation; TBI, traumatic brain injury.

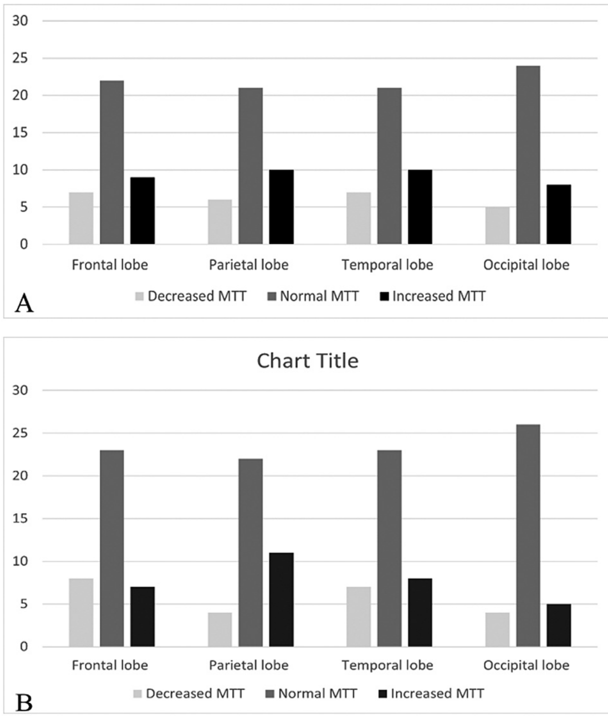

Fig. 1 Bar chart showing cerebral perfusion based on mean transit time (MTT). It compares the number of patients with normal, increased, and decreased MTT values in the (**A**) right and (**B**) left hemispheres.

performance score of each neuropsychological test for the patients with normal and hypoperfusion is given in ►**Supplementary Table S1** (available in the online version). The mean number of mistakes in Stroop A (3.8 vs. 0.91; $p = 0.006$), Stroop B (4.08 vs. 0.45; $p = 0.006$), and Stroop C (36.08 vs. 1.2; $p = 0.001$) tests was higher in patients with hypoperfusion in the right frontal lobe compared with those with normal perfusion. This suggested that patients with normal perfusion parameters in the right frontal lobe performed significantly better in cognitive functions like attention, cognitive flexibility, and inhibitory or interference control than patients with hypoperfusion. The patients having hypoperfusion in the right parietal lobe, in general, had poor performance in neuropsychological tests, but the difference was statically significant only in DST-F (3.56 vs. 4.31; $p = 0.03$), which suggests that the patients with normal perfusion in the right parietal lobe had a better working memory as compared with those with hypoperfusion.

We found no statistically significant difference in the cognitive functions in relation to perfusion deficits in the right temporal and occipital lobes (►**Supplementary Table S1**, available in the online version). Despite perfusion deficits in the right temporal and occipital lobes, patients' cognitive status was comparable among those with normal fusion and hypoperfusion.

Patients with normal perfusion in the left frontal lobe performed statistically better in neuropsychological tests. The patients with normal perfusion made fewer mistakes in Stroop A (1.5 vs. 3.5; $p = 0.05$), Stroop B (1.2 vs. 3.8; $p = 0.03$), and Stroop C (2.9 vs. 36.7; $p = 0.01$) tests. They scored better in DST-F (4.68 vs. 3.6; $p = 0.003$) and DST-B (2.9 vs. 2.3; $p = 0.02$) tests and took less time in the TMT-B test (234.6 vs. 301.6; $p = 0.04$) as compared with patients having hypoperfusion. They also showed a tendency for better performance in TMT-A (81.5 vs. 131.6; $p = 0.09$) and AFT (9.5 vs. 7.9; $p = 0.06$). In other words, patients with hypoperfusion of the left frontal lobe had deficits in all domains of cognitive functions, including attention, planning, motor performance, cognitive flexibility, verbal fluency, and working memory. Patients with normal perfusion in the left parietal lobe had a statistically significant better performance in neuropsychological tests like Stroop A (2.0 vs. 3.9; $p = 0.03$), Stroop B (1.5 vs. 4.5; $p = 0.007$), and Stroop C (19.7 vs. 30.8; $p = 0.002$) tests. They also showed a tendency to perform better in the DST-F test (4.2 vs. 3.6; $p = 0.06$) than patients with hypoperfusion. Patients with poor perfusion of the left parietal lobe had defective attention, cognitive flexibility, inhibitory control, and working memory.

