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INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 17, Issue, 04, pp.32576-32584, April, 2025
DOI: https://doi.org/10.24941/ijcr.48744.04.2025

ISSN: 0975-833X

REVIEW ARTICLE

MRI FACTORS ASSOCIATED WITH COGNITIVE FUNCTIONING AFTER TRAUMATIC BRAIN INJURY: A SYSTEMATIC REVIEW AND META-ANALYSIS

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ARTICLE INFO

Article History:
Received 20th January, 2025
Received in revised form
19th February, 2025
Accepted 26th March, 2025
Published online 30th April, 2025

Key words:

TBI, Traumatic Brain Injury, Mri Factors, Cognitive Functions, Brain Injury.

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ABSTRACT

Traumatic brain injury represents a significant social and economic challenge impacting individuals worldwide. This study conducted a systematic review and meta-analysis to evaluate the relationship between cognitive performance following traumatic brain injury and various magnetic resonance imaging parameters. A thorough search was performed across multiple databases, identifying English-language peer-reviewed studies published from 2019 to 2024. Eleven studies, comprising a diverse array of magnetic resonance imaging techniques and cognitive assessment domains, met the inclusion criteria, with a total sample size of 1,200 participants. The analysis revealed that reduced cerebral blood flow in grey matter is commonly observed in individuals with traumatic brain injury and correlates with the severity of cognitive deficits. Additionally, both diffusion tensor imaging and structural magnetic resonance imaging indicated white matter abnormalities, including decreased complexity and volume loss, which are linked to impairments in executive functions and memory. Advanced imaging techniques, such as perfusion magnetic resonance imaging, have further illuminated regional blood flow abnormalities and their association with cognitive impairments post-injury. These findings underscore the potential of advanced magnetic resonance imaging evaluations to enhance understanding and prediction of cognitive deficits following traumatic brain injury, suggesting that MRI-based biomarkers may improve clinical outcomes for affected individuals. Future research is essential to validate these findings and optimize the clinical application of magnetic resonance imaging in evaluating and treating traumatic brain injury.

Citation: Rakesh, K. R., Singh, L., Roslin, P. and Joseph, B. 2025. *"MRI Factors Associated with Cognitive Functioning after Traumatic Brain Injury: A Systematic Review and Meta-Analysis". International Journal of Current Research, 17, (04), 32576-32584.*

INTRODUCTION

Worldwide, traumatic brain injury (TBI) is a common and expensive issue. Its estimated yearly worldwide incidence of about 27 million new cases is probably an underestimate because to the challenges in getting timely and reliable data (James *et al*., 2019). The high incidence affects local, national, and worldwide economies via lost worker productivity and care costs, and it places significant demand on global health systems to manage the acute treatment and long-term consequences of traumatic brain injury. Geographically and demographically, TBIs may be caused by a broad range of events; nevertheless, typical causes include violent incidents, bicycle accidents, car accidents, mechanical falls, sports-related injuries, and violence (Vos *et al*., 2017). It makes sense that, because many of these injuries are avoidable, public health initiatives have shifted their attention to addressing upstream variables that might lower the incidence of traumatic brain injuries. Traumatic brain injury (TBI) is defined as any temporary or permanent disturbance of consciousness, motor function, sensory function, autonomic function, or ordinary brain function. The Glasgow Coma Scale (GCS) is used in clinical settings to classify traumatic brain injury (TBI) severity. A mild TBI is defined as GCS > 13, a moderate TBI as GCS 9–12, and a severe TBI as GCS 3–8 (Nadel *et al*., 2021). When a patient comes in with a suspected traumatic brain injury, the first emphasis of the work-up is often on getting a quick neurological exam and, if necessary, cranial imaging. The majority of US facilities adhere to the American College of Radiology Appropriateness standards for deciding whether a patient in an urgent situation needs to get a head computed tomography (CT) scan. According to these recommendations, every patient who comes with a moderate or severe TBI (GCS <12) should have a noncontract CT scan of the brain performed in order to rule out an operative injury, such as an acute epidural hematoma or subdural hematoma (Shetty *et al*., 2016). Additionally, following a traumatic brain injury (TBI), CT angiography (CTA) may be utilized to rule out any vascular damage, particularly when there are skull base fractures (Mutch *et al*., 2016; Al-Mufti *et al*., 2017). While major intracranial diseases may be seen with CT, more subtle alterations resulting from traumatic brain injury might not be apparent. The ability of CT to predict a patient's final functional result after a traumatic brain injury is limited. Furthermore, there is an increased risk of ionizing radiation exposure with CT, particularly in pediatric patients (Miglioretti *et al*., 2013). The advantages of taking many CT scans in close temporal proximity may be outweighed by this. Because of this, there has been a lot of interest in examining how newer, more sophisticated imaging methods may be used to monitor and evaluate TBI patients. MRI indicators have the potential to identify individuals who are susceptible to cognitive deficits and provide insight into the underlying processes. Patients suffering from dementia or neurodegenerative disorders have participated in the bulk of the research conducted on this subject. Lower functional connectivity (FC) within the default-mode network (DMN), lower fractional anisotropy (FA) in many brain areas, and smaller hippocampus and cortical volumes have all been linked to worse cognitive performance (Binnewijzend *et al*., 2012; Wu *et al*., 2019). The cognitive function of individuals with traumatic brain damage has been linked to comparable MRI indicators. reduced hippocampus volume(Selnes *et al*., 2015), reduced FA in the cingulum (De Simoni *et al*., 2016), and worse FC in resting-state networks (Palacios *et al*., 2017) have all been linked to worse cognitive performance in individuals with ischemic stroke and traumatic brain injury. The inconsistency of the data, which arises from significant variations in research designs and effect sizes, makes it difficult to evaluate and contrast the several MRI indicators of cognitive function after traumatic brain injury.

