Original Article

CT Brain Findings In COVID-19 Patients With Neurological Symptoms: A Descriptive Study From A Tertiary Care Hospital In Pakistan

Nasreen Aman[1], Rukhsana Aziz[2]

Abstract

Objectives: This study aimed to explore the spectrum of CT brain findings in COVID-19 patients presenting with neurological symptoms and to evaluate their association with age and underlying comorbidities.

Methods: A retrospective review was conducted on 60 RT-PCR–confirmed COVID-19 patients who underwent CT brain at Lady Reading Hospital, Peshawar, from March to November 2021 due to neurological complaints such as altered mental status, headache, seizures, or focal deficits. Patient data, including demographics, comorbid conditions, and imaging findings, were collected. Data was analysed using descriptive and inferential statistics.

Results: The most frequent abnormality observed was ischemic infarction, present in 40% of patients, with a clear predominance among elderly individuals and those with comorbidities such as hypertension and diabetes mellitus. Brain atrophy was identified in 11.7% of cases, while intracranial haemorrhage was noted in 10%. Other, less common findings included hypoxic changes and nonspecific white matter abnormalities. Statistical testing revealed significant associations between age groups, comorbidity status, and occurrence of ischemic or hemorrhagic events ($p < 0.05$).

Conclusion: CT brain imaging in COVID-19 patients with neurological manifestations demonstrated a high frequency of structural abnormalities, particularly vascular insults. These findings suggest that SARS-CoV-2 infection may exacerbate cerebrovascular vulnerability in older and comorbid populations. Early neuroimaging in such patients is crucial for timely diagnosis and management. Further large-scale prospective studies are warranted to validate these associations and to guide neuroimaging protocols in severe COVID-19.

Keywords: COVID-19, Computed Tomography of Brain, Neurologic Manifestations, Cerebral Infarction, Hypertension.

Contributions:
NA - Conception, Design
NA, RA - Acquisition, Analysis, Interpretation
NA, RA - Drafting
NA, RA - Critical Review

All authors approved the final version to be published & agreed to be accountable for all aspects of the work.

Conflicts of Interest: None
Financial Support: None to report
Potential Competing Interests: None to report

Institutional Review Board Approval
442/LRH/MTI
26-07-2022
Lady Reading Hospital, Peshawar

Review began 09/07/2025
Review ended 30/12/2025
Published 30/12/2025

How to cite this article: Aman N, Aziz R. CT Brain Findings in COVID-19 Patients with Neurological Symptoms: A Descriptive Study from a Tertiary Care Hospital in Pakistan. JRMC. 2025 Dec. 31;29(4).

https://doi.org/10.37939/jrmc.v29i4.2964

Introduction

The Severe Acute Respiratory Syndrome Virus (SARS-CoV-2) is the cause of COVID-19, a global illness that was first identified in Wuhan, China, in December 2019. The disease rapidly evolved into a global pandemic, resulting in millions of deaths and significant morbidity worldwide.[1, 2]

While COVID-19 is primarily known for causing acute respiratory distress syndrome (ARDS), its systemic impact –including cardiovascular, renal, and neurological involvement is now well established.

Neurological manifestations in COVID-19 patients range from mild symptoms such as headache, dizziness, confusion, anosmia, and myalgia to severe complications including stroke, encephalopathy, encephalitis, and seizures.[3-6] Evidence suggests that neurological complications are more prevalent in patients with severe or critical forms of COVID-19, possibly due to a combination of direct viral invasion, immune–mediated injury, systemic inflammation (cytokine storm), and a hypercoagulable state.[7-9]

Imaging plays a key role in the evaluation of neurological symptoms in COVID-19 patients. While MRI offers higher sensitivity, non-contrast CT (NECT) remains the first-line modality in many settings due to its rapid acquisition time, wide availability, and compatibility with critically ill, oxygen-dependent patients—many of whom have contraindications to MRI such as unstable vitals or renal dysfunctions, thus minimising risk.[10,11.]

