Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Original Investigation

Neuroradiological Features of Mild and Severe SARS-CoV-2 Infection

Simon Pan, PhD, Willam C. Chen, MD, Joe D. Baal, MD, Leo P. Sugrue, MD, PhD

Rationale and Objectives: An increasing number of neurological complications and corresponding radiological findings have been reported in patients with COVID-19 infection. The purpose of this study is to systematically review the current literature on COVID-19-associated neuroradiological findings and examine the prevalence of different findings in patients with both severe and mild COVID-19 infection.

Materials and Methods: A comprehensive literature search of the PubMed and Embase databases was performed. Any studies reporting CT or MRI neuroimaging findings in patients with confirmed COVID-19 infection were included. Patient demographics, main radiological findings, neurological symptoms, and severity of COVID-19 infection were tabulated and quantified according to infection severity.

Results: Sixty-one studies published between 2019 and 2020 comprising 711 patients were analyzed according to severity of respiratory symptoms. The main neuroradiological findings for patients with mild classification were cranial nerve abnormalities, ischemic infarction, and white matter abnormalities, while the main findings in patients with severe classification were white matter abnormalities, ischemic infarction, and hemorrhagic events.

Conclusion: Neuroradiological manifestations in COVID-19 infection are highly heterogeneous and differ based on the severity of COVID-19 infection. Cranial nerve abnormalities appear exclusive to mild infection, with a high degree of olfactory tract involvement, while hemorrhagic events are more common in severe infection. Notably, ischemic infarction was equally prevalent in both mild and severe COVID-19 infection. Healthcare providers treating COVID-19 patients should be aware of these potential complications and consider neurological assessment and neuroimaging studies when indicated.

Keywords: COVID-19; SARS-CoV-2; Neuroradiology; Neuroimaging; MRI.

INTRODUCTION

In 2019, the novel SARS-CoV-2 coronavirus was first reported in Wuhan, China and commenced a global pandemic that has resulted in over 21 million confirmed cases and 762,997 deaths as of August 2020 (1). Although the major cause of morbidity and mortality in COVID-19 infection is acute respiratory distress syndrome (ARDS) and subsequent respiratory failure, a surprising number of patients have been reported to exhibit neurological symptoms, ranging from acute cerebrovascular insults, encephalitis, inflammatory demyelination, to isolated sensorineural deficits—in particular, anosmia and dysgeusia (2). Therefore, it is of critical importance for healthcare providers to be aware of the spectrum of neurological and neuroradiological manifestations that can either present as an incidental finding or initial symptom of COVID-19 infection, or as potential sequelae to a primary COVID-19 pneumonia. In particular, it is poorly understood how presentation of neurological symptoms can vary in patients with different severities of COVID-19 infection. Towards this end, a systematic review was conducted on the current literature thus far on neuroradiological findings in the setting of mild and severe SARS-CoV-2 infection.

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From the Department of Radiology and Biomedical Imaging, Neuroradiology Section, University of California, San Francisco, California, USA (S.P., J.D.B., L.P.S.); Department of Radiation Oncology, University of California, San Francisco, 505 Parnassus Ave, San Francisco, California, 94143, USA (W.C.C.). Received August 5, 2020; revised August 19, 2020; accepted August 21, 2020. Conflicts of Interest: Authors declare that they have no conflicts of interest. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. **Address correspondence to:** L.P.S. e-mail: leo.sugrue@ucsf.edu

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METHODS

Literature Search

A systematic search was conducted via query of the Pubmed and Embase electronic databases with the following search terms: "((brain or neurological or neurology or neuropsychiatric or neuroimaging or anosmia or neuroradiological or neuroradiology) AND (MRI or magnetic resonance imaging or CT or computerized tomography or radiology or radiological or imaging) AND (COVID-19 or novel coronavirus or SARS-COV-2 or 2019-nCoV))." Duplicate records between the two databases and studies without sufficient abstract and title relevance were excluded in an initial screen. Screening based on the full-text of the article was then performed on the remaining studies,

excluding any that met the following predetermined criteria: (1) the study did not contain CT or MRI findings of the brain, (2) the study did not involve patients with confirmed COVID-19 infection, (3) the study was a review, editorial, or commentary (Fig 1). Literature search and study screening were performed by a single investigator and was completed by July 17, 2020. The quality of included studies was examined based on the nine item National Institutes of Health (NIH) Quality Assessment Tool for Case Series, which assesses the quality of data in a study based on the following nine questions: (1) Was the study question or objective clearly stated? (2) Was the study population clearly and fully described, including a case definition? (3) Were the cases consecutive? (4) Were the subjects comparable? (5) Was the intervention clearly described? (6) Were the outcome measures clearly defined, valid, reliable, and implemented consistently across all study participants? (7) Was the length of follow-up adequate? (8) Were the statistical methods well-described? and (9) Were the results well-described?; an overall rating of "good," "fair," or "poor" was then assigned (3). Studies Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklists were utilized for the study selection process (4). No institutional review board approval was required for this study.