There have previously been several systematic evaluations conducted on the MRI factors linked to traumatic brain damage. In order to determine the value of early magnetic resonance imaging (MRI) biomarkers of brain connection in forecasting outcomes after mild traumatic brain injury (mTBI), Puig *et al*. carried out a comprehensive study(Puig *et al*., 2020). The most popular outcome measure among the many MRI biomarkers investigated—global functional connectivity, default-mode network, and fractional anisotropy (FA)—was the assessment of symptom burden. According to the research, brain connection indicators derived from MRIs that were collected in the first month after an injury may be useful in forecasting outcomes in mTBI. A comprehensive study of MRI measures of cognition after acute brain damage was carried out by Verhulst *et al*.(Verhulst *et al*., 2023). They discovered recurrent correlations between worse cognition and smaller hippocampus volume, lower fractional anisotropy in the cingulum and fornix, and reduced functional connectivity within the default-mode network. Because the most current Verhulst systematic review is not specifically focused on traumatic brain injury, or because these systematic reviews are not updated. As a result, we provide a comprehensive assessment of the literature and a meta-analysis of the MRI characteristics linked to cognitive functioning impairments after traumatic brain injury.

METHODOLOGY

Study Design: Studies evaluating the association between MRI findings and cognitive functioning in individuals following traumatic brain injury were systematically reviewed.

Sample Selection: The objective of the search approach was to systematically locate relevant research on the association between MRI findings and cognitive functioning after traumatic brain injury. The search was conducted using a combination of keywords and MeSH terms with Boolean operators (AND, OR) in databases such as PubMed, Embase, and Psyc INFO. The search terms "traumatic brain injury" OR "TBI" AND "MRI" OR "magnetic resonance imaging" AND "cognitive functioning" OR "cognitive outcomes" were used.

Inclusion Criteria

- Studies investigating the association between MRI findings and cognitive functioning in individuals with traumatic brain injury.
- Research articles written in English.
- Studies involving human subjects.
- Publications from January 2019 to December 2024.
- Articles published in peer-reviewed journals.
- Studies provide clear methodologies and data on MRI findings and their association with cognitive functioning after traumatic brain injury.

Exclusion Criteria

- Review articles, editorials, letters, and conference abstracts.
- Studies focus solely on MRI techniques without examining their association with cognitive functioning.
- Studies not specifically examining cognitive functioning outcomes in relation to MRI findings after traumatic brain injury.
- Non-English articles.
- Studies with insufficient or unclear methodology and data.

Study Method: In addition to the electronic search for articles, studies were evaluated based on their abstracts and titles. The full texts of selected articles were then carefully assessed, considering specific inclusion and exclusion criteria. The review included only articles meeting the inclusion criteria.

Sample Size: A total of 11 articles were ultimately included for data extraction and analysis.