Despite the growing literature on neuro-COVID, there is a lack of region-specific data from low-resource settings, particularly regarding CT brain findings in patients with neurological symptoms. Understanding the radiological patterns in such populations is essential for timely diagnosis and intervention.

We hypothesise that ischemic infarctions are common CT brain findings in COVID-19 patients with neurological symptoms and that their frequency increases with age and comorbidities such as diabetes and hypertension. We also suspect that the use of anticoagulants in COVID-19 patients leads to increased susceptibility to intracranial haemorrhage.

Therefore, this study aims to explore the CT brain findings in COVID-19 patients presenting with neurological symptoms and their association with age and comorbidities at a tertiary care hospital in Peshawar, Pakistan.

Materials And Methods

A cross-sectional hospital-based retrospective study was conducted at the Radiology Department of Lady Reading Hospital (LRH), Peshawar, Pakistan, over nine months from March 2021 to November 2021. Ethical approval was obtained from the institutional research and ethical committee (Reference number 422/LRH/MTI).

Original Article

The study population comprised hospitalised, RT–PCR–confirmed COVID-19 patients of all ages and both sexes who developed neurological symptoms during admission and were referred for non–contrast–enhanced CT (NECT) brain imaging. To minimise selection bias, a non-probability consecutive convenience sampling technique was employed, as this is an exploratory descriptive study in a high-risk subgroup, to include all eligible patients scanned during the study period. Patients referred from the outpatient department (OPD) for elective brain imaging were excluded, or if neurological symptoms were clearly attributable to pre-existing conditions or trauma.

A total of 60 patients were included using consecutive convenience sampling, justified by including only those patients with neurological symptoms severe enough to warrant CT, limited access to imaging and pandemic-related logistic constraints. While not random, this approach aimed to reduce subjective selection bias and reflect real-world clinical triage patterns.

All CT brain scans were performed on a Toshiba Aquilion Prime 160 slice CT scanner, with patients positioned supine. The imaging protocol included 1 mm-thick axial sections, followed by multiplanar reformats for optimal visualisation.

Clinical information and imaging data were retrieved retrospectively from the Health Management Information System (HMIS) and recorded on a structured data collection proforma. CT brain images were reviewed and interpreted by a consultant radiologist with at least five years of post-specialisation experience.

The collected data were entered and analysed using SPSS V 26. Descriptive statistics were calculated for demographic variables, clinical symptoms, and imaging findings. Inferential statistics (Chi-square test, Fisher's exact test where applicable) were used to assess the association between CT findings and patient age groups or comorbidities. A p-value was considered statistically significant.

Results

The mean age of the 60 COVID-19 patients with neurological symptoms was 56.7 ± 20.3 years, with the median and mode being 60 years (data not shown). The patients were categorised into three age groups: young, middle-aged, and old age; 28 (46.7%) were over 60 years old, 23 (38.3%) were between 30 and 60 years, and 9 (15%) were under 30 years of age (Fig. 1A). There were 32; 53.3% male patients and 28; 46.7% females (Fig 1A). The duration of illness was 11.4 days on average, with a median of 8 and a mean of 10 days (maximum: 57 days, minimum: 02 days). Among the 60 patients, neurological history could not be retrieved for approximately 10 (17%). The most common presenting symptom was altered consciousness, observed in 32 patients (53.3%). Other referral indications included disorientation in 10 patients, hemiplegia in 7, and paraplegia in 1 patient. Additionally, a few patients presented with neck stiffness, agitation, irrelevant speech, aphasia, and paraparesis. (Fig 1-B). Altered consciousness emerged as the most prevalent neurological symptom across all age groups, followed by confusion and hemiplegia (Fig. 1B). Among the patients, 28 (46.6%) had hypertension, 30 (50%) had diabetes mellitus either alone or in combination with other comorbidities, and 18 (30%) had no comorbidity (Fig. 2A).

