A Comprehensive Review on Neuroimaging Investigations for Chronic Impact of SARS-COV-2

By

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A thesis submitted to the School of Pharmacy in partial fulfillment of the requirements for the degree of Bachelor of Pharmacy (Hons.)

School of Pharmacy
Brac University
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Declaration

It is hereby declared that

1. The thesis submitted is my own original work while completing a degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I have acknowledged all main sources of help.

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Approval

The thesis titled " A Comprehensive Review on Neuroimaging Investigations for Chronic Impact of SARS-COV-2" submitted by Sadia Amin Lamia (18346082), of Fall 2018 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Pharmacy.

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Ethics Statement

No living organism were harmed during this project.

Abstract:

This review explores the lingering impacts of COVID-19 on neuroimaging investigations. The paramount need for ongoing investigations into the effects of SARS COV 2 on neuroimaging is made evident by this evaluation. Besides, it highlights- the neuroimaging methods used for the investigations and the neurological problems resulted from the chronic impact of COVID-19. This study also extracted the types of studies along with the number of participants from different regions of the world. Through enhancing outcomes for patients alongside creating health promotion tactics in the years following a pandemic demand an in-depth comprehension of the implications. Furthermore, this comprehensive review provides a clear understanding about the outcome of neuroimaging investigations after SARS COV 2 that can help individuals to conscious about the impacts and take precautions.

Keywords: COVID 19, SARS COV 2, neuroimaging, impact, virus.

Dedication

I would like to dedicate my work to my parents who have guided me in my life and my teachers who have structured me to become a good person.

Acknowledgement

I am grateful to Almighty Allah for providing me the opportunity to work with such wonderful people from the School of Pharmacy who have always been idealistic and encouraging throughout my journey. I am indebted to my supervisor Dr. Afrina Afrose (Associate Professor, School of Pharmacy, Brac University) for giving me the privilege to work as a thesis student. In addition, her support, guidance, dedication, enthusiasm and expertise in this arena have driven me more interested in thesis work and helped me to complete the research properly. Furthermore, I would like to thank Professor Dr. Hasina Yasmin (Program Director and Assistant Dean, School of Pharmacy, BRAC University) for providing me with huge knowledge to make my journey easy and convenient. Most significantly, I would love to thank Professor Dr. Eva Rahman Kabir (Dean, School of Pharmacy, BRAC University) for her support and motivation. Lastly, I am grateful to all of the faculty members of School of Pharmacy, BRAC University for their enormous efforts for the accomplishment of my graduation.

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List of Acronyms

SARS COV 2	Severe acute respiratory syndrome coronavirus 2
FDG PET	Fluorodeoxyglucose positron emission tomography
MRI	Magnetic resonance imaging
HBOT	Hyperbaric oxygen therapy

Chapter 1

Introduction

1.1 Background

Coronavirus infection-2, which causes severe pulmonary syndrome is the virus that causes COVID-19 is a contagious illness. Numerous millions of residents have died as a result of it globally and hundreds of professions, including the healthcare, education, and economic sectors, have been harmed greatly. The circulatory system is where COVID-19 spreads via a number of pathways. Coughing, sniffing, speaking, singing or breathing can all cause an infected person to release the virus into the air. Inhaled by those nearby, this can result in short-range aerosol or droplet transmission. When the virus enters the respiratory system, it can travel in droplets of aerosol and settle there depositing itself in various parts of the circulatory system according to its size. Despite the main focus of initial investigations was on the neurological difficulties that COVID patients faced, current investigations have shown a variety of neurological imaging issues as well as long-term issues that they might encounter. This in-depth examination discusses the connection between Sars Cov-2 and the brain and nervous system including the kinds of neurological disorders that Sars Cov-2 patients recently encountered and may encounter in the future. This neuroimaging investigation of neurological impact study helps to differentiate what type of difficulties are faced SARS COV 2 patients and in future what are the possibilities of facing these difficulties. Many individuals are made increasingly conscious of these issues thanks to these reviews.

1.2 Research Gap

The infectious agent known as SARS-CoV-2 is the root cause of COVID-19 or coronavirus disease 2019. In accordance with most recent studies, discovered data that extends until 2021 with regard to neuroimaging results in patients with COVID-19. Nonetheless I'll be assembling data through 2023.Moreover, this comprehensive evaluation demands a lot more work and time. Although the most recent investigation only demonstrates olfactory bulb abnormality, white matter abnormality, acute/subacute ischemic infraction, and encephalopathy, I found numerous additional challenges while conducting my research, including cerebral hemorrhage, ischemic stroke, encephalopathy, Alzheimer's disease, seizure, viral infection, CNS vasculitis, endovascular embolization, ataxia, pneumonia, bilateral obstruction, and chronic endovascular impairment (Kim et al., 2021). Retrospective, prospective, observational, case report, case series, and cross-sectional studies comprise some of the various kinds of investigations I have worked with; however, the most recent one only used cohort-based consequences. In contradiction to additional recent research, the present review encompasses a lot more details concerning neuroimaging problems with the environment.

1.3 Objectives

The objectives of this research are -

1. To compile a list of all the studies that were conducted in order to investigate the Covid 19 patient's brain using neuroimaging scans.

2. To pay attention to neurological issues discovered by means of studies using neuroimaging.

3. Enumerate the procedures utilized in neuroimaging studies.

4. To figure out more about the concerns and gain awareness of the neurological obstacles as well as a great deal more information in one article.

Overall it can be said that, explore neuroimaging investigations of Covid 19 patients so that individuals can achieve knowledge about neurological problems and take precautions to get rid of future problems.

1.4 Significance

There are sporadic links between COVID-19 and numerous central nervous system (CNS) disorders. The objective was to showcase the CNS involvement's neuroimaging characteristics. Furthermore, try to find common neuroimaging patterns that might point to potential neurological symptoms connected to COVID-19. To accomplish such results, neurology imaging has emerged as a highly important tool. Also, imaging is used as a decision-making tool in stroke, neuro-oncology, and neurotrauma according to internationally recognized standards of clinical practice. Beside this, cognitive tomographic imaging and magnetic resonance imaging are two neuroimaging methodologies that can aid in the early identification and detection of COVID-19-related neurological problems. Additionally, the spectrum of neurological involvement from minor alterations to more serious consequences can be mapped by investigators with the aid of neuroimaging research. Rehabilitating strategies can be guided by neurological imaging in patients recuperating from neurological conditions related to COVID-19. Comprehending the precise brain areas impacted can facilitate the creation of customized rehabilitation plans aimed at rehabilitating psychological and motor deficits. After all, studies using neuroimaging contribute to the expanding corpus of scientific data regarding SARS-CoV-2's effects on the neurological system.

To sum up, research using neuroimaging are essential for comprehending the neurological consequences of SARS-CoV-2, helping with early identification, assessment, and subsequent therapy organizing. They also add to the growing body of knowledge regarding COVID-19.