Quality Assessment: The methodological quality of the included studies was assessed using appropriate tools such as the Newcastle-Ottawa Scale (NOS) for observational studies or the Cochrane Collaboration's tool for randomized controlled trials. Quality assessment was performed independently by two reviewers, with any discrepancies resolved through discussion or consultation with a third reviewer if necessary.

Data Extraction: Data were extracted from selected studies using a standardized form. Key information including study characteristics (e.g., author, publication year), MRI techniques and findings, cognitive assessment measures, and relevant outcomes were systematically recorded.

Data Analysis: A meta-analysis was conducted to synthesize the quantitative data from included studies. Effect sizes, such as standardized mean differences or odds ratios, were calculated as appropriate for continuous or dichotomous outcomes, respectively. Statistical heterogeneity among studies was assessed using the I^2 statistic, with values greater than 50% indicating substantial heterogeneity. Random-effect models were employed to account for anticipated variability between studies. Sensitivity analyses and subgroup analyses were conducted to explore sources of heterogeneity and assess the robustness of findings.

RESULTS

1156 publications in all were found during the first literature search. Following a meticulous assessment of abstracts and titles, 121 articles were deemed relevant, and their full texts were acquired for further examination. Excluded studies did not fulfil the inclusion criteria or did not explicitly investigate MRI characteristics related to cognitive performance after traumatic brain injury (TBI). After a thorough screening procedure, ten papers were found to be appropriate for the systematic review and meta-analysis. Eleven observational studies were included in the systematic evaluation of MRI parameters linked to cognitive performance after traumatic brain injury (TBI). While one research (n = 1. 9%) was a prospective cohort and one study (n = 1.9%) was a prospective longitudinal cohort, the bulk of studies (n = 9.82%) were observational cross-sectional studies. The research included a wide range of TBI groups, from Vietnam War veterans with TBI to pediatric TBI participants. Each research had a different participant count; some included as little as 17 TBI patients, while others had bigger cohorts, including 176 TBI patients. The majority of the studies included controls, with sample sizes ranging from 13 to 103 people.

Across the trials, several cognitive domains were evaluated, including working memory impairment, reasoning, memory, executive function, attention, learning, and episodic memory. The time and kind of neuropsychological assessments differed throughout research. ASL, structural MRI, diffusion tensor imaging (DTI), diffusion kurtosis imaging (DKI), resting-state functional magnetic resonance imaging (fMRI), proton magnetic resonance spectroscopic imaging (MRSI), and a combination of MRI and cerebrospinal fluid (CSF) biomarkers were among the MRI sequences used in the studies. The studies' findings demonstrated correlations between MRI characteristics and cognitive functioning following traumatic brain injury (TBI). These factors included decreased cerebral blood flow (CBF) in the grey matter, changes in default mode network (DMN) connectivity, structural alterations in the white matter (WM), impairment in working memory related to microstructure measures, and white matter injury linked to symptoms following mild traumatic brain injury (mTBI).

Within the framework of cognitive functioning, the meta-analysis looked at changes in fractional anisotropy (FA) after traumatic brain injury (TBI) as measured by MRI. The analysis includes three studies: Richter *et al.* (2021), Stenberg *et al.* (2021), and Jolly *et al.* (2021).Standard deviations ranged from 0.07 to 0.09, whereas the mean FA values in the experimental group (TBI patients) varied from 0.4 to 0.55. Mean FA values were consistently 0.6, with a standard deviation of 0.07 in the control group (those without TBI).A substantial overall impact showing reduced FA in TBI patients relative to controls was found in the meta-analysis. Between TBI patients and controls, the mean difference in FA varied from -0.05 to -0.20. The control group was favoured by the total effect size of -0.13 (95% CI: -0.21 to -0.05). Although there was little