Comorbidities and Age Group

A cross-tabulation of comorbidities and age groups among the 60 COVID-19 patients presenting with neurological symptoms was conducted. The most common comorbidities observed were diabetes mellitus (DM), hypertension (HTN), both DM and HTN, ischemic heart disease (IHD) with HTN, and DM with IHD (Fig. 2A). Among young patients, the majority had no known comorbidities (n=5), while a few had DM (n=2) or HTN (n=1). In the middle-aged group, the most frequent comorbidity was the combination of DM and HTN (n=7), followed by isolated HTN (n=3) and DM (n=3). In the old age group, the most common comorbidity was also DM and HTN combined (n=10), followed by DM (n=5), and HTN (n=4).

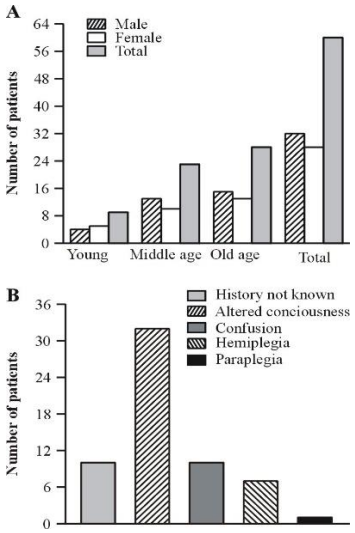

Figure 1: Graphical presentation of COVID-19 patients. A; Age wise gender distribution of patients, B; Neurological symptoms at presentation

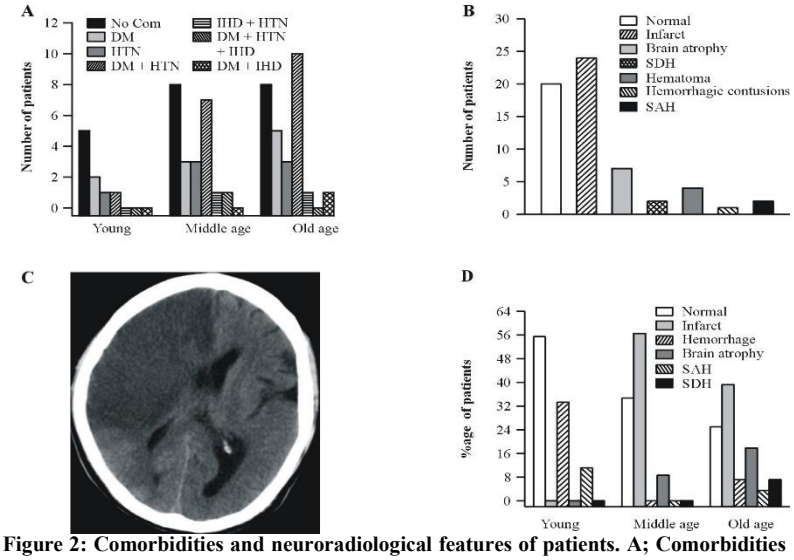

Figure 2: Comorbidities and neuroradiological features of patients. A; Comorbidities in different age groups B; Brain CT scan findings. Note that ischemic infarct was present in 24 patients followed by brain atrophy in 7 patients. A brain CT scan of patient having ischemic infarct (C), Distribution of CT Brain findings among different age groups (D)

Overall, the highest proportion of patients with combined DM + HTN (n=18) and no comorbidities (n=21) was seen across all age groups.
A Pearson chi-square test was performed to assess the association between age group and the presence of comorbidities. The test revealed: Pearson Chi-Square = 5.204, df = 10, p = 0.877 and likelihood Ratio = 5.988, p = 0.816. Linear-by-Linear Association = 1.569, p = 0.210
These results indicate no statistically significant association between age group and type of comorbidity ($p > 0.05$).
Ischemic infarct was found as the most common CT Brain finding in 24 (40%) patients. Four patients had cerebral haemorrhage, while 2 patients had subarachnoid haemorrhage. In 7;11.7% patients, there was evidence of brain atrophy (Fig. 2B).