Chapter 2

2.1 Method

Inclusion criteria for articles were:

- Studies that reported neuroimaging impacts of Covid 19
- Complete studies with results
- Original full text article
- Article that must be written in English

Exclusion criteria for articles were:

- Studies that show no results
- Review article
- Systemic review
- Incomplete studies
- Vaccination studies
- Studies that happened before pandemic

2.2 Data Extraction

Between December 12, 2019 and April 11, 2023 a systematic search was conducted across multiple databases including PubMed, Google Scholar, Springer, Science Direct, and Scopus utilizing some keywords such as SARS COV 2 to identify relevant research articles in English related to neuroimaging investigations. A total of 91 articles were found on PubMed while Google Scholar yielded 3200 results, Springer contributed 373 articles, Science Direct provided 278 articles and Scopus contributed 190 articles. After screening, 58 articles from

PubMed, 45 from Google Scholar, 155 from Springer, 71 from Science Direct, 132 from Scopus were deemed eligible based on inclusion criteria. After reviewing the abstracts and titled and removing duplicates got my 45 articles as well as applying exclusion criteria. Exclusion criteria were applied to filter out reviews, Meta analyses, systemic reviews, and vaccination studies. Finally, 45 articles were ultimately included into systemic review with inclusion criteria.

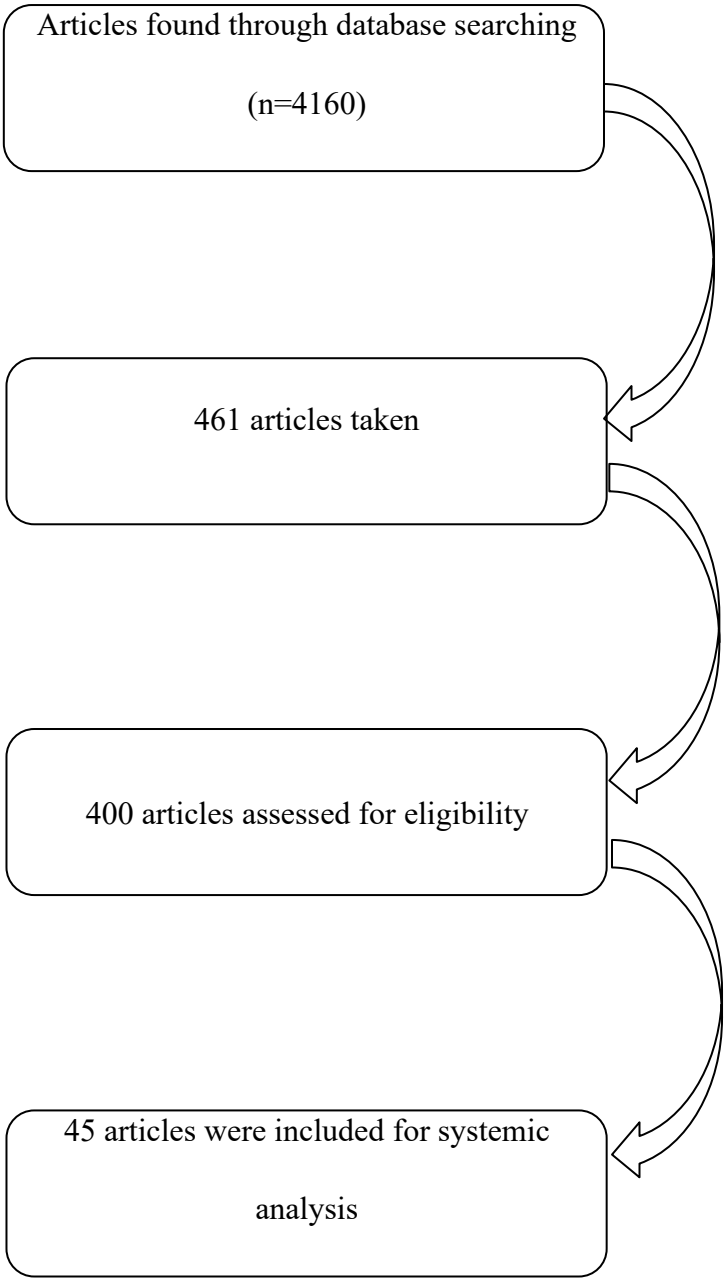

Fig 1: Flow diagram showing literature searching process of the study

Chapter 3

3.1 Types of Study

This chapter is about types of study, number of studies, number of participants, types of participants, region, method that used and result. Table 1 – consist of number of study and participant as well as types of participants if they are covid patient or non-covid or post covid survivors. Table 2- consists of the name of study, method that was used and the outcomes of what kind of complications they faced.

Table 1 – consist of number of study and participant as well as types of participants if they are covid patient or non-covid or post covid survivors.

Study type	Number of study	Participant type	Number of participant	Region	Reference
1. Hospital based study	1	1.Patient with covid 19	439	Egypt	Khedr, Eman M. ; 2021
2. Retrospective study	5	1.patient with Covid 19 2.patient with	7 43	NF NF	Ferrucci, Roberta; 2023 Ross W. Paterson,2020

		suspected or confirmed SARS COV 2 3.covid 19 patient 4.covid 19 patient 5.covid 19 patient	NF 6 49.06%	NF NF NF	Zhang J, 2020 Sibel Laçinel Gürlevik; 2022 Jakub Udzik; 2023
3. Research paper	2	1.hyposmia after SARS COV 2, drug naive PD patient with hyposmia	126	NF	Silvia Morbell,2022

		2.covid 19 patient	26	NF	Anna Lisa Martin,2022
4. Case study	1	1.Post covid	1	NF	Francesco Latini,2022
5. Journal article	1	1.Covid patient	32	NF	Pfefferle S ,2020
6. Case report	13	1.covid 19 2. covid 19 3.covid 19 4. non covid Caucasian women	1 1 1 1	NF NF Europe Europe	Sidhartha Chattopadhyay, 2022 Watts J, 2020 Isabel Butt; 2020 Juan Antonio García-Carmona; 2022

		5.covid patient	1	NF	Mukherjee D,2020
		6.covid 19 patient	1	NF	Frisullo G, 2020
		7.SARS COV 2	2	NF	Madihah Hepburn,2021
		8.covid 19 patient	1	NF	Alexandros Zachariadis,2020
		9.covid recover patient	1	NF	Hafsa Mobeen; 2021
		10.SARS COV 2 patient	1	NF	Mayra Montalvo; 2022

		11.SARS COV 2 patient 12.covid 19 patient 13.non covid patient	1 1 1	NF NF NF	M Russo; 2021 Keith J.Kincaid,2021 Mariana Dias da Costa,2021
7. Prospective study	7	1.Covid 19 survivors 2.covid 19 patient 3.covid recover patient	58 61 237	Italy NF NF	Paolini, Marco; 2023 Nersesjan,2021 Du, Yanyao; 2023

		4.post covid patient 5.covid 19 patient 6.covid 19 patient 7.covid 19 patient	171 12 NF 90	NF NF NF South east asia	Michael Fleischer,2022 Maxime Niesen ,2021 Kamen A Tsvetanov; 2022 Jasmine Shimin Koh,2020
8. Dutch multicenter,prospective,follow up cohort study	1	1.Covid patient	200	Europe	Simona Klinkhammer,2021
9. Observational study	8	1.covid patient	45	NF	Jakub Stępień,2022