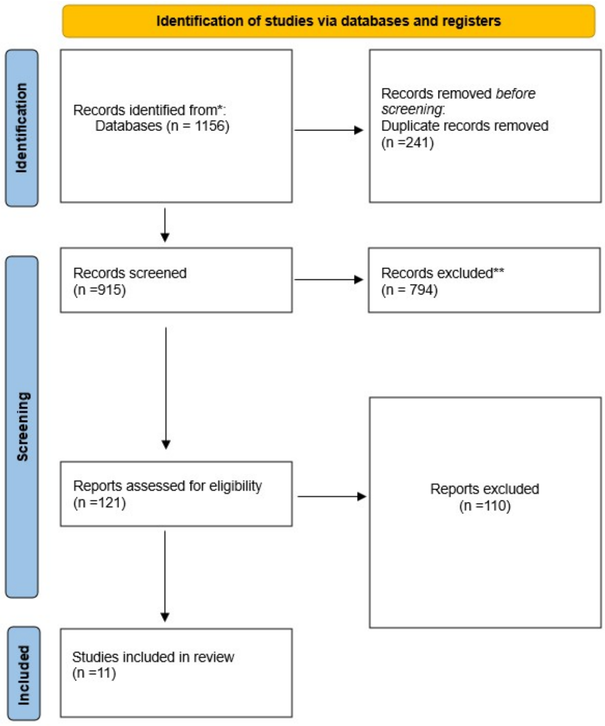

Figure 1. Prima Flow Diagram

heterogeneity amongst the trials (Tau = 0.00), there was statistical significance (Chi = 66.63, df = 2, P < 0.00001). With Z = 3.32 (P = 0.0009), the overall impact was statistically significant and showed a continuous tendency of lower FA in TBI patients as compared to controls in all of the included trials.

DISCUSSION

Thorough evidence of the results from several research examining the complex relationship between MRI indicators and cognitive performance in people with traumatic brain injury (TBI) is provided in this systematic review. Several studies highlight the connection between grey matter CBF decreases and cognitive failure in traumatic brain injury (TBI) patients, including Ware *et al.* (2020b) and Li *et al.* (2020). Li *et al.* found regional CBF anomalies in acute mTBI patients, indicating a connection between altered perfusion and cognitive impairments. Ware *et al.* found extensive decreases in grey matter CBF, which correlated with injury severity and cognitive impairment. In comparison to controls, Patel *et al.* observed reduced volumes in a number of grey matter areas and hyperintensities in the white matter of mTBI patients(Patel *et al.*, 2020).

After mTBI, the complex network dynamics in the brain are clarified by Santhanam *et al.* (2019) and Stenberg *et al.* (2021). While Stenberg *et al.* showed worse white matter microstructural integrity initially after injury in patients with persistent post-concussion symptoms (PPCS)(Stenberg *et al.*, 2021), Santhanam *et al.* found increased connectivity in the default mode network (DMN) among mTBI patients (Santhanam *et al.*, 2019). All of these results highlight the intricate link that exists between functional connectivity and cognitive outcomes after traumatic brain injury (TBI), with differences in network dynamics possibly affecting the time it takes for cognitive recovery to occur. After traumatic brain injury (TBI), white matter integrity undergoes structural changes that are explained by Rajagopalan *et al.* (2019),

Table 1. Summary of MRI Acquisition and Analysis Details Across Studies

Study	MRI Sequence	MRI scanner type and brand	Imaging sequence	Imaging Analysis Processing
Ware *et al*., 2020a	ASL, structural MRI (Structural: Yes; Functional: No)	3T Siemens Prisma	T1-W using MPRAGE and FLAIR	ANTs and FSL
Santhanam *et al*., 2019	Resting state fMRI (DMN) (Structural: Yes; Functional: Yes; Resting)	3T Philips Achieva	T2-W and FLAIR	FSL
Rajagopalan *et al*., 2019	Structural MRI, DTI (Structural: Yes; Functional: No)	3 T Siemens Allegra	MRI: T1-W using MPRAGE; DTI: SS-EPI	FSL
Chung *et al*., 2019	Multi-shell diffusion MRI (Structural: Yes; Functional: No)	3T Siemens Magnetom Skyra	DW-EPI (5 b-values - 250, 1000, 1500, 2000, and2500 s/mm2 and 5)	FSL
Richter *et al*., 2021	Advanced MRI (Structural: Yes; Functional: No)	3T (model and make not reported)	T1-W, FLAIR, T2-W, susceptibility-weighted imaging and DTI (b-value=1000, 32 noncollinear and 63 collinear directions)	FSL
Patel *et al*., 2020	3T MRI (Structural: Yes; Functional: No)	3T Philips Achieva	3D T1-W, T2-W, T2 FLAIR, and 2D T2-W	FreeSurfer
Jolly *et al*., 2021	Diffusion imaging (Structural: Yes; Functional: No)	3 T Siemens Magnetom Verio Syngo	T1-W MPRAGE; FLAIR and DTI (64 directions, b = 100 s/mm2)	FSL
Li *et al*., 2020	pCASL perfusion MRI (Structural: Yes; Functional: Yes, Resting)	3T Philips Ingenia	T1-W using 3D-TFE	ASLtbx and SPM8
Holshouser *et al*., 2019a	3D proton MRSI (Structural: Yes; Functional: No)	3T Siemens Trio/Tim	T1-W, T2-W and FLAIR; 3D proton MRSI using PRESS	LCModel
Stenberg *et al*., 2021	MRI. DTI and DKI (Structural: Yes; Functional: No)	3T Siemens Skyra	MRI: 3D T1-W with MPRAGE, 2D DWI-W, 3D T2-W DTI/DKI: SS-EPI (3 b-values – b=0, b=1000 and b = 2000sec/mm2; 30 non-collinear directions)	FSL and DKE
Wang *et al*., 2022	MRI, CSF biomarkers (Structural: Yes; Functional: No)	3T Siemens and 3T GE (make not reported in the study; parameters and protocol used were identical for both scanners)	T1-W, T2-W, FLAIR and T2-STAR	ADNI1, ADNI 2 and ADNI3