Data extraction

Patient demographics (age, sex, and number), main radiological findings (imaging modality, anatomical localization of findings, textual descriptions, and interpretation), neurological symptoms, and severity of COVID-19 infection (out-patient, in-patient, admission to the intensive care unit (ICU), intubation, and mechanical ventilation status) were systematically extracted from primary literature by two investigators. Severity of COVID-19 infection was then binarized into mild or severe infections, in which any mention of admission to the ICU for respiratory illness, ARDS, or invasive respiratory support was classified as severe. General categories of textual descriptions of imaging findings were then quantified and tabulated by two investigators, with disputes mediated by consensual discussions and/or arbitration by the main investigator.

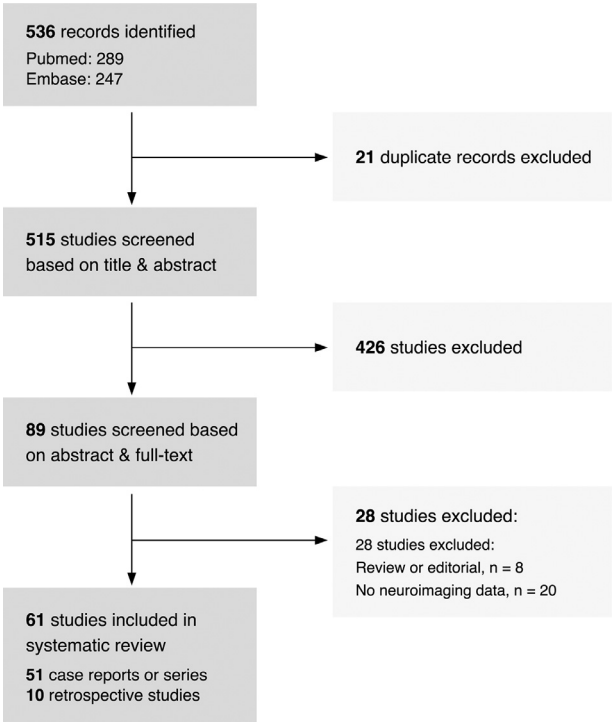

Fig. 1. PRISMA schematic of literature search and screening.

RESULTS

Overview of included studies

In total, 536 records were identified from Pubmed and Embase and 89 nonduplicate studies were screened based on title and abstract relevance. Twenty-eight studies were then excluded from this pool, primarily those that reported neurological symptoms in patients but did not include radiological findings. Because the SARS-COV-2 pandemic has been a rapidly emergent phenomenon, there is a relatively low number of large-scale retrospective and observational studies reporting neuroradiological findings currently represented in the literature. Consequently, we decided to include 51 case reports and case series in this review for a total of 61 studies (5–65) comprising 711 patients. All of these studies used a combination of CT and MRI, with the exception of a singular instance of PET-CT to evaluate orbitofrontal function in a patient with anosmia (41). The methodological quality of the included studies as determined by the NIH quality assessment tool are detailed in Table 1 and were generally rated as "fair" and "good."

Synopsis of retrospective studies

Ten observational or retrospective studies with study cohort >10 patients describing 628 patients of median age 66 were identified and screened for inclusion in the current study (Table 2, Fig 2) (5–14). The vast majority of these patients (579, 92.2%) were admitted to the ICU, intubated and placed on mechanical ventilation, or were reported to have ARDS, and thus were classified as having severe COVID-19 infection. The predominant neuroradiological findings in this population of 628 patients were nonspecific white matter abnormalities (162, 25.8%), ischemic infarct (141, 22.5%), and cerebral hemorrhage (78, 12.4%). Less commonly reported findings included leptomeningeal enhancement (13, 2.1%), venous thrombosis (3, 0.48%), posterior reversible encephalopathy syndrome (3, 0.48%), olfactory bulb abnormalities (3, 0.48%), encephalitis (1, 0.16%). Study-specific neuroradiological findings for each of the 10 retrospective studies are detailed in Supplementary Table 1.