		2.covid patient 3.covid patient 4.contracted with covid 5. SARS COV 2 6.covid 19 patient 7.covid 19 patient	33 110 1 35 317 NF	NF NF NF NF NF Europe	Maria Rubega; 2022 Philippe Voruz; 2022 Diógenes Diego de Carvalho Bispo; 2022 Zsofia Kolkedi; 2022 Benjamin Musheyev,2021 Davide Villa,2021

		8.post covid patient	21	NF	Sergio Bagnato,2021
10. Randomized ,sham-controlled,double blind clinical trial	1	1.post covid	NF	NF	Merav Catalogna;2022
11. Cross sectional study	6	1.covid patient 2.covid patient 3.covid 19 patients 4.covid patient 5.covid 19 patient	102 50 NF 226 84	NF NF NF NF NF	Voruz, Philippe; 2022 Julia Bungenberg; 2022 Anna Caroli;2023 BE.Sahin ,2022 Jane Agergaard ,2023

		6.covid 19 patient	NF	NF	Bianca Besteher,2022
12. Case series	1	1.covid 19 patient	5	NF	Jose Manuel Gutierrez Amezcua,2020
13. Guideline issue by German society of neurology	1	1.Post covid	NF	NF	Christiana Franke,2022
14. Longitudinal design	1	1.Covid 19 patient	785	Europe	Xiaoxing Liu,2022
15. Retrospective case series	1	1.Covid 19 patient	NF	NF	Razia Rehmani ,2021
16. Pilot study	1	1.Covid patient and healthy control	10	NF	Thapaliya, Kiran; 2023
17. Consensus report	1	1.Covid 19 patient	NF	NF	Stéphane Kreme,2022
18. Exploratory study	1	1.Recovered from covid	43	NF	Pelizzari, Laura; 2022
19. Multimodal magnetic resonance imaging study	1	1.Covid 19 patient	50	Europe	Benedetti, Francesco; 2021

20. Ambispective study	1	1.SARS COV 2 patient	18	NF	Lokesh Saini.DM ,2022
21. Source based morphometry analysis	1	1.Covid 19 patient	120	NF	Kuaikuai Duan,2021
22. Comparative study	1	1.Non covid patient	107	NF	Ludovica Brusaferri; 2022

3.1.1 Retrospective study

3.1.1.1- Number of study, number of participants

Retrospective studies use data on past events to conduct a posteriori analysis. For the most part, the information has already been collected and is kept in the registry. Five retrospective studies are found from my observation. 105 participants are included in this study.

3.1.1.2 - Method

18F-FDG PET/CT, RNA PCR, Brain MRI, Lumbar puncture, CT head imaging, Intravenous immunoglobulin and corticosteroids as immunotherapies, retrospective observational case series method, Neuroimaging and EEG monitoring, Laboratory tests, Electroencephalography (EEG), and Magnetic Resonance Imaging (MRI).

3.1.1.3 – Result

At T2, the brain metabolic activity of every patient was evaluated using the 18F-FDG PET/CT scan. Out of the seven individuals under investigation, four exhibited typical brain glucose metabolisms. Asymmetric parietal impairment was observed in three patients with different patterns of brain hypometabolism: (1) unilateral hypometabolism in the left temporal mesial area; (2) involvement of the pontine area; and (3) bilateral abnormalities in the prefrontal area. Encephalopathies characterized by delirium/psychosis without obvious abnormalities in the CSF or MRI of which 9/10 recover fully or partially with supportive treatment alone. Acute disseminated encephalomyelitis, isolated myelitis, and encephalitis are examples of inflammatory CNS disorders. Ten of these patients had corticosteroid treatment and three of them additionally received intravenous immunoglobulin; out of these, one patient fully recovered, ten of the patients made partial recovery, and one patient passed away. Ischemic strokes were linked to a prothrombotic condition, in which one patient passed away. Peripheral nervous system conditions, such as brachial plexopathy and Guillain-Barre syndrome, of which six out of eight patients have made a partial and continuous recovery. Other central diseases that did not fall under these categories (Paterson et al. 2020). Individuals exposed to confirmed instances of COVID-19 had a lower chance of contracting the virus when they get arbiter post-exposure prophylaxis (Jin-Nong et al. 2020). A multi-organ illness called COVID infection might present itself outside of the more typical lung presentation as a quickly progressing

neurological condition (Rehmani et al. 2021). Four of the six patients who were diagnosed with seizures had EEGs taken at the time of admission all but one of them had normal EEGs. Six individuals underwent electroencephalogram exams. On admission, the third day of hospitalization, and in one patient who was identified as having a fever, electrographic seizure activity was observed on the right parieto-occipital area on a low voltage background (Gorelik et al. 2022). Additionally, aberrant brain activity was observed in 49.06% of patients with eligible EEG recordings and COVID-19-associated MRI abnormalities were observed in 27.59% of the study group. The presence of abnormalities in EEG and MRI however did not correspond with the frequency of moderate neurological symptoms associated with COVID-19. Furthermore, the predictive significance of CRP, IL-6, and NLR in non-severe COVID-19 did not appear to be affected by the interval between the start of the SARS-CoV-2 infection and hospital admission. The study concluded by demonstrating that epilepsy and epileptic seizures may be precipitated by mild-to-moderate SARSCoV-2 infection (Udzik et al. 2023). Analysis of a particular scenario and a discussion of its various components' theoretical connections are necessary for case reports. An organization, person, or group of people, a case may be related to a hypothetical or actual event, problem, or issue. Thirteen case reports are found from my observation. 14 participants are included in this study.

3.1.2 - Case report

3.1.2.1- Number of study, number of participants

Caucasian individuals are in the spotlight of one case report out of 13 cases involving COVID-19 patients. On top of that, some reports rely on non-Covid patients. Thirteen studies are found from my observation. 14 participants are included in this study.

3.1.2.2- Method

MRI, analysis of medical history ,laboratory test, imaging study, clinical finding of patients head CT scan and chest X-ray, Synthetic glue N-butyl-cyanoacrylate, brain CT scans, electroencephalography (EEG),clinical symptoms, laboratory findings, radiological imaging, cerebrospinal fluid analysis, imaging studies, HRCT CHEST, Scintigraphic evaluation, esophagogastroduodenoscopy, complete abdominal and pelvic ultrasounds, MRI of- the head, chest, abdomen, and pelvis, Electroencephalogram with quantitative analysis, Lumbar puncture for cerebrospinal fluid analysis.