Association between CT Brain Findings and Comorbidities
A cross-tabulation was performed to explore the relationship between CT brain findings and underlying comorbidities in 54 hospitalised COVID-19 patients presenting with neurological symptoms.
Ischemic infarction was the most frequently observed CT finding, present in 21 (38.9%) patients. It was most commonly associated with patients having both diabetes mellitus and hypertension (n = 7, 33.3% of infarcts) and was also seen in those with isolated diabetes (n = 5) or hypertension (n = 1). Notably, ischemic infarctions were present in 50% of diabetic patients, 41.2% of patients with combined DM+HTN, and 100% of those with IHD+HTN or DM+IHD.
Brain atrophy was the second most common finding, seen in 7 (13%) patients, with over half (57.1%) occurring in the DM+HTN group. Hematomas, including parenchymal haemorrhages (7.4%), subarachnoid haemorrhage (3.7%), and chronic subdural haematoma (1.9%), were found mostly in patients with no significant comorbidities or a trauma history.
Among patients without any listed comorbidities (n = 18), the majority (44.4%) had normal CT brain scans, while 39% still showed ischemic infarcts.
To assess statistical significance, a Pearson Chi-Square test was conducted: Chi-Square Value = 27.776, df = 30, p = 0.582
This indicates no statistically significant association between CT brain findings and the type of comorbidity ($p > 0.05$). However, interpretation must be made with caution, as 90.5% of the cells had expected counts less than 5, suggesting that the test may be underpowered due to small subgroup sizes.

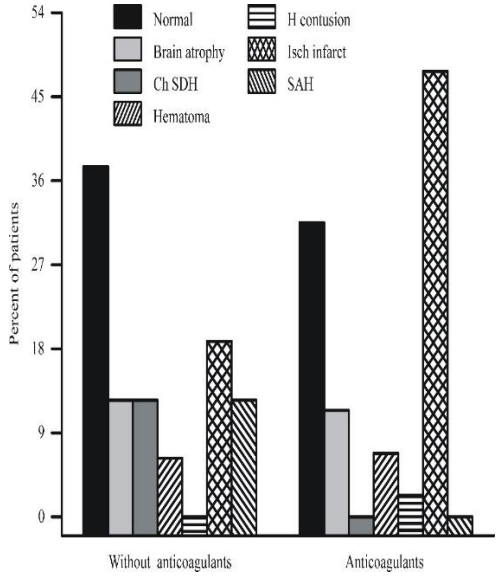

Figure 3: Graphical representation of relationship between anticoagulant use and CT brain abnormalities in COVID-19 patients

Association between CT Brain Findings and Age Group
CT brain findings were analysed in relation to patient age groups: young (<30 years), middle-aged (30–60 years), and older (>60 years). Among the 60 COVID-19 patients (Fig 2D): Ischemic infarction was the most common CT finding, observed in 24 patients (40%), with the highest proportion in the middle-aged group (56.5%), followed by the older group (39.3%). Notably, no ischemic infarcts were found in young patients. Brain atrophy was exclusively observed in middle-aged and older patients, with 71.4% of cases in the elderly group. No case was found in the younger age group. Hematomas, including chronic subdural hematoma and parenchymal haemorrhage, were more frequent in older patients. Normal CT scans were more common in younger patients (55.6%) compared to middle-aged (34.8%) and older adults (25%).
A Pearson Chi-Square test was performed to assess the association between age group and CT findings: Chi-Square value = 24.415, df = 12, p = 0.018 and Likelihood Ratio = 27.916, p = 0.006
These results indicate a statistically significant association between age group and CT brain findings ($p < 0.05$). This suggests that older age is significantly associated with more abnormal CT findings, particularly ischemic infarcts and brain atrophy.
However, it should be noted that 81% of the cells had expected counts less than 5, which may limit the reliability of the chi-square test due to small subgroup sizes.
Association between Anticoagulant Use and CT Brain Findings
To investigate the relationship between anticoagulant use and CT brain abnormalities in COVID-19 patients with neurological symptoms, a cross-tabulation was conducted. Of the 60 patients, 44 (73.3%) received anticoagulants, while 16 (26.7%) did not. Among patients not given

anticoagulants, the most frequent CT findings were as follows: Normal scans (n = 6; 37.5%), Ischemic infarct (n = 3; 18.8%) and Brain atrophy and SAH were also observed in 12.5% each.