In comparison to the patients having hypoperfusion, the patients with normal perfusion in the left temporal lobe showed better performance in Stroop A (2.0 vs. 3.9; $p = 0.02$), Stroop B (2.0 vs. 3.9; $p = 0.02$), and Stroop C (3.6 vs. 50.7; $p = 0.002$) tests and DST-F (4.2 vs. 3.6; $p = 0.02$). They also showed a tendency to perform better in TMT-A (100 vs. 132.5; $p = 0.07$) and AFT (9.2 vs. 7.4; $p = 0.09$). There was no statistically significant difference in neuropsychological performance or cognitive functions between patients with hypoperfusion and normal perfusion in the left occipital lobe.

On Spearman's correlation analysis, it was found that both CBF and CBV in the white matter of the bilateral frontal and left parietal lobes showed a statistically significant negative correlation with the number of mistakes committed in Stroop A ($r = -0.31$ to -0.44; $p < 0.05$), Stroop B ($r = -0.31$ to -0.47; $p < 0.05$), and Stroop C ($r = -0.32$ to -0.49; $p < 0.05$) tests. Similarly, the CBF and CBV in the left temporal lobe white matter showed a negative correlation with TMT-A and TMT-B ($r = -0.35$ to -0.46; $p < 0.05$) and a positive correlation with AFT ($r = 0.35$; $p = 0.02$). The CBF and CBV in the white matter of the right parietal ($r = 0.39$; $p = 0.01$) and left frontal ($r = 0.38$; $p = 0.01$) lobes also showed a positive correlation with AFT.

We assessed the association between cerebral perfusion (CBF) in different brain regions and GOSE at 3 months. Based on the GOSE score, the patients were divided into favorable (GOSE 8) and unfavorable (GOSE < 8) outcome groups. Favorable and unfavorable GOSE scores were seen in 17 (42.5%) and 23 (57.5%) patients, respectively. We could not find any significant difference in the mean CBF of either gray or white matter of different regions in the brain between those with favorable and unfavorable GOSE score at 3 months.

Neuropsychological Outcome and Severity of Head Injury

We compared the neuropsychological outcomes of patients with mild and moderate head injuries (►**Table 4**). The mean score of neuropsychological tests, as evaluated at 3 months of

Table 4 Comparison of neuropsychological outcome between mild ad moderate TBI patients

Neuropsychological test	Mild TBI	Moderate TBI	*p*-value
DST-F	3.97 (1.06)	3.91 (1.02)	0.80
DST-B	2.52 (0.74)	2.53 (0.73)	0.83
TMT-A	96.28 (67.81)	132.23 (81.14)	0.08
TMT-B	250.95 (76.41)	302.35 (118.46)	0.04
Stroop A (time)	177.38 (67.74)	183.52 (88.1)	0.95
Stroop A (mistakes)	2.90 (4.57)	2.58 (3.06)	0.65
Stroop B (time)	180.95 (72.79)	184.41 (64.37)	0.88
Stroop B (mistakes)	3.61 (5.06)	1.68 (1.89)	0.84
Stroop C (time)	268.09 (78.46)	280.00 (55.79)	0.64
Stroop C (mistakes)	6.28 (7.11)	47.25 (118.23)	0.78
AFT	9.14 (2.24)	7.64 (3.44)	0.01

Abbreviations: AFT, animal fluency test; DST-B, digit span test-backward; DST-F, digit span test-forward; TBI, traumatic brain injury; TMT, trail making test.

follow-up, was compared. Patients with mild head injury showed a significantly better performance in TMT-A, TMT-B ($p = 0.04$), and AFTs (0.01) compared with those with moderate TBI. However, there was no significant difference in Stroop tests, DST-F, and DST-B. Patients with mild head injury showed better neuropsychological recovery as compared with those with moderate head injury at 3 months of follow-up.