3.1.2.3- Result

The 70-year-old male patient who recovered from COVID-19 three weeks ago is the subject of a case study in this publication. He has cerebellar ataxia. The preceding three years had been spent treating the patient for posttraumatic epilepsy. Additional causes of ataxia were ruled out, and investigations pointed to post-infectious cerebellar ataxia. Upon discharge with a slight tremor and ataxia, the patient showed good response to pulse methylprednisolone therapy. After contracting COVID-19, the paper emphasizes the significance of timely diagnosis and appropriate treatment for post-infectious cerebellar ataxia (Sidhartha Chattopadhyay, 2022). A possible case of CNS vasculitis linked to COVID-19 (Watts and Gaddamanugu 2020). Spread the word that in individuals exhibiting acute confusion without obvious respiratory symptoms, COVID-19 should be regarded as a differential diagnosis (Butt et al. 2020). Endovascular embolization with synthetic glue N-butyl-cyanoacrylate was utilized to successfully treat a cerebral pseudoaneurysm brought on by an infection with SARS-CoV-2 (Juan Antonio García-Carmona; 2022). An instance of SARS COV 2 infection that has been verified, presenting with ataxia (Mukherjee D, 2020). Brain magnet resonance imaging revealed two small cortical acute ischemic lesions in right pre and post gyrus without signs of previous ischemic lesions and hemorrhagic infraction (Frisullo et al. 2020). In patients who are not epileptic but have severe

COVID-19 illness, the research describes two incidences of sudden symptomatic seizures. It was levetiracetam that helped to end the seizures. Electroencephalography monitoring and/or empirical anti-epileptic therapy may be beneficial for patients exhibiting clinical indications of seizures or other unexplained encephalopathy, according to the work. Still, the publication offers little information on the patients' long-term results (Madihah Hepburn, 2021). Human immunoglobulins and corticosteroid treatment were administered intravenously to the patient in the case study (Alexandros Zachariadis, 2020). An uncommon instance of mucormycosis in a patient who had recovered from SARS-CoV-2 infection was successfully diagnosed and treated as a result of the paper (Mobeen et al. 2021). According to the findings of this study, intravenous immunoglobulin was effective in treating the patient's autoimmune gastrointestinal dysmotility (AGID) after contracting SARS-CoV-2 (Mayra Montalvo; 2022). This study results in the diagnosis of mania with psychotic aspects in one patient, brought on by a Sars-Cov-2 infection. The symptoms of the patient gradually subsided after receiving lamotrigine and haloperidol treatment (M Russo; 2021). Initial documentation of a post-infection seizure following a COVID etiology underscores the possible significance of keeping an eye out for neurological manifestations in COVID following recovery (Kincaid et al. 2021). Long-term oral corticosteroid therapy improved the patient's condition significantly, according to the paper. More prospective research is nevertheless required to determine the recurrence risk in this patient subgroup. (Da Costa et al. 2021).

3.1.3 - Prospective study

3.1.3.1 – Number of study, number of participant

Prospective research offers the advantage of being specifically tailored to gather particular exposure data and may be more comprehensive because it is designed with specific data collection methods in mind. Seven case reports are found from my observation. 629 participants are included in this study.

3.1.3.2 - Method

DTI, daily screening, CT scans, MRI, EEG, CSF investigations, voxel-based morphometry method (VBM), Neuropsychiatric and neurocognitive test scales, Neurovascular, electrophysiological, blood analysis, lumbar puncture, Neuropsychological, psychosomatic, and fatigue assessment, Nerve conduction studies, brain magnetic Functional magnetic resonance imaging (fMRI), COVID-19 WHO Progression Scale, inflammatory and coagulator biomarkers resonance imaging (MRI), positron emission tomography with [18F]-fluorodeoxyglucose (FDG-PET), spectrum of COVID 19 neurology.

3.1.3.3 – Result

The inferior front-occipital fasciculus, uncinated fasciculus, corona radiata, and multiple areas of the corpus callosum were among the widespread regions of the brain where COVID-19 survivors with subjective cognitive impairments exhibited greater white matter disruption, as demonstrated by significant differences in DTI measures between cognitive and non-cognitive complainers. Also, certain left hemisphere white matter tracts exhibited higher axial diffusion coefficients while certain interhemispheric associative tracts showed higher radial diffusivity in correlation with the increase in white matter disruption (Paolini et al., 2023). In hospitalized COVID-19 patients, the paper sought to systematically describe problems with the central and peripheral nervous systems. According to the study, Critical illness was frequently the cause of CNS and PNS complications in hospalized COVID-19 patients, especially in the ICU

(Nersesjan et al., 2021). Moreover as indicated by the Athens Insomnia Scale (AIS) and inflammatory factors, the paper's findings indicate that GMV recovery coexisted with injury in COVID-19 recovered patients. While the GMVs in the left middle frontal gyrus, right middle temporal gyrus, inferior frontal gyrus of the operculum, and inferior temporal gyrus decreased, they returned to normal in COVID-19 two. The GMVs in the cerebellum and vermis were reduced in COVID-19 one and COVID-19 two. In COVID-19 two, the GMV in the left temporal cortex was aggravated and positively correlated. With C-reactive protein, whereas the decreased GMV in the left frontal lobe was negatively correlated with AIS (Du et al., 2023). Patients were mostly middle-aged females with mild-to-moderate acute COVID-19 infections. Weariness, focus issues, and memory deficits were the most common post-COVID19 grievances. A thorough neurological examination revealed no abnormalities in the majority of patients (85.8%). The identification of post-COVID-19 syndrome was made in 97.7% of the cases, or Mark Stettner and Christoph Kleinschnitz had a role (Fleischer et al., 2022). Six individuals had bilateral olfactory cleft blockage, and three had mild olfactory bulb an imbalance. There was no abnormal MRI signal observed downstream of the olfactory tract. In the core olfactory and high-order neocortical areas, there was a decrease or increase in deviations related to glucose metabolism ($p < .001$ uncorrected, $k \geq 50$ voxels). Correlation analyses revealed that the degree and duration of COVID-19 related dysosmia affected geographic regions cerebral metabolism of glucose (Maxime Niesen, 2021). According to this paper, severe acute COVID-19 is followed by chronic cerebrovascular impairment, which may have long-term effects on mental health and cognitive function. According to acute severity, unfavorable clinical outcomes, and data from control groups, the long-term impact of COVID-19 on cerebrovascular health was investigated (Tsvetanov et al., 2022). Finally, a broad range of disimmune thrombotic disorders can be found in COVID 19 neurology (Jasmine Shimin Koh, 2020).

3.1.4 - Observational study

3.1.4.1- Number of study, number of participants

Studies that collect data from participants or examine previously collected data are known as observational studies. Researchers track groups of individuals over time in observational studies. Eight observational studies are found from my observation. 562 participants are included in this study.

3.1.4.2 – Method

Nerve conduction study (NCS), needle EMG, High-density electroencephalography (EEG), Functional Magnetic resonance imaging (fMRI), Bundle-specific tractography approach, d-MRI metrics, Swept source optical coherence tomography (OCT), OCT angiography, in vivo corneal confocal microscopy, Mental status, intensive-care-unit (ICU) Mobility Scale, Barthel Index, nerve conduction studies (NCS), unilateral concentric-needle electromyography (EMG), brain [18F]-FDG PET, nerve conduction studies and electromyography (EMG).