Synopsis of case reports and series

Fifty-one case reports and case series describing 83 patients of median age 54 years were included in the current study,

TABLE 1. NIH Quality Assessment Tool for Case Series

Citation	NIH Quality Assessment Tool Criteria									Overall Rating
	1	2	3	4	5	6	7	8	9	
Radmanesh, 2020 (5)	Yes	Yes	NR	Yes	NA	Yes	NA	Yes	Yes	Fair
Helms, 2020 (6)	Yes	Yes	CD	Yes	NA	Yes	NA	Yes	Yes	Good
Giorgianni, 2020 (7)	Yes	Yes	Yes	Yes	NA	Yes	NA	Yes	Yes	Fair
Jain, 2020 (8)	Yes	Yes	CD	Yes	NA	Yes	NA	Yes	Yes	Good
Kandemirli, 2020 (9)	Yes	Yes	CD	Yes	NA	Yes	NA	Yes	Yes	Fair
Kremer, 2020 (10)	Yes	Yes	CD	Yes	NA	Yes	NA	Yes	Yes	Fair
Coolen, 2020 (11)	Yes	Yes	Yes	Yes	NA	Yes	NA	Yes	Yes	Good
Mahammedi, 2020 (12)	Yes	Yes	CD	Yes	NA	Yes	NA	Yes	Yes	Good
Radmanesh, 2020 (13)	Yes	Yes	Yes	Yes	NA	Yes	NA	Yes	Yes	Good
Chougar, 2020 (14)	Yes	Yes	Yes	Yes	NA	Yes	NA	Yes	Yes	Good
Falcone, 2020 (15)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Abdi, 2020 (16)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Hutchins, 2020 (17)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Virhammar, 2020 (18)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Li, 2020 (19)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Pinto, 2020 (20)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Sancho-Saldaña, 2020 (21)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Oguz–Akarsu, 2020 (22)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Zhang, 2020 (23)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Mirzaee,2020 (24)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Novi, 2020 (25)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Efe, 2020 (26)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Hayashi, 2020 (27)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Politi, 2020 (28)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Laurendon, 2020 (29)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Garaci, 2020 (30)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Hemasian, 2020 (31)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Wong, 2020 (32)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Vollono, 2020 (33)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Galougahi, 2020 (34)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Moriguchi, 2020 (35)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Alberti, 2020 (36)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Lantos, 2020 (37)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Yin, 2020 (38)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Al-olama, 2020 (39)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Farhadian, 2020 (40)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Karimi-Galougahi, 2020 (41)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Good
Dinkin, 2020 (42)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Franceschi, 2020 (43)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Aragão, 2020 (44)	Yes	Yes	CD	Yes	NA	Yes	NA	Yes	Yes	Good
Kulick-Soper, 2020 (45)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Cariddi, 2020 (46)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Hanafi, 2020 (47)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Li, 2020 (48)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Espinosa, 2020 (49)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Haddadi, 2020 (50)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Radmanesh, 2020 (51)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Parsons, 2020 (52)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Afshar, 2020 (53)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Dixon, 2020 (54)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Sachs, 2020 (55)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Zanin, 2020 (56)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Kaya, 2020 (57)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Poyiadji, 2020 (58)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair

(*continued*)

TABLE 1. (Continued)

Citation	NIH Quality Assessment Tool Criteria									Overall Rating
	1	2	3	4	5	6	7	8	9	
Nicholson, 2020 (59)	Yes	Yes	CD	Yes	NA	Yes	NA	Yes	Yes	Good
Avula, 2020 (60)	Yes	Yes	Yes	Yes	NA	Yes	NA	Yes	Yes	Good
Malentacchi, 2020 (61)	Yes	Yes	NA	NA	NA	NA	NA	NA	Yes	Fair
Kishfy, 2020 (62)	Yes	Yes	CD	Yes	NA	Yes	NA	Yes	Yes	Fair
Lang, 2020 (63)	Yes	Yes	Yes	Yes	NA	Yes	NA	Yes	Yes	Fair
Ashrafi, 2020 (64)	Yes	Yes	NR	Yes	NA	Yes	NA	Yes	Yes	Good
Morassi, 2020 (65)	Yes	Yes	NR	Yes	NA	Yes	NA	Yes	Yes	Fair