Among patients who received anticoagulants, the CT findings were as follows: Ischemic infarct was the most common finding (n = 21; 47.7%), Normal scans were seen in 14 patients (31.8%), and Hemorrhagic findings (e.g., hematoma and hemorrhagic contusions) occurred in 4 patients (9.1%)

A Pearson Chi-Square test demonstrated a statistically significant association between anticoagulant use and CT brain findings: Chi-square = 13.959, df = 6, p = 0.030, Likelihood ratio = 14.196, p = 0.028. These findings indicate that CT brain abnormalities varied significantly with anticoagulant use, particularly with a higher frequency of ischemic infarcts observed in patients receiving anticoagulants. However, hemorrhagic complications were rare and not statistically associated with anticoagulant use alone. Note: 64.3% of cells had expected counts less than 5, which may limit the robustness of the chi-square test.

Discussion

Neurological complications of COVID-19 have been increasingly reported since the beginning of the pandemic[1,7]. Neurological complications were reported to occur in approximately 13 % of COVID-19 patients in some studies.[12] While in another study by Beghi et al, neurological manifestations were diagnosed in 79.6% of infected patients.[13] The mechanism by which SARS-CoV-2 affects the central nervous system remains under investigation but is believed to involve direct viral neuroinvasion, immune-mediated injury, and systemic complications such as coagulopathy and hypoxia.

Our retrospective study evaluated the neurological complications observed in hospitalised COVID-19 patients using NECT brain imaging and examined their associations with age, comorbidities, anticoagulant use, and steroid therapy. The aim was to better understand the patterns of neurological involvement and radiological abnormalities in patients with SARS-CoV-2 infection, a virus now recognised to cause both direct and indirect neuro-inflammatory and thrombotic events.

Imaging plays a pivotal role not only in the diagnosis of COVID-19 but also in the assessment of its various complications. The choice of non-enhanced CT (NECT) as the primary imaging modality in this study is of pragmatic concern. NECT was used as its rapid, widely available, and logistically feasible imaging tool in critically ill patients who are oxygen-dependent and often have renal dysfunction, precluding the use of contrast agents. Moreover, strict infection control protocols during the peak of the pandemic limited access to MRI in many settings, including our own. While MRI remains the gold standard for detecting subtle parenchymal changes, small infarcts, demyelination, and encephalitis, NECT retains diagnostic value in identifying acute haemorrhage, large infarcts, and mass effect.[5,11] Nonetheless, the inherent limitations of CT in detecting early ischemia or non-structural encephalopathies suggest that our findings may underrepresent the true burden of neurological involvement.

Our findings reinforce that neurological manifestations are common in COVID-19, with altered consciousness being the most prevalent symptom across all age groups, followed by confusion and hemiplegia. This aligns with previous studies reporting high incidence of encephalopathy, delirium and focal neurological deficits in hospitalised critically ill COVID-19 patients.[14,15]

In our study, ischemic infarction emerged as the most frequent (40%), consistent with earlier literature emphasising the pro-thrombotic state associated with COVID-19 and its predisposition to cerebrovascular accidents.[16,17] These findings are consistent with the broader literature describing cerebrovascular events in COVID-19, which have been linked to endothelial dysfunction, cytokine storm, platelet activation, and a hypercoagulable state.[18,19] In the Faro et al multicenter report,[20] stroke was the most common finding on neuroimaging, similar to our study, with an incidence of 6.4% followed by intracranial haemorrhage 3.8%. Acute to subacute cerebral infarction is the most common finding in these patients.[21] Among the various CT abnormalities observed, Brain atrophy was noted in 11.7% of cases, primarily in older individuals and those with comorbid diabetes and hypertension, possibly reflecting pre-existing cerebrovascular disease or COVID-related neurodegeneration. Hemorrhagic findings (hematomas, SAH) were less common but significant due to their potential association with anticoagulant use or disease-related coagulopathy. A significant association was observed between age and CT abnormalities (p = 0.018). Older patients were more likely to show abnormal imaging findings, particularly ischemic infarcts and atrophy. This supports the well-established notion that elderly COVID-19 patients are at higher risk for cerebrovascular complications, both due to age-related vascular fragility and increased baseline prevalence of chronic comorbidities.[22]