3.1.4.3 – Result

Neurophysiological abnormalities were observed in the motor and sensory nerve fibers of COVID-19 individuals who survived exhibiting symptoms of neuropathy in the study that was presented. In the case of the sural nerve's sensory action potential amplitude, the NCS variables were found to be significantly reduced. Furthermore, the correlation between amplitude and conduction velocity in sensory and motor neuron fibers in the arms and legs was the strongest. Even six months after COVID, these anomalies were still present (Jakub Stępień, 2022). Following a year of discharge from the intensive care unit (ICU), COVID-19 survivors showed

a reorganization of spindle cortical generators as a result of a high degree of EEG appraisal (Rubega et al., 2022). Besides, only excessive connectivity patterns were seen in the neuroimaging of moderate patients, whereas hypofunctional and hyper functional connectivities were seen in the cases of severe patients (Voruz et al., 2022). Show that d-MRI observations of brain microstructural alterations in COVID-19 post-acute patients have been made, offering new information about the neurological harm that SARS-CoV-2 infection has either directly or indirectly caused (Diógenes Diego de Carvalho Bispo; 2022). This paper's conclusion is that mild or asymptomatic SARS-CoV-2 infection may still result in peripheral neurodegenerative changes (Kölkedi et al., 2022). Also the study looked into a number of outcomes for COVID-19 survivors who were not in critical conditions, such as functional status at hospital discharge, aids for discharge, recommendations for follow-up medical care, and dependency prior to COVID-19 admission (Musheyev et al., 2021). The paper concludes that muscle involvement in SARS-CoV-2 infection can happen even in the absence of clinical signs or symptoms, and it should be regarded as a spectrum of the illness. Although the subjects did not exhibit any symptoms of muscle involvement, the study discovered that 6 out of 12 had myopathic changes in their needle electromyography (Davide Villa,2021). Evaluation of the brain metabolic correlates of isolated persistent hyposmia following mild-to-moderate COVID-19 infection and comparison with the metabolic processes signature of hyposmia among individuals with drug-naïve Parkinson's disease (PD) were the main goals of the study (Morbelli et al., 2022). According to the nature and extent of neuromuscular involvement, the paper did provide specific outcomes for each patient. Certain patients underwent specialized rehabilitative programs and longer hospital stays due to more severe clinical involvement, while other patients had milder involvement and had better outcomes upon discharge (Sergio Bagnato, 2021).

3.1.5 - Cross sectional study

3.1.5.1- Number of study, number of participants

A sort of research design known as a cross-sectional study involves gathering data at one particular time from a large number of different people. Observing variables without changing them is the goal of cross sectional research. Six cross sectional studies are found from my observation. 462 participants are included in this study.

3.1.5.2 – Method

MRI, Diffusion weighted imaging and T1-weighted MRI scans, Quantitative electromyography, single fiber electromyography, muscle histopathology, voxel based morphometry.

3.1.5.3 – Result

The study conducted functional connection analyses which showed a significant decrease in connectivity within and between the following kinds of networks: the bilateral somatosensory motor, the right executive control, the right salient ventral attention and the bilateral dorsal attention networks, the right Lobules IV and V of the cerebellum, the left default mode, and the right salient ventral attention and the bilaterally dorsal consideration networks (Voruz et al., 2022). According to the study, microbleeds were only detected by brain MRI in hospitalized patients (n = 5) (Bungenberg et al., 2022). Based on DWI and T1-weighted MRI scans, the research paper's findings demonstrate that patients with COVID-19 who exhibit neurological symptoms have notable changes in brain diffusion properties. The changes were located to be connected with the duration from the initial appearance of the disease and were seen in both the white matter and gray matter regions of the brain (Caroli et al., 2023). Infection with COVID increases the likelihood of bilateral, prolonged, and moderate to severe headaches that

are resistant to analgesics (Sahin et al., 2022). Of 84 patients exhibiting prolonged COVID neuromuscular symptoms, 63% displayed myopathy changes in PEMG and increased Jitter in SFEMG (Agergaard et al., 2023). Long-term COVID-19 patients exhibiting neuropsychiatric symptoms exhibited noticeably increased gray matter volumes in multiple brain regions (Besteher et al., 2022).

3.1.6 - Others

3.1.6.1- Number of study, number of participants

Hospital based study, case study, journal article, Dutch multi center prospective follow up cohort study, randomized sham-controlled double blind clinical trial, case series, Guideline issue by German society of neurology, longitudinal design, pilot study, consensus report, exploratory study, multimodal magnetic resonance imaging study, ambispective study, source based morphometry analysis, comparative study. Seventeen studies are found from my observation. 1936 participants are included.

3.1.6.2 – Method

Observational method, retrospective method, CT, MRI, [18F]-FDG PET imaging, [18F]-fluorodeoxyglucose position emission tomography (FDG-PET) scans, Diffusion tensor imaging, standard magnetic resonance imaging, anti spike immunofluorescence techniques, The Montreal Cognitive Assessment, The Rey's Auditory Verbal Learning Test, The Trail Making Test A/B, Stroop Test, Digit Span Test, The Judgement of Line Orientation, The Boston Naming Task and Controlled Oral Word Associations Task, Pre- and post-treatment resting-state brain functional magnetic resonance imaging (fMRI), Immune involvement detection, longitudinal MRI studies, Statistical analysis, 3T magnetic resonance imaging (MRI), Gray matter (GM) volume, white matter (WM) hyperintensity volume, WM

microstructural integrity, 3.0 T scanner, VBM, Resting-state connectivity, Systemic immune inflammation index (SII), Combination of multimodal molecular brain imaging.

3.1.6.3 – Result

Two individuals experienced an acute cerebral hemorrhage as shown by a CT/MRI scan, and three patients had a recent ischemic stroke with seizure onset following COVID-19 infection (Khedr, Eman M: 2021). Along with olfactory perception-related cortical regions are included in the metabolic signature of persistent hyposmia following COVID-19, and these regions do not overlap with those involved in Parkinson's disease (Morbelli et al., 2022). With post-COVID-19 autoimmune encephalitis, DTI may be a helpful Diagnostic technique (Latini et al., 2022). Viral infection and vascular response modulation in carotid arteries by SARS COV 2 are productive (Pfefferle et al., 2020). In addition, examine hospitalized COVID-19 survivors' neurological and neuropsychological aftereffects and how they affect the patients' and their loved ones' quality of life. The study's specific goals are to assess the extent and nature of neuropsychological dysfunction, look into the presence and nature of neurological consequences, link cognitive complaints to both neuropsychological dysfunction and underlying structural brain damage, examine the long-term effects of these conditions on patients' and their loved ones' well-being, and find clinical predictors linked to a higher risk of both neuropsychological dysfunction and structural brain damage (Klinkhammer et al., 2021). After COVID-19 patients, HBOT improves white matter tract disruptions and modifies the functional connectivity organization of neural pathways linked to cognitive and emotional recovery (Catalogna et al., 2022). It offers guidelines for the treatment of individuals experiencing COVID-19-related neurological symptoms. Guidance on the diagnosis and treatment of neurological manifestations of PCS and COVID-19 is provided in this paper, rather than specific study results (Christiana Franke, 2022). The study discovered notable anomalies in the brain areas related to the olfactory and cognitive systems, such as a reduction