CD, cannot determine; NA, not applicable; NIH, National Institutes of Health; NR, not reported. The NIH Quality Assessment Tool for Case Series (3) is based on nine questions: (1) Was the study question or objective clearly stated? (2) Was the study population clearly and fully described, including a case definition? (3) Were the cases consecutive? (4) Were the subjects comparable? (5) Was the intervention clearly described? (6) Were the outcome measures clearly defined, valid, reliable, and implemented consistently across all study participants? (7) Was the length of follow-up adequate? (8) Were the statistical methods well-described? (9) Were the results well-described?

summarized in (Table 3, Fig 3) (15–65). The severity of COVID-19 patients in this pool was more diverse, with 41 patients (49.4%) classified as mild and 42 patients (50.6%) classified as severe. As there is a large variation in both the neurological presentation and severity of respiratory symptoms in COVID-19 patients, we listed the prevalence of major neuroradiological findings in mild and severe COVID-19 patients separately. Amongst the 41 mild patients, the most prevalent radiological findings were cranial nerve abnormalities (13, 31.7%), many of which were abnormalities in the olfactory tract (9, 30.0%), followed closely by cerebral infarction (12, 29.3%) and white matter abnormalities (8, 19.5%). Leptomeningeal enhancement (3, 7.3%), myelopathy (2, 4.9%), cerebral hemorrhage (1, 2.4%), venous thrombosis (1, 2.4%), peripheral nerve abnormalities (1, 2.4%), and normal imaging (3, 7.3%) were less commonly reported findings. Amongst the 42 severe patients, the most prevalent radiological findings were white matter abnormalities (21, 50%), followed by cerebral infarct (13, 33.3%) and cerebral hemorrhage (13, 33.3%). Posterior reversible encephalopathy syndrome (4, 9.5%) and venous thrombosis (1, 2.4%) were less commonly reported findings. Study-specific radiological findings and neurological symptoms are detailed for mild patients in Supplementary Table 2 and severe patients in Supplementary Table 3.

TABLE 2. Summary of Retrospective Studies

Total number of retrospective studies	10 studies
Total number of patients	628 patients
Median age	66 years
Severity of respiratory symptoms	49 mild patients (7.8%) in 2 studies 579 severe patients (92.2%) in 9 studies
Neuroradiological findings (628 patients)	
White matter abnormalities	162 (25.8%)
Ischemic infarct	141 (22.5%)
Cerebral hemorrhage	78 (12.4%)
Leptomeningeal enhancement	13 (0.54%)
Venous thrombosis	3 (0.48%)
Posterior reversible encephalopathy syndrome	3 (0.48%)
Olfactory bulb abnormalities	3 (0.48%)
Encephalitis	1 (0.16%)

DISCUSSION

In this study, the range of potential neuroradiological findings that have been reported in patients with SARS-CoV-2 infection were systematically tabulated according to severity of the primary respiratory infection. To the best of our knowledge, this is the first systematic review on neuroradiological findings in COVID-19 performed in this manner. Surprisingly, cerebral infarction was commonly reported in cases of both mild and severe COVID-19 infection, suggesting that ischemic stroke may be a result of a virally-induced hypercoagulable state and not merely a consequence of severe systemic disease. Hemorrhagic events are also a commonly reported finding, but in contrast to ischemic infarction, the prevalence of hemorrhage appears to be more specific for severe COVID-19 patients. Although the majority of retrospective cohorts analyzed consisted solely of severe patients, one recently published study examined a comparable amount of ICU and non-ICU patients and similarly concluded that ischemic lesions were equally present across both populations while hemorrhages were limited to those with severe disease (14). In contrast, isolated cranial nerve abnormalities were exclusively reported in patients with mild infection, with a high degree of olfactory tract involvement. These structural findings are corroborated by ^{18}FDG PET/CT imaging of an otherwise asymptomatic COVID-19 patient with anosmia demonstrating hypometabolism in the orbitofrontal cortex (41). These data suggests that cranial nerve abnormalities and anosmia could present as the initial or sole indicator of COVID-19 infection.

Many pathophysiological mechanisms of nervous system involvement in COVID-19 infection have been proposed.