Discussion

A significant impairment in neuropsychological function has been reported, especially in memory function, attention, psychomotor speed, and executive abilities following TBI.[8,18] The most common mechanism responsible for such deficits is thought to be DAI. Despite having a normal conventional CT, patients with DAI experience notable neurological impairment. The neuropsychological outcome depends not only on the severity of TBI but also on several other factors, such as premorbid factors, the extent and nature of the sustained structural damage, the person's neuropsychological reserve, and non-neurological factors. The underlying pathoanatomical features of the TBI may be more relevant than the severity of injury for the neuropsychological sequelae.

TBI is associated with significant impairment in cerebral perfusion. CBF has been shown to decrease following mild TBI, the duration of which can extend depending on the severity of the injury.[19,20] The pathophysiology of CBF impairment in mild TBI is poorly understood. The possible mechanisms for low cerebral perfusion are failure of cerebral autoregulation, cerebrovascular reactivity loss due to metabolic factors, and neuroautonomic cardiovascular dysregulation.[21] The cerebral autoregulation can remain impaired for several days (as long as 14 days) following mild TBI.[22,23] Studies have demonstrated that mild TBI impairs CBF response to carbon dioxide, while moderate to severe TBI abolishes such response during the acute stage.[24]

CTP can be used to evaluate cerebral perfusion both qualitatively and quantitatively and has the advantages of easy availability, short acquisition time, and lower radiation dose.[25] Several studies explored the role of CTP in predicting functional outcomes as assessed by the GOS and GOSE following TBI. Studies have shown impaired cerebral perfusion, as measured by CTP, is associated with unfavorable outcomes in TBI.[10,11,26] Most of these studies evaluated cerebral perfusion in patients with severe TBI. Few studies have examined cerebral perfusion in patients with mild to moderate TBI.[12,27] Metting et al reported that the patients with GCS scores of 13 to 14 at admission and with suboptimal GOSE scores at 3 months ($GOSE < 8$) had lower CBF in the frontal and occipital regions compared with healthy controls and patients with a GCS score of 15 and optimal outcome ($GOSE = 8$).[27] However, we found no significant association between cerebral perfusion and GOSE at 3 months following mild and moderate TBI.

Cerebral Perfusion and Neuropsychological Outcomes

Furlonger et al reported poor neuropsychological outcomes in patients with cerebral perfusion pressure lower than 70 mm Hg following severe head injury.[28] However, the role of impaired regional cerebral perfusion during the acute phase of mild to moderate TBI in the neuropsychological outcome has not been explored in detail.[12,13] We studied the association between the cerebral perfusion parameters (CBF, CBV, and MTT) assessed by CTP and neuropsychological outcomes in this study.

We examined the neuropsychological outcome with respect to cerebral perfusion in mild to moderate head injury patients with normal or minimal findings (suggestive of DAI) in the initial CT scan after the injury. Our study showed that patients with low regional perfusion in bilateral frontal lobes had statistically significant deficits in executive functions like attention, cognitive flexibility, and inhibitory or interference control compared with patients with normal perfusion. Patients with impaired perfusion in the right parietal lobe had poor performance in working memory as tested by the DST. In contrast, those with low perfusion in the left parietal lobe showed impaired attention and inhibitory control compared with patients with normal perfusion. Perfusion deficits in the left temporal lobe led to poor overall cognitive outcomes with poor performance in all four neuropsychological tests. No significant deterioration in cognitive functions was seen in relation to perfusion deficits in the right temporal lobe and bilateral occipital lobes.