in the volume of the cerebellum's cognitive lobule And a loss of gray matter thickness in the left lateral orbitofrontal cortex and Para hippocampal gyrus. The study's 51–81-year-old subjects showed notable longitudinal loss in certain brain areas, particularly those functionally linked to the olfactory system (Liu et al., 2022). An indication of COVID-19's CNS involvement could be the fronto-insular cortex, which is a neuro-metabolic signature. According to the study, patients with neuro-COVID-19 infection are likely to experience temporary, nearly reversible cortical functional impairment. Neurological dysfunctions may be reversible when systemic virus mediated inflammation and brief hypoxia occur, but brain hypermetabolism appears to be persistent and associated with the processes that cause persistent inflammation (Anna Lisa Martin, 2022). In ME/CFS, pons ($p = 0.004$) and whole brainstem ($p = 0.01$), as well as in long COVID, pons ($p = 0.003$), superior cerebellar peduncle ($p = 0.009$), and whole brainstem ($p = 0.005$), there were significantly larger volumes observed in the groups compared with HC. Between long COVID volumes and ME/CFS, no discernible differences were found. In ME/CFS, we found that whole brain stem volumes with "pain" and the pons had positive correlations, while whole brain stem volumes with "breathing difficulty" had negative correlations with the midbrain. The midbrain volume and "breathing difficulty" were found to be strongly negatively correlated in long-term COVID patients. Consistent with the overlapping symptoms, the study showed abnormal brainstem volume in both long COVID and ME/CFS patients (Thapaliya et al., 2023). The neurological and neuroradiological symptoms that COVID-19 patients experience are covered in the paper, along with the necessity of standardizing clinical indications for neuroimaging, MRI acquisition procedures, and follow-up exams (Kremer et al., 2022). After mild to moderate COVID-19, assess the brain metabolic correlates of isolated persistent hyposmia and compare them with the metabolic signature of hyposmia in patients with medication-naïve Parkinson's disease (Morbelli et al., 2022). Comparing the GM volume, WM hyperintensity volume, and CBF of the COV+ and

COV− groups, no discernible changes were found. Comparing COV+ with COV− using tract-based spatial statistics, on the other hand, revealed local WM microstructural changes. To be more precise, COV+ outperformed COV− in multiple WM regions with lower FA (PFWE-peak = 0.035) and higher RD (PFWEpeak = 0.038) (Pelizzari, Laura; 2022). The research discovered that grey matter (GM) was involved in prefrontal, anterior cingulate (ACC), and insular cortex, and that survivors of COVID-19 had white matter (WM) hypodensities/hyperintensities. Moreover, the study discovered that abnormal functional connectivity (FC) among resting-state networks, widespread lower diffusivity along the main axis of WM tracts, and self-rated depression and PTSD were all predicted by systemic immune inflammation index (SII) measured in the emergency department. Axial diffusivity, GM volumes in the ACC and insula, and FC were all negatively correlated with self-rated depression and PTSD (Benedetti et al., 2021). In children, delayed neurological complications from SARS COVID 2 infection are observed (Lokesh Saini. DM, 2022). The spectrum of disimmunes thrombotic disorder in COVID-19 neurology is broad (Jasmine Shimin Koh, 2020). Fever or oxygen deprivation are two secondary ways that COVID can impact the frontal and temporal networks (Duan et al., 2021). The study's findings indicated that, in comparison to pre-lockdown subjects, the brain levels of two distinct neuroinflammatory markers—the 18 kDa translocator protein, TSPO, and myoinositol—were higher in healthy individuals examined following the implementation of lockdown/stay-at-home measures (Brusaferri et al., 2022).

Table 2- consists of the name of study, method that was used and the outcomes of what kind of complications they faced.

List of study	Method	Outcome	Reference
1.Hospital based study	Observational retrospective cohort study CT MRI	Acute cerebral hemorrhage confirmed by CT/MRI brain imaging was seen in two patients, and three patients had a recent ischemic stroke with seizure onset following COVID-19 infection.	Khedr, Eman M. ; 2021
2.Retrospective study	18F-FDG PET/CT	During T2, evaluate each patient's brain metabolism. Out of the seven individuals examined, four exhibited normal cerebral glucose metabolism. Brain hypometabolism patterns varied among the three patients.	Ferrucci, Roberta; 2023
	RNA PCR Brain MRI EEG	Encephalopathies in which there are no obvious abnormalities in the CSF or MRI but delirium and psychosis. One patient	Ross W. Paterson, 2020

	Lumbar puncture CT head imaging Intravenous immunoglobulin and corticosteroids as immunotherapies	recovered fully, ten of the twelve made a partial recovery, and one patient passed away after receiving corticosteroid treatment and intravenous immunoglobulin.	
	Retrospective method	Among those exposed to confirmed cases of the virus, arbitol post-exposure prophylaxis is linked to a lower risk of COVID infection	Zhang J, 2020
	Retrospective observational case series method	A multi-organ illness called COVID infection can present itself outside of the more typical pulmonary presentation as a quickly progressing neurological disease.	Razia Rehmani ,2021

	Neuroimaging and EEG monitoring	Six patients underwent electroencephalograms (EEGs); of these, four patients were diagnosed with seizures; all but one had normal EEGs at admission.	Sibel Laçinel Gürlevik; 2022
	Laboratory tests, Electroencephalography (EEG), and Magnetic Resonance Imaging (MRI)	27.59% of the study population had MRIs linked to COVID-19, and 49.06% of patients with eligible EEG recordings showed abnormal brain activity.	Jakub Udzik; 2023
3.Research paper	[18F]-FDG PET imaging	Cortical regions involved in olfactory perception are encompassed in the metabolic signature of persistent hyposmia after COVID-19, and this signature does not overlap with Alzheimer's disease.	Morbelli S, 2022

	[18F]-fluorodeoxyglucose position emission tomography (FDG-PET) scans.	One neuro-metabolic signature of COVID-19's involvement in the central nervous system is the fronto-insular cortex.	Anna Lisa Martin,2022
4.Case study	Diffusion tensor imaging and standard magnetic resonance imaging	DTI may be helpful in the diagnosis of autoimmune encephalities following COVID-19.	Francesco Latini,2022
5.Journal article	Anti-spike immunofluorescence techniques	Viral infection and cerebrovascular response modulation in carotid arteries by SARS COV 2 are synergistic.	Pfefferle S ,2020
6.Case report	MRI	After recuperating from COVID-19, the patient experienced ataxia of the brain for three weeks.	Sidhartha Chattopadhyay,2022

	Analysis of medical history , laboratory test, imaging study, clinical finding of patients	A suspected case of CNS vasculitis linked to COVID-19	Watts J, 2020
	Head CT scan and chest X-ray.	Inform people that if a patient exhibits acute disorientation without obvious respiratory manifestations, COVID-19 should be evaluated out as an alternative diagnosis.	Isabel Butt; 2020
	Synthetic glue N-butyl-cyanoacrylate, brain CT scans and MRI	Endovascular embolization with synthetic glue N-butyl-cyanocrylate was used to successfully treat a cranial the surgical treatment brought on by an infection with SARS-CoV-2.	Juan Antonio García-Carmona; 2022