Table 2. Summary of the study characteristics and findings

Author(s)	Study Design	Population Type and Number	Cognitive Domains	Results with Statistics	Conclusion
Ware *et al*., 2020a	Prospective longitudinal cohort study	TBI subjects: 42, Controls: 35	Executive function, attention, speed of information processing, learning, and memory	Grey matter CBF was widely reduced in the TBI group. Cognitive impairment and damage severity were linked with CBF. CBF may be used to forecast future improvement in certain cognitive areas.	Gray matter CBF deficits in early chronic TBI are associated with cognitive dysfunction and may predict subsequent cognitive recovery.
Santhanam *et al*., 2019	observational cross-sectional study.	mTBI (n = 27), those with mTBI + PTSD diagnosis (n = 24; all male), and controls without TBI or PTSD (n = 55)	Memory	Compared to controls and mTBI + PTSD, the mTBI alone group had greater connectivity in DMN. PTSD symptoms and connectivity have an inverse relationship.	Differential relationships were found between the anterior and posterior nodes of the DMN and post-traumatic symptoms as well as cognitive results in mTBI.
Rajagopalan *et al*., 2019	observational cross-sectional study	17 individuals with moderate to severe TBI and healthy controls (HC) (n = 13)	WM structural changes, Memory, executive functioning	The bilateral structural complexity (FD) was lower in the TBI group. Beyond DTI and demographic characteristics, WM FD linked with executive functioning and processing speed.	With TBI, FD may be a sensitive indicator of damage and a predictor of prognosis as it shows WM structural alterations that traditional MRI measurements miss.

Continue ….