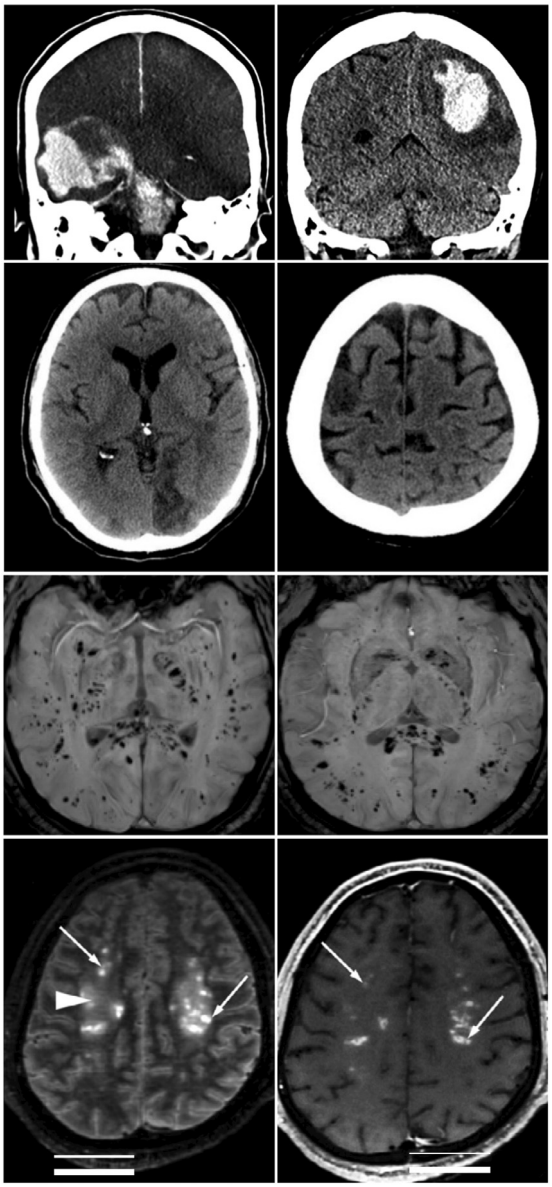

Fig. 2. Neuroimaging findings in patients with severe COVID-19 infection Head CT depicting (a) extensive acute intracranial hemorrhage in a 74-year-old man with absent brainstem reflexes following uncal, subfalcine, and transtentorial herniation and (b) left parietal intraparenchymal hemorrhage with surrounding vasogenic edema in a 61-year-old woman with right-sided weakness and numbness (13). (c,d) Noncontrast head CT showing two different ischemic lesions in the left occipital and right frontal lobes of a 64-year-old man with elevated coagulation tests (65). (e,f) Axial susceptibility weighted imaging of extensive microhemorrhages in a 57-year-old man, primarily in the subcortical white matter, corpus callosum, internal capsule and cerebellar peduncles (10). (g,h) White matter abnormalities that are hyperintense on axial T2 FLAIR imaging (g) and show perivascular enhancement on postcontrast T1-weighted images (h) in a 37-year-old male who developed ARDS and multiple organ failure (14). Panels a and b reproduced from Radmanesh et al. (13) with permission from the American Society of Neuroradiology, panels c and d reproduced from Morassi et al. (65) with permission from Springer Nature (COVID-19 PMC Open Access Subset). Panels e and f reproduced from Kremer et al. (10) and panels g and h reproduced from Chougar et al. (14) with permission from the Radiological Society of North America (COVID-19 PMC Open Access Subset).

TABLE 3. Summary of Case Reports and Series

Total number of case reports and series	42 case reports, 9 case series
Total number of patients	83 patients
Median age	54 years
Severity of respiratory symptoms	41 mild patients (49.4%) in 30 (57.7%) studies 42 severe patients (50.6%) in 21 (42.3%) studies
Neuroradiological findings in mild COVID-19 infection (41 patients)	
Cranial nerve abnormalities	13 (31.7%) 9 (30.0%) associated with the olfactory tract
Ischemic infarct	12 (29.3%)
White matter abnormalities	8 (19.5%)
Normal imaging	3 (7.3%)
Leptomeningeal enhancement	2 (4.9%)
Myelopathy	2 (4.9%)
Cerebral hemorrhage	1 (2.4%)
Venous thrombosis	1 (2.4%)
Peripheral nerve abnormality	1 (2.4%)
Neuroradiological findings in severe COVID-19 infection (42 patients)	
White matter abnormalities	21 (50%)
Ischemic infarct	13 (33.3%)
Cerebral hemorrhage	13 (31.0%)
Posterior reversible encephalopathy syndrome	4 (9.5%)
Venous thrombosis	1 (2.4%)