	▪ NF	Ataxia is a providing feature in a confirmed instance of COVID-19 infection.	Mukherjee D,2020
	Brain magnet resonance imaging	Lacking any indications of prior caused by ischemic wounds or hemorrhagic infraction, two small cortical acute ischemic lesions in the right prior to and following the gyrus were discovered.	Frisullo G, 2020
	electroencephalography (EEG)	Describes two instances of severe COVID-19 illness in non-epileptic patients who experienced acute indicative epileptic fits.	Madihah Hepburn,2021
	Clinical symptoms, laboratory	Administered intravenously with human immunoglobulins and corticosteroid medication.	Alexandros Zachariadis,2020

	findings, radiological imaging, cerebrospinal fluid analysis, and imaging studies.		
	MRI, HRCT CHEST	The patient who had recovered from SARS-CoV-2 infection had an uncommon instance of pneumonia, which was successfully diagnosed and managed.	Hafsa Mobeen; 2021
	Scintigraphic evaluation, esophagogastroduodenoscopy, complete abdominal and pelvic ultrasounds,	Intravenous immunoglobulin proved to be a successful treatment for the patient's autoimmune gastrointestinal dysmotility (AGID) post-SARS-CoV-2 infection. The recognition of mania in a single individual with psychotic	Mayra Montalvo; 2022

	and MRI of the head, chest, abdomen, and pelvis.	features brought on by Sars-Cov-2 infection.	
	Brain MRI scan, Electroencephalogram with quantitative analysis, Lumbar puncture for cerebrospinal fluid analysis	The initial recorded instance of a post-infection seizure following a COVID cause underscores the possible importance of keeping an eye out for neurological effects in COVID following recovery.	M Russo; 2021
	▪ NF	A significant improvement in the patient's symptoms after receiving oral steroid medication medication for an extended period of time.	Keith J.Kincaid,2021

7.Prospective study	DTI	In COVID-19 survivors with arbitrary cognitive deficits, there was greater impairment of white matter in broader brain regions when comparing DTI measures between cognitive and non-cognitive the complainants.	Paolini, Marco; 2023
	daily screening, CT scans, MRI scans, EEG, CSF investigations	In the hospital COVID-19 patients with problems with their central and peripheral nervous systems, especially in the intensive care unit, which are frequently related to serious illness.	Nersesjan,2021
	MRI, voxel-based morphometry method (VBM), Neuropsychiatric	Using the Athens Insomnia Scale (AIS) and inflammatory factors were linked to GMV recovery in COVID-19 recovering individuals	Du, Yanyao; 2023

	and neurocognitive test scales.		
	Neurovascular, electrophysiological, and blood analysis Magnetic resonance imaging (MRI) and lumbar puncture, Neuropsychological, psychosomatic, and fatigue assessment	Clients were middle-aged or older mostly female, and had primarily mild-to-moderate acute COVID-19 infections.	Michael Fleischer,2022
	Nerve conduction studies brain magnetic resonance imaging (MRI) and positron emission	Six patients had bilateral obstruction of the olfactory cleft, and three had mild asymmetry of the olfactory bulb	Maxime Niesen ,2021

	tomography with [18F]-fluorodeoxyglucose (FDG-PET)		
	Functional magnetic resonance imaging (fMRI), COVID-19 WHO Progression Scale,	Severe acute COVID-19 is associated with chronic cerebrovascular impairment, which may have a long-lasting impact on mental health and ability to think.	Kamen A Tsvetanov; 2022
	inflammatory and coagulatory biomarkers spectrum of COVID 19 neurology	The spectrum of disimmune thrombotic disorder in COVID-19 neurology is broad.	Jasmine Shimin Koh,2020

8.Dutch multi center, prospective follow up cohort study	The Montreal Cognitive Assessment, The Rey's Auditory Verbal Learning Test, The Trail Making Test A/B, Stroop Test, Digit Span Test, The Judgement of Line Orientation, The Boston Naming Task and Controlled Oral Word Associations Task	Examine how neurological and psychological problems affect patients' and their loved ones' quality of life. Look into the existence and type of neurological in nature aftereffects.	Simona Klinkhammer, 2021
9.Observational study	nerve conduction study (NCS), needle EMG	Those who survived COVID-19 and experienced signs of neuropathy showed deviations in their neurophysiology in both sensory and motor nerve fibers.	Jakub Stępień,2022

	High-density electroencephalography (EEG)	reorganization of COVID-19 survivors' spindle cortical generators.	Maria Rubega; 2022
	Functional magnetic resonance imaging (fMRI)	Patterns of hyperfunctional and hypofunctional connectivities were identified by neuroimaging in patients with severe conditions.	Philippe Voruz; 2022
	Bundle-specific tractography approach and d-MRI metrics	Describe how d-MRI was able to identify changes in brain microstructural characteristics in patients who were in the COVID-19 posttraumatic phase.	Diógenes Diego de Carvalho Bispo; 2022
	Swept-source optical coherence tomography (OCT), OCT angiography,	Furthermore, in cases of mild or asymptomatic SARS-CoV-2 infection, peripheral	Zsofia Kolkedi; 2022

	in vivo corneal confocal microscopy	neurological impairment may manifest.	
	Mental status, intensive-care-unit (ICU) Mobility Scale, and Barthel Index	Dependence prior to COVID-19 admission, release with assistance devices	Benjamin Musheyev,2021
	nerve conduction studies (NCS) and unilateral concentric-needle electromyography (EMG).	Though symptoms and clinical signs are absent in cases of SARS-CoV-2 infection, muscular involvement can still occur and is a part of the illness spectrum.	Davide Villa,2021
	brain [18F]-FDG PET	Analyze the correlations between brain metabolism and isolated persistent hyposmia following mild-to-moderate COLIV-19	Silvia Morbell,2022

	nerve conduction studies and electromyography (EMG)	Depending on the kind and degree of neuromuscular involvement, each patient's unique results	Sergio Bagnato,2021
10.Randomized, sham Controlled,double blind clinical trial	Pre- and post-treatment resting-state brain functional magnetic resonance imaging (fMRI)	HBOT ameliorates white matter tract interruptions and modifies the functional connectivity structure of neural pathways linked to post-COVID-19 intellectual and emotional healing.	Merav Catalogna;2022
11.Cross sectional study	MRI	A substantial decrease in connectivity was found by the functional connectivity analyses between the anosognosic and nosognosic groups.	Voruz, Philippe; 2022

	Brain magnetic resonance imaging (MRI)	Only in hospitalized patients did brain MRIs reveal microbleeds.	Julia Bungenberg; 2022
	Diffusion weighted imaging and T1-weighted MRI scans.	There are notable changes in cerebral dissemination in COVID-19 patients who exhibit symptoms of neurological disease.	Anna Caroli;2023
	▪ NF	By using DWI and T1-weighted MRI scans, COVID-19 patients who exhibit neurological symptoms have notable changes in brain the diffusivity.	BE.Sahin ,2022
	Quantitative electromyography ,single fibre electromyography, muscle histopathology	Disease with COVID increases the likelihood of bilateral, long-lasting, moderate to serious headaches that are resistant to analgesic medications	Jane Agergaard ,2023