Although comorbid conditions such as diabetes and hypertension were highly prevalent in this cohort, no statistically significant association was found between comorbidity and CT findings (p = 0.582). This may be attributed to the small sample size and underpowered subgroup analyses. Nevertheless, descriptive trends suggest that ischemic strokes were more common in patients with DM+HTN, consistent with previous evidence that these conditions predispose to endothelial dysfunction and hypercoagulability in COVID-19.[23]

A statistically significant association was observed between anticoagulant use and CT brain findings (p = 0.030), with ischemic infarcts more frequently identified among patients who received anticoagulation. Although this may initially seem paradoxical—since anticoagulants are intended to prevent thrombotic events—it likely reflects a clinical selection bias: patients at higher risk of thromboembolic complications or with more severe illness were more likely to receive anticoagulants. Contrary to earlier studies that reported a higher incidence of hemorrhagic complications among anticoagulated COVID-19 patients,[20,24,] our study did not find a significant association between anticoagulant use and intracranial haemorrhage. This suggests that anticoagulants were used judiciously in our cohort, with no measurable increase in bleeding risk. These findings are consistent with other reports supporting the relative safety of anticoagulation in the management of COVID-19 patients at high risk for thrombotic events.[25,26] Steroid use was not significantly associated with CT abnormalities (p = 0.261). Given the widespread use of steroids during the pandemic for managing severe COVID-19, particularly to mitigate cytokine storm, this result may indicate that steroid therapy does not have a strong independent effect on acute neuroimaging findings. However, the overwhelming use of steroids in the sample (59 out of 60 patients) likely limited comparative power.

This study has several limitations. First, the retrospective design and use of convenience sampling may introduce selection bias and limit the generalizability of findings. Second, the absence of a control group makes it difficult to determine the relative frequency of CT abnormalities compared to non-COVID populations or milder cases. Third, only CT brain imaging was used, which may miss subtle or early neurological changes detectable by MRI. Additionally, important laboratory parameters such as D-dimer and CRP were not included, which could have provided more insight into thrombo-inflammatory states. Lastly, no follow-up imaging or clinical outcomes were assessed, preventing evaluation of the long-term neurological sequelae.

Conclusions

This study underscores the importance of early neurological evaluation in COVID-19 patients, especially in those with altered consciousness and vascular risk factors. NECT brain imaging, despite its limitations compared to MRI, remains a valuable and accessible diagnostic tool in resource-constrained, acutely ill populations. Our results also highlight the complex interplay of age, comorbidities, and therapeutic interventions in influencing the neurological outcomes of COVID-19 patients. Larger multicenter studies with inferential imaging techniques are needed to further delineate these relationships and guide clinical management.

Author Information

1,2. Assistant Professor, Lady Reading Hospital, Peshawar.
Corresponding author: Dr. Rukhsana Aziz mahamsheikh2003@gmail.com