These include a hypercoagulable state leading to thromboembolic events, endothelial cell and neurovascular injury via ACE2-mediated tropism and subsequent hemorrhage, hypoxic ischemia secondary to acute respiratory failure, direct neurotropism and access to the brain via hematogenous spread or retrograde migration along the olfactory nerve, and inflammatory injury secondary to cytokine storms (2,66). Although anosmia can conceivably be caused by rhinitis or mucus plugging as in influenza and other viral infections, these are not typical symptoms of COVID-19 infection nor would this explanation be consistent with the length of anosmia and central localization of reported structural and functional brain abnormalities (2,8,41). The prevalence of these findings in patients with mild or asymptomatic infection further argue against a conductive anosmia and more supports a sensorineural etiology. Although some coronaviruses can invade the olfactory bulb via the cribriform plate (67), a lack of evidence for *Ace2* expression in murine neurons (68) argues against direct neurotropism of SARS-CoV-2, although a recent study reported *Ace2* expression in mitral cells of the olfactory bulb (69). Rather, SARS-CoV-2 may indirectly influence olfactory neural circuits via infection of non-neuronal *Ace2*-positive cells such as oligodendrocytes,

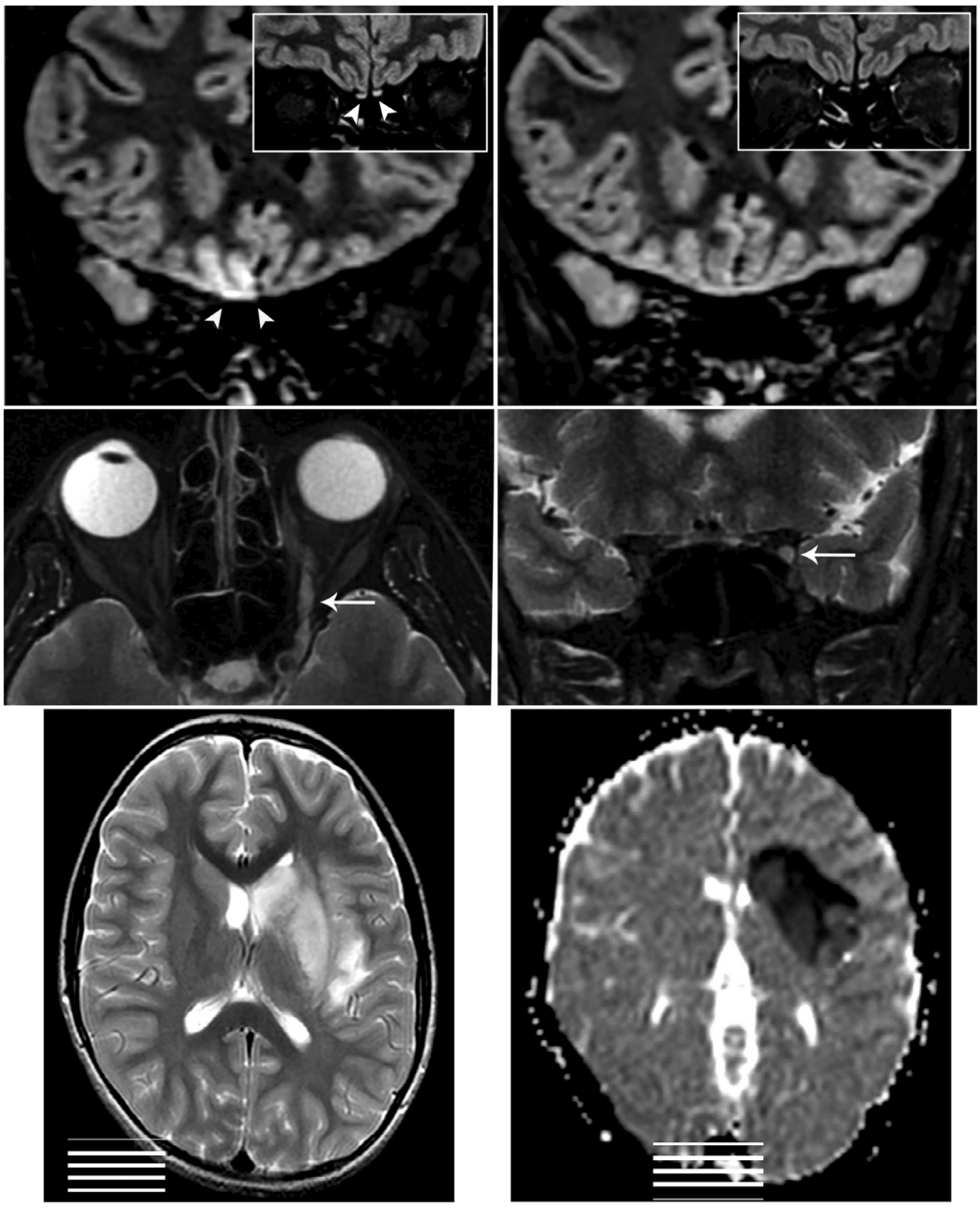

Fig. 3. Neuroimaging findings in patients with mild COVID-19 infection. (a) Coronal T2 FLAIR view of a cortical hyperintensity in the right gyrus rectus (yellow arrowheads) and subtle hyperintensities in the bilateral olfactory bulbs (inset, white arrowheads) of a 25-year-old woman with anosmia and PCR-confirmed SARS-CoV-2 infection; (b) 28 days later, the cortical hyperintensity is completely resolved with slight reductions in the intensity and thickness of the olfactory bulbs (28). Axial (c) and coronal (d) T2-weighted fat-suppressed images depicting an enlarged CN III and increased signal of the cavernous sinus-exiting nerve in a 36-year-old man (37). Axial T2-weighted MRI (e) and apparent diffusion coefficient (ADC) map (f) depicting an acute ischemic stroke in the left basal ganglia and insula, likely from focal arterial vasculopathy, in a previously healthy SARS-CoV-2-positive 12-year-old boy with seizures, right hemiparesis, and dysarthria but no respiratory symptoms or chest CT findings (24). Panels a and b reproduced from Politi et al. (28) with permission from American Medical Association, panels c and d reproduced from Lantos et al. (37) with permission from the American Society of Neuroradiology. Panels e and f reproduced from Mirzaee et al. (24) with permission from the Radiological Society of North America (COVID-19 PMC Open Access Subset).