Chung *et al*., 2019	observational cross-sectional study	Patients with MTBI: 19, Controls: 20	Working memory impairment	In MTBI patients, there is a positive association between working memory function and axial kurtosis, primarily in the right superior longitudinal fasciculus.	Axonal disturbances that arise after damage may be the cause of differences in working memory function and microstructure measurements between MTBI patients and controls.
Richter *et al*., 2021	Prospective multicenter cohort	Patients with mTBI: 81	Symptoms, white matter volume, diffusion parameters	The volume of white matter decreased (MR2:MR1 ratio, 0.98; 95% CI, 0.96-0.99). Ventricular volume rose (95% CI, 1.02-1.10), with an MR2:MR1 ratio of 1.06.	- White matter injury linked to symptoms after mTBI was discovered using advanced MRI. The strongest correlation between clinical recovery and early imaging within 72 hours was seen.
Patel *et al*.. 2020	Observational cross-sectional	Patients with mTBI: 71, Controls: 75	Regional brain volumes, cognitive deficits, sleep disturbances, behavioral/affective changes.	Compared to 60% of controls, 81% of the mTBI group had WM hyperintensities. Reduced volumes were seen in two subcortical grey matter areas, one white matter region, and seven grey matter regions.	Regional parenchymal volume loss and WM hyperintensities were two structural imaging results linked to mTBI. When making a differential diagnosis for multifocal white matter abnormalities, take past trauma into account.
Jolly *et al*., 2021	Prospective cohort	Patients with moderate-severe TBI: 92, Subacute TBI patients: 25, Controls: 103	Executive function, information processing, reasoning, and episodic memory	Diffusion imaging analysis pipeline showed good specificity, sensitivity, and test-retest reliability in detecting axonal damage in major white matter tracts in TBI patients. Axonal damage was seen in 52% of chronic and 28% of subacute individuals. Unlike localised lesions or microbleeds, axonal damage greatly worsened cognitive and functional results.	The pipeline presented offers a sensitive and complementary approach to traditional MRI methods, providing valuable insights into axonal injury that may not be captured by standard imaging techniques. Guidelines for implementing this pipeline in a clinical setting are discussed, highlighting its potential to enhance patient care and outcome prediction in TBI management.
Li *et al*., 2020	Prospective observational cross-sectional study	Acute mTBI patients: 45, Healthy controls: 42	visuospatial/execution, attention, naming, language, abstraction, memory, CBF changes	mTBI patients had higher CBF in bilateral inferior temporal gyrus and lower CBF in right middle frontal, bilateral superior, and right cerebellar posterior lobes than controls.	Cognitive impairment may be caused by regional CBF abnormalities and CBF connection deficiencies seen in acute mTBI patients.
Holshouser *et al*., 2019a	prospective longitudinal cohort study.	Pediatric TBI	Memory	Reduced NAA is an early indicator of tissue injury. Subcortical brain regions are more predictive of long-term cognitive outcome.	Early changes in acute MRSI predict 1-year neuropsychological outcomes in pediatric TBI patients.
Stenberg *et al*., 2021	Prospective cohort	Patients with mTBI: 176, Controls: 78	Persistent post-concussion symptoms, white matter microstructural integrity	Acutely after injury, patients with PPCS had reduced white matter microstructural integrity. Variations become less noticeable when cognitive reserve is taken into account.	White matter microstructural integrity acutely after mTBI predicts persistent post-concussion symptoms.
Wang *et al*., 2022	Observational cohort study.	Vietnam War veterans with TBI: 55, Non-TBI veterans: 52	verbal memory,Cognitive impairment	MRI-visible CSO-PVS more common in TBI group. High CSO-PVS associated with poor verbal memory, partially mediated by CSF p-tau.	MRI-visible CSO-PVS associated with cognitive impairment in TBI veterans, partially mediated by CSF p-tau.

Table 3. Quality assessment of the reviewed studies by New Castle Ottowa Scale

Study	Representativeness of the exposed cohort (1)	Selection of the non-exposed cohort (1)	Ascertainment of exposure (1)	Demonstration that outcome of interest was not present at start of study (1)	Compare ability of cohorts on the basis of the design or analysis (2)	Assessment of outcome (1)	Was follow-up long enough for outcomes to occur (1)	Adequacy of follow up of cohorts (1)	Representativeness of the exposed cohort (1)
Ware *et al*., 2020a	1	1	1		2	1	1	1	1
Santhanam *et al*., 2019	1	1	1	1	2	1	1	1	1
Rajagopalan *et al*., 2019	1	1	1		2	1	1	1	1
Chung *et al*., 2019	1		1		1	1	1	1	1
Richter *et al*., 2021	1		1		1	1	1	1	1
Patel *et al*., 2020	1	1	1		2	1	1	1	1
Jolly *et al*., 2021	1	1	1	1	2	1	1	1	1
Li *et al*., 2020	1	1	1		2	1	1	1	1
Holshouser *et al*., 2019	1	1	1	1	1	1	1	1	1
Stenberg *et al*., 2021	1		1	1	1	1	1	1	1
Wang *et al*., 2022	1	1	1	1	2	1	1	1	1

Table 3. Forest Plot of Meta-Analysis Comparing Experimental and Control Groups Across Three Studies

	Experimental			Control				Mean Difference
Study	Mean	SD	Total	Mean	SD	Total	Weight	95% CI
Jolly et al., 2021	0.45	0.09	103	0.6	0.07	100	33.49%	-0.15 [-0.17, -0.13]
Richter et al., 2021	0.40	0.07	81	0.6	0.07	100	33.60%	-0.20 [-0.22, -0.18]
Stenberg et al., 2021	0.55	0.08	35	0.6	0.08	141	32.91%	-0.05 [-0.08, -0.02]
Total (95% CI)			219			341	100%	-0.13 [-0.22, -0.05]
Heterogeneity: $Tau^2= 0.0056$ (SE=0.0058); Q = 66.628; $I^2 = 97.47\%$;								
Test for overall effect: Z=3.32 (P-0.0009)								