References

1. Choi Y, Lee MK. Neuroimaging findings of brain MRI and CT in patients with COVID-19: A systematic review and meta-analysis. European journal of radiology. 2020 Dec 1;133:109393. https://doi.org/10.1016/j.ejrad.2020.109393
2. Brauer T, Paika S, Kotwani R, Khanna D. Neurological Complications of COVID-19 Infection: A Comprehensive Review. Cureus. 2024 Jul 23;16(7). https://doi.org/10.7759/cureus. 65192
3. Carod-Artal FJ. Complicaciones neurológicas por coronavirus y COVID-19. Rev Neurol. 2020 Jan 1;70(9):311-22.
4. Chen N, Zhou M, Dong X, Qu J, Gong F, Han Y, Qiu Y, Wang J, Liu Y, Wei Y, Xia JA. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. The Lancet. 2020 Feb 15;395(10223):507-13.
5. Chou SH, Beghi E, Helbok R, Moro E, Sampson J, Altamirano V, Mainali S, Bassetti C, Suarez JI, McNett M, Nolan L. Global incidence of neurological manifestations among patients hospitalised with COVID-19—a report for the GCS-NeuroCOVID consortium and the ENERGY consortium. JAMA Network Open. 2021 May 3;4(5):e2112131-. https://doi.org/10.1001/jamanetworkopen.2021.12131
6. Widyadharma IP, Hendellyn A, Laksmi Dewi AP, Adnyana IM, Samatra DP, Utami DK. Neurologic manifestations of COVID-19 infection in Asia: a systematic review. The Egyptian Journal of Neurology, Psychiatry and Neurosurgery. 2021 Feb 17;57(1):28. https://doi.org/10.1186/s41983-021-00279-3
7. Mao L, Jin H, Wang M, Hu Y, Chen S, He Q, Chang J, Hong C, Zhou Y, Wang D, Miao X. Neurologic manifestations of hospitalised patients with coronavirus disease 2019 in Wuhan, China. JAMA Neurology. 2020 Jun 1;77(6):683-90. https://doi.org/10.1001/jamaneurol 2020.1127
8. Moonis G, Filippi CG, Kirsch CF, Mohan S, Stein EG, Hirsch JA, Mahajan A. The spectrum of neuroimaging findings on CT and MRI in adults with COVID-19. American Journal of Roentgenology. 2021 Oct 25;217(4):959-74. https://doi.org/10.2214/AJR.20.24839
9. Aghagoli G, Gallo Marin B, Katchur NJ, Chaves-Sell F, Asaad WF, Murphy SA. Neurological involvement in COVID-19 and potential mechanisms: a review. Neurocritical care. 2021 Jun;34(3):1062-71. https://doi.org/10.1007/s12028-020-01049-4
10. Helms J, Kremer S, Merdji H, Clere-Jehl R, Schenck M, Kummerlen C, Collange O, Boulay C, Fafi-Kremer S, Ohana M, Anheim M. Neurologic features in severe SARS-CoV-2 infection. New England Journal of Medicine. 2020 Jun 4;382(23):2268-70. https://doi.org/10.1056/NEJMc2008597
11. Kandemirli SG, Dogan L, Sarikaya ZT, Kara S, Akinci C, Kaya D, Kaya Y, Yildirim D, Tuzuner F, Yildirim MS, Ozluk E. Brain MRI findings in patients in the intensive care unit with COVID-19 infection. Radiology. 2020 Oct;297(1):E232-5. https://doi.org/10.1148/radiol.2020201697
12. Brola W, Wilski M. Neurological consequences of COVID-19. Pharmacological Reports. 2022 Dec;74(6):1208-22. https://doi.org/10.1007/s43440-022-00424-6
13. Beghi E, Moro E, Davidescu EI, Popescu BO, Grosu O, Valzania F, Cotelli MS, Kiteva-Trenchevska G, Zakharova M, Kovács T, Armon C. Comparative features and outcomes of major neurological complications of COVID-19. European journal of neurology. 2023 Feb;30(2):413-33. https://doi.org/10.1111/ene.15617
14. Ellul MA, Benjamin L, Singh B, Lant S, Michael BD, Easton A, Kneen R, Defres S, Sejvar J, Solomon T. Neurological associations of COVID-19. The Lancet Neurology. 2020 Sep 1;19(9):767-83.
15. Liotta EM, Batra A, Clark JR, Shlobin NA, Hoffman SC, Orban ZS, Koralnik IJ. Frequent neurologic manifestations and encephalopathy-associated morbidity in Covid-19 patients. Annals of clinical and translational neurology. 2020 Nov;7(11):2221-30.https://doi.org/10.1002/acn3.51210
16. Oxley TJ, Mocco J, Majidi S, Kellner CP, Shoirah H, Singh IP, De Leacy RA, Shigematsu T, Ladner TR, Yaeger KA, Skliut M. Large-vessel stroke as a presenting feature of Covid-19 in the young. New England Journal of Medicine. 2020 May 14;382(20):e60. https://doi.org/10.1056/NEJMc2009787
17. Yaghi S, Ishida K, Torres J, Mac Grory B, Raz E, Humbert K, Henninger N, Trivedi T, Lillemoe K, Alam S, Sanger M. SARS-CoV-2 and stroke in a New York healthcare system. Stroke. 2020 Jul;51(7):2002-11. https://doi.org/org/10.1161/STROKEAHA.120.030335
18. Wu Y, Xu X, Chen Z, Duan J, Hashimoto K, Yang L, Liu C, Yang C. Nervous system involvement after infection with COVID-19 and other coronaviruses. Brain, behavior, and immunity. 2020 Jul 1;87:18-22. doi.org/10.1016/j.bbi.2020.03.031
19. Liguori C, Pierantozzi M, Spanetta M, Sarmati L, Cesta N, Iannetta M, Ora J, Mina GG, Puxeddu E, Balbi O, Pezzuto G. Subjective neurological symptoms frequently occur in patients with SARS-CoV2 infection. Brain, behavior, and immunity. 2020 Aug 1;88:11-6. https://doi.org/10.1016/j.bbi.2020.05.037
20. Faro SH, Manmatharayan A, Leiby B, Jain N, Mohamed FB, Talekar KS, Doshi A, Jambor I, Chang S, Finkelstein M, Kremer S. Neuroimaging findings in 4342 hospitalized COVID-19 subjects: a multicenter report from the United States and Europe. Journal of Neuroimaging. 2023 Sep;33(5):752-63. https://doi.org/10.1111/jon.13140
21. Yoon BC, Buch K, Lang M, Applewhite BP, Li MD, Mehan WA, Leslie-Mazwi TM, Rincon SP. Clinical and neuroimaging correlation in patients with COVID-19. American Journal of Neuroradiology. 2020 Oct 1;41(10):1791-6. https://doi.org/10.3174/ajnr.A6717