astrocytes, and endothelial cells by pathologically altering axonal conduction velocity, metabolic and neurotransmitter homeostasis, and/or cerebral perfusion (68,70,71). The high prevalence of white matter abnormalities, ischemic infarction, and hemorrhage found on neuroimaging of COVID-19 patients support these disease mechanisms. Given the wide range of potential neurological symptoms reported in COVID-19 patients, it is likely that many or all of these mechanisms are involved to some degree across the patient population.

There are several limitations to this study. It is difficult to standardize reporting of radiological data, which can be in the

form of objective observations or presumptive diagnoses that may be subject to clinical bias. Reporting standards also varied for MRI sequence details, clinical neurological symptoms, and descriptions of findings. A subset of neuroimaging abnormalities, particularly in the population of elderly, ill patients with severe infection, may be incidental findings unrelated to acute COVID-19 infection. Routine neuroimaging represents an unnecessary viral exposure risk and is not indicated in most COVID-19 patients, and so brain imaging studies are likely to be selectively done in patients with significant neurological symptoms, underreporting potential findings in patients with mild disease. Conversely, there is a high probability of publication bias in the reviewed case reports as COVID-19 patients with unremarkable neuroimaging findings are unlikely to be published.

Concluding remarks

We suggest that the findings of this systematic review provides public health utility in that incidental neuroimaging findings or unexplained neurological symptoms can prompt evaluation for mild COVID-19 infection and prevention of asymptomatic spread, as well as clinical utility in aiding surveillance and management of potential life-threatening neurological sequalae in the setting of severe COVID-19 infection such as cerebral infarction and hemorrhage. Amidst a global pandemic, dissemination of information to the medical community at all levels—from case reports to retrospective studies to meta-analyses—will be required for clinicians to make informed decisions when caring for patients with SARS-CoV-2. From a pathophysiological perspective, lateral integration of clinical data, neuroimaging findings, pathology reports, animal models, and molecular studies will be necessary to fully understand the effects of COVID-19 infection on the nervous system.

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SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.acra.2020.08.026.