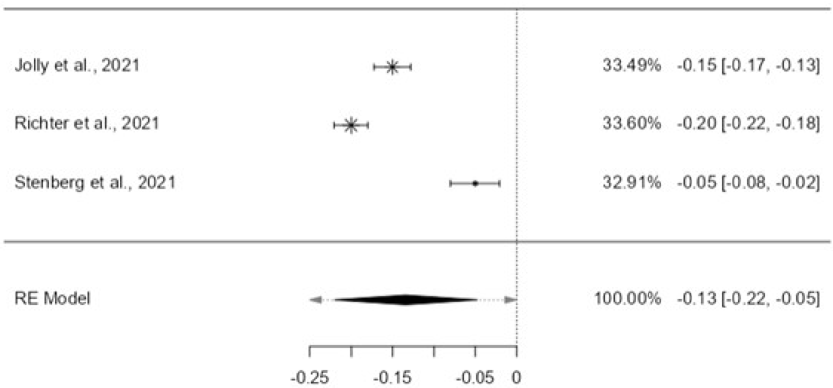

Figure 2. Forest Plot

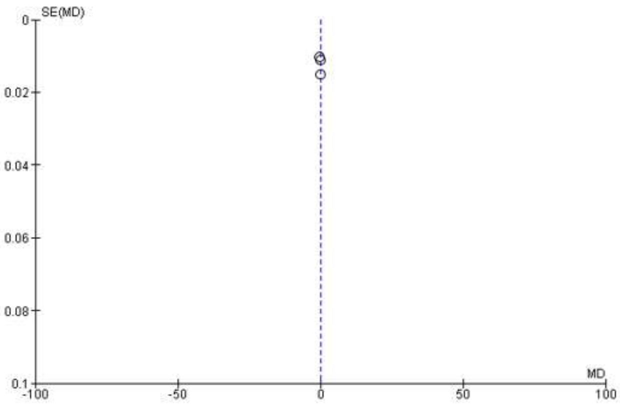

Figure 3: Funnel plot

Figure 3. Funnel plot

Stenberg *et al*. (2021), and Richter *et al*. (2021). Richter *et al*. showed decreased white matter volume and increased ventricular volume after mild traumatic brain injury (TBI), indicating widespread white matter injury associated with cognitive symptoms(Richter *et al*., 2021). Rajagopalan *et al*. found lower white matter structural complexity, correlating with executive functioning and processing speed (Rajagopalan *et al*., 2019). According to Stenberg *et al*. (2021), persistent post-concussion symptoms were predicted by lower white matter microstructural integrity immediately after damage(Stenberg *et al*., 2021).The results of this research show that traumatic brain injury (TBI) has a widespread effect on white matter integrity and may have an influence on cognitive outcomes. After traumatic brain injury (TBI), Chung *et al*. (2019) and Jolly *et al*. (2021) examine the microstructural alterations in axonal integrity. Chung *et al*. discovered a significant relationship between working memory function and axial kurtosis in MTBI patients, highlighting the significance of diffusion MRI measurements in predicting cognitive outcomes(Chung *et al*., 2019). Similarly, Jolly *et al*. showed that diffusion MRI is sensitive in identifying axonal damage at both subacute and chronic time periods(Jolly *et al*., 2021). This finding has therapeutic decision-making implications for therapies related to cognitive rehabilitation. Regional cerebral blood flow (CBF) abnormalities were found by Li *et al*. (2020) in individuals with acute mTBI, indicating a possible connection between altered perfusion and cognitive impairment(Li *et al*., 2020). This highlights the value of perfusion MRI as a diagnostic tool for identifying people at risk of cognitive impairment and its capacity to identify early anomalies linked to cognitive dysfunction after traumatic brain injury. Holshouser *et al*. (2019) and Wang *et al*. (2022) provide information on the metabolic and biochemical alterations linked to traumatic brain injury. Reduced N-acetylaspartate (NAA) levels have been shown by Holshouser *et al*. to function as an early marker of tissue damage, with potential prognostic implications for long-term cognitive consequences(Holshouser *et al*., 2019b). On the other hand, Wang *et al*. found that CSF biomarkers may play a role in the identification of MRI-visible perivascular spaces (CSO-PVS) as possible indicators of cognitive impairment in TBI veterans(Wang *et al*., 2022). Together, these results demonstrate the complex nature of cognitive impairment after traumatic brain injury, with implications for individualized treatment and diagnostic approaches.