	Voxel based morphometry	In 63 out of 84 patients with prolonged COVID neuromascular symptoms, myopathic alterations in qEMG and elevated jitter in SfEMG were observed. Grey matter volume was markedly increased in multiple brain regions in long-term COVID-19 patients exhibiting neuropsychiatric symptoms.	Bianca Besteher,2022
12.Case series	▪ NF	▪ NF	Jose Manuel Gutierrez Amezcua,2020
13.Guideline issue by German society of neurology	Immune involvement detection and longitudinal MRI studies.	Offers guidelines for the treatment of individuals experiencing COVID-19-related symptoms of neurological disease.	Christiana Franke,2022

14.Longitudinal design	Magnetic resonance imaging (MRI) and diffusion tensor imaging (DTI)	Olfactory and cognitive systems-related brain regions were shown to have significant abnormalities.	Xiaoxing Liu,2022
15.Pilot study	MRI and Statistical analysis	In ME/CFS, pons ($p = 0.004$) and whole brainstem ($p = 0.01$), as well as in long COVID, pons ($p = 0.003$), superior cerebellar peduncle ($p = 0.009$), and whole brainstem ($p = 0.005$), group comparisons using HC revealed significantly larger volumes.	Thapaliya, Kiran; 2023
16.Consensus report	MRI and CT	The need to standardize clinical indications for neuroimaging, MRI acquisition protocols, and follow-up examinations in patients with COVID-19.	Stéphane Kreme,2022
17.Exploratory study	3T magnetic resonance imaging (MRI), Gray matter (GM) volume, white	Regarding GM volume, no discernible variations were found between the COV+ and COV− groups.	Pelizzari, Laura; 2022

	matter (WM) hyperintensity volume, WM microstructural integrity		
18.Multimodal magnetic resonance imaging study	MRI, 3.0 T scanner, VBM, DTI, Resting-state connectivity, Systemic immune-inflammation index (SII).	Grey matter (GM) was involved in prefrontal, anterior cingulate (ACC), and insular cortex in COVID-19 survivors, and white matter (WM) hypodensities/hyperintensities were present.	Benedetti, Francesco; 2021
19.Ambispective study	▪ NF	Children who contract SARS COV-2 often experience delayed neurological complications.	Lokesh Saini.DM ,2022
20.Source based morphometry analysis	CT scan	By causing a fever or oxygen shortage, COVID can indirectly impact the frontal and temporal networks.	Kuaikuai Duan,2021
21.Comparative study	Combination of multimodal	Two distinct neuroinflammatory markers were detected at higher levels in the brains of healthy individuals	Ludovica Brusaferri; 2022

	molecular brain imaging	who were examined following the implementation of lockdown/stay-at-home measures. Two distinct neuroinflammatory markers were detected at higher levels in the brains of healthy individuals who were examined following the implementation of lockdown/stay-at-home measures.	

3.2 - Overall discussion

Studies of twenty-two distinct kinds on the neuroimaging examinations of COVID-19 patients. There are patients with suspected or confirmed SARS COV 2, hyposmia following SARS COV 2, drug-naive PD patients with hyposmia, post-covid patients, non-covid patients, and covid patients. Neuroimaging investigations employ a variety of methods, including CT scans, MRIs, DTIs, and EEGs. The most commonly used ones are CT and MRI scans.

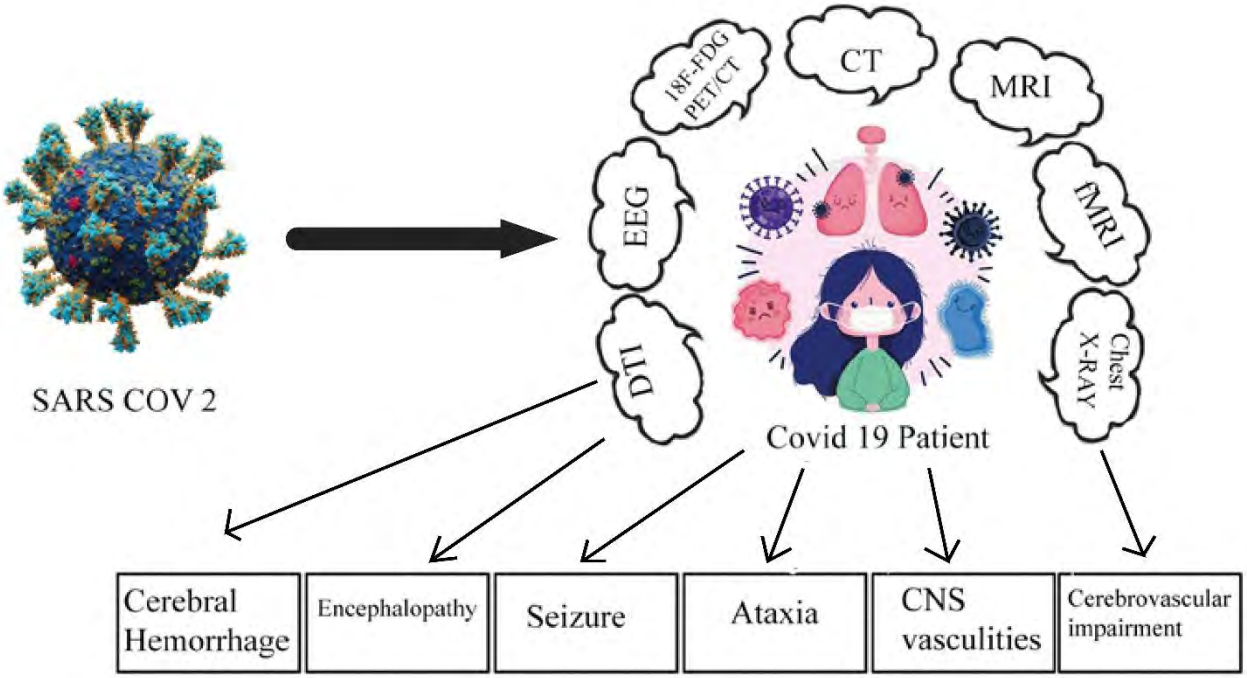

Fig 2: Common Investigational Tools used and Common Difficulties among Participants

Chapter 4

Conclusion

Summarizing the subject matter's main conclusions in brief, analysis of 45 publications has been executed successfully to gain insight into how SARS COV 2 influences neurological imaging. In the medical setting and within the discipline of neuroscience, neuroimaging research has several advantages. The development of innovative treatments and their evaluation in clinical trials are made easier by this potent tool in the field of neurotherapeutics. With the aid of neuroimaging techniques like electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), researchers can study neurological disorders and comprehend their underlying mechanisms by gaining detailed insights into brain activity and function. Through the detection of neurological dysfunctions and the ability to differentiate them from other conditions, neuroimaging is also essential in the diagnosis of psychiatric disorders. Neuroimaging also plays a role in predicting the risk of recurrence identifying reward processing and cognitive control circuits, and comprehending the neurobiology of addiction in the brain. In the end, advances in brain function and the creation of novel diagnostic approaches are facilitated by methods for in general, neuroimaging methods help us create new diagnostic approaches and deepen our understanding of how the brain functions.

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