Metting et al examined neuropsychological outcomes in 18 patients with mild TBI and normal brain CT scans in relation to cerebral perfusion assessed by CTP scan.[12] They reported impaired executive function and emotional perception in patients with significantly lower CBV in the right frontal and bilateral parietal-temporal white matter. However, our study showed a correlation between impaired executive function and hypoperfusion in the bilateral frontal and left parietal lobes. Similarly, Mehrazin et al evaluated cerebral perfusion with single photon emission tomography (SPET) in patients with mild TBI and abnormal CT scans of the brain.[13] These authors reported that a perfusion abnormality on SPET was associated with a greater chance of long-standing memory deficits. However, it is unclear whether the memory deficits were due to perfusion deficits or abnormal findings in this study's plain CT scan following TBI. Early studies have demonstrated significant cognitive impairments in patients with detectable intracranial abnormalities in the acute phase of CT scans compared with those with normal CT scans.[29,30]

Our study shows the importance of white matter in neuropsychological functions. The study results show a significant correlation between perfusion of cerebral white matter in different lobes and performance in specific neuropsychological tests. Ware et al reported a significant correlation between widespread gray matter perfusion deficits and cognitive dysfunction.[31] However, they evaluated cerebral perfusion in patients with chronic TBI (3 months postinjury), unlike our patients who underwent an evaluation of cerebral perfusion during the acute phase (within 48 hours of injury). The findings of our study also signify the importance of frontal and parietal lobes in executive and memory functions. Studies have demonstrated the necessity of neuronal circuits in the prefrontal lobe for executive function. The parietal lobe also plays a significant role in executive function, such as visual attention.[32] Papadaki et al reported a significant association between changes in specific regional perfusion and psychoemotional symptoms in patients with chronic mild TBI.[33] They reported a significant association between depression and lower perfusion in bilateral anterior cingulate gyri. They also found that anxiety was associated with lower perfusion in the hippocampus.

Neuropsychological Outcome and Severity of TBI

Patients with mild head injury performed better in neuropsychological functions, especially in the domain of working memory and verbal fluency, as compared with those with moderate head injury. The mild head injury patients showed a better neuropsychological recovery at 3 months of follow-up. At the same time, those with moderate TBI continued to have poor mean scores in neuropsychological tests like AFT and TMT-A and TMT-B. Previous studies have also shown that the neuropsychological dysfunction in patients with mild TBI usually recovers 3 months after the injury.[12,27] Similar results were reported by Taylor et al who found significantly lower scores on a battery of tests in children and adolescents with moderate TBI compared with those with mild TBI.[34]

The drawback of our study is that we did not study the changes in cerebral perfusion over a period of time after head injury. We also did not evaluate long-term neuropsychological outcomes. Future studies with large sample sizes are required to confirm our study findings and to study the impact of cerebral perfusion on long-term neuropsychological outcomes.

Conclusion

Our study signifies that cerebral perfusion can be affected in patients with mild to moderate TBI. Cerebral perfusion can be reliably assessed by CTP scan in patients with TBI. Posttraumatic cerebral ischemia may have an impact on the neuropsychological functions of patients with mild to moderate TBI. CTP scan done in the early course of the TBI may be helpful to predict the neuropsychological outcome during follow-up. Cerebral hypoperfusion in the bilateral frontal lobes and left parietal lobes, as assessed by CBF, is associated with impaired executive functions like attention, cognitive flexibility, visual attention, and inhibitory control. Similarly, low perfusion in the right parietal lobe is associated with working memory impairment. Patients with low cerebral perfusion in the left temporal lobe can have overall poor cognitive outcome. Patients with mild TBI show better neuropsychological function at 3 months of follow-up than those with moderate TBI.

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Conflict of Interest

None declared.

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