22. Merkler AE, Parikh NS, Mir S, Gupta A, Kamel H, Lin E, Lantos J, Schenck EJ, Goyal P, Bruce SS, Kahan J. Risk of ischemic stroke in patients with coronavirus disease 2019 (COVID-19) vs patients with influenza. JAMA neurology. 2020 Nov 1;77(11):1366-72. https://doi.org/10.1001/jamaneurol.2020.2730
23. Gupta A, Madhavan MV, Sehgal K, Nair N, Mahajan S, Sehrawat TS, Bikdeli B, Ahluwalia N, Ausiello JC, Wan EY, Freedberg DE. Extrapulmonary manifestations of COVID-19. Nature medicine. 2020 Jul;26(7):1017-32. doi.org/10.1038/s41591-020-0968-3
24. Sawlani V, Scotton S, Nader K, Jen JP, Patel M, Gokani K, Denno P, Thaller M, Englezou C, Janjua U, Bowen M. COVID-19-related intracranial imaging findings: a large single-centre experience. Clinical radiology. 2021 Feb 1;76(2):108-16. https://doi.org/10.1016/j.crad.2020.09.002
25. Paranjpe I, Fuster V, Lala A, Russak AJ, Glicksberg BS, Levin MA, Charney AW, Narula J, Fayad ZA, Bagiella E, Zhao S. Association of treatment dose anticoagulation with in-hospital survival among hospitalized patients with COVID-19. Journal of the American College of Cardiology. 2020 Jul 7;76(1):122-4.
26. Lopes RD, Furtado RH, Macedo AV, Bronhara B, Damiani LP, Barbosa LM, de Aveiro Morata J, Ramacciotti E, de Aquino Martins P, de Oliveira AL, Nunes VS. Therapeutic versus prophylactic anticoagulation for patients admitted to hospital with COVID-19 and elevated D-dimer concentration (ACTION): an open-label, multicentre, randomised, controlled trial. The Lancet. 2021 Jun 12;397(10291):2253-63. https://doi.org/10.1016/S0140-6736(21)01203-4