The goal of the systematic review and meta-analysis was to look at the relationship between MRI characteristics and cognitive performance after traumatic brain injury (TBI).The meta-analysis's conclusions showed that, across the included trials, TBI patients had lower FA on average than controls. This implies that white matter microstructure, as shown by FA values, is significantly impacted by TBI. Reduced FA values often signify disturbances in the structure and integrity of white matter tracts, potentially impacting brain communication and information processing. The recorded decreases in FA are in line with other studies that indicate TBI often results in diffuse axonal damage and anomalies of the white matter. The cognitive abnormalities that are often seen in TBI patients, including problems with attention, memory, and executive function, may be caused by these anatomical changes. Thus, MRI-based FA change detection shows promise as a prospective biomarker for evaluating cognitive impairment after traumatic brain injury. Although the systematic review and meta-analysis yielded useful insights, it is essential to acknowledge numerous limitations. Firstly, there might be biases and variability in the results due to the variation in patient demographics, MRI methods, research designs, and cognitive assessment instruments. A more consistent approach and set of outcome measures across research might improve the findings' robustness and comparability. Second, the bulk of the included studies were observational in character, which makes it difficult to draw conclusions about causality and emphasises the need of long-term research to clarify the temporal correlations between cognitive results and MRI markers. Furthermore, some research' dependence on cross-sectional data may make it impossible to evaluate how dynamic changes in MRI markers and cognitive performance occur over time. Lastly, considerations like sample characteristics—such as age, severity of the injury, and comorbidities—as well as differences in healthcare settings and availability to cutting-edge imaging equipment may have an impact on how generalizable the results are. Future study directions are suggested by the results of this systematic review and meta-analysis. Initially, in order to investigate the changes in MRI markers and cognitive functioning from acute to chronic phases of traumatic brain injury recovery, longitudinal studies are required. A thorough grasp of the predictive usefulness of MRI indicators in predicting cognitive outcomes and functional recovery would be made possible by long-term follow-up evaluations. Second, in order to improve the repeatability and consistency of results across investigations, efforts to standardise MRI procedures and analytic methods have to be given top priority. The development of consensus criteria for the MRI-based evaluation of TBI-related cognitive deficits might be accomplished via collaborative initiatives, which could also help to harmonise research efforts and translate findings into clinical practice. Furthermore, improvements in neuroimaging technology, such as multimodal imaging techniques and machine learning algorithms, show promise for enhancing the precision and accuracy of MRI-based biomarkers for cognitive performance after traumatic brain injury. By incorporating these cutting-edge methods into clinical practice, it may be possible to evaluate therapeutic responses in TBI patients, optimise therapy, and conduct personalised risk assessments. Finally, multidisciplinary partnerships between technologists, clinicians, and neuroscientists are critical to promoting innovation and converting research results into practical understandings that may enhance the quality of life for TBI victims.

CONCLUSION

The association between brain imaging indicators and cognitive outcomes after traumatic brain injury (TBI) is explained in great detail by the systematic review and meta-analysis of MRI parameters linked to cognitive functioning. There were significant correlations found between MRI results and cognitive deficits after traumatic brain injury (TBI) across a range of research types and patient demographics. These results highlight the significance of using cutting-edge MRI methods, such as diffusion imaging and functional MRI, to evaluate cognitive outcomes and forecast prognosis in TBI patients. Furthermore, the discovery of certain MRI indicators—such as modifications in cerebral blood flow, disturbances in functional connectivity, and structural abnormalities in the white matter—highlights the complex character of cognitive failure after traumatic brain injury. By incorporating these MRI-based indicators into clinical practice, it may be possible to improve long-term outcomes for TBI patients as well as patient monitoring and treatment planning. To improve the therapeutic usefulness and diagnostic accuracy of MRI indicators in predicting outcomes related to cognitive functioning after traumatic brain injury, further investigation and validation studies are necessary.

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