—Case Reports—

New-Onset Schizophrenia in an Adolescent after COVID-19

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Schizophrenia develops during adolescence. Maternal infections during the fetal period increase the incidence of schizophrenia in children, which suggests that the pathogenesis involves neuroinflammation. Here, we report a case of new-onset schizophrenia in a 16-year-old boy after COVID-19. After developing COVID-19, he entered a catatonic state 4 days later and was hospitalized. Benzodiazepines alleviated his catatonia, but hallucinations and delusions persisted. Encephalitis and epilepsy were excluded by magnetic resonance imaging (MRI), encephalography, and cerebrospinal fluid examination. Psychosis persisted after the virus titer declined and the inflammatory response subsided. Moreover, the patient exhibited delusions of control-a Schneider's first-rank symptom. Schizophrenia was diagnosed, and olanzapine improved his symptoms. He had a brief history of insomnia before COVID-19 but his symptoms did not satisfy the ultra-high-risk criteria. However, COVID-19 may have facilitated development of schizophrenia through neuroinflammation and volume reduction in the gray matter of the right medial temporal lobe. This case demonstrates that infectious diseases in adolescents should be carefully managed, to prevent schizophrenia. (J Nippon Med Sch 2025; 92: 287–295)

Key words: schizophrenia, COVID-19, first-episode psychosis, neuroinflammation

Introduction

The first episode of schizophrenia typically occurs in adolescence[1]. The vulnerability-stress model has been proposed to explain the onset mechanisms of schizophrenia[2]. When exposed to stressors such as infections, life events, or environmental factors, vulnerable persons may develop schizophrenia. Maternal or postnatal infections[3,4] and allergic diseases[5] are also risk factors.

The prefrontal cortex develops during puberty through synaptic pruning by microglia[6]. Excessive synaptic pruning is a cause of schizophrenia[7]. Complement component 3 or 4[8] and autoantibodies[9] are involved in schizophrenia, suggesting that inflammation and excess microglial activity could promote disease onset.

Coronavirus disease 2019 (COVID-19) is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which disrupts immunity and considerably impacts mental health. A 2-year retrospective cohort study of more than 1.2 million patients[10] revealed that patients younger than 18 years diagnosed with COVID-19 did not have a higher risk of mood or anxiety disorders, but the risk of psychotic disorders remained high even 2 years after a COVID-19 diagnosis. Moreover, young patients with a history of COVID-19 had a higher incidence of psychotic disorders than did those diagnosed with other respiratory infections. The reasons for this increase in the

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Table 1A Blood test results upon hospitalization. There were no obvious abnormal values

Leucocyte	4.58 $10^3/\mu L$
Erythrocyte	4.73 $10^6/\mu L$
Hemoglobin	14.2 g/dL
Hematocrit	42.9 %
Platelet	337 $10^3/\mu L$
Neutrophil	59.2 %
Lymphocyte	32.5 %
Monocyte	7 %
Eosinophil	0.9 %
Basophil	0.4 %
Prothrombin time (PT)	14 sec
Activated partial thromboplastin time (APTT)	28.3 sec
Fibrinogen	270.3 mg/dL
D-dimer	≤0.5 μg/mL
Alkaline Phosphatase (ALP)	95 IU/L
Aspartate Transferase (AST)	30 IU/L
Alanine Transaminase (ALT)	11 IU/L
Lactate Dehydrogenase (LDH)	280 IU/L
γ-glutamyl transpeptidase (γ-GTP)	20 IU/L
Cholinesterase	299 IU/L
Creatine Kinase (CK)	133 IU/L
Amylase	40 IU/L
Sodium	140 mEq/L
Potassium	4.4 mEq/L
Chloride	103 mEq/L
Calcium	9.9 mg/dL
Inorganic Phosphate (IP)	3.6 mg/dL
Magnesium	2 mg/dL
Total protein (TP)	7.3 g/dL
Albumin	4.7 g/dL
Ammonia	50 μg/dL
Blood Urea Nitrogen (BUN)	14.1 mg/dL
Creatinine	0.84 mg/dL
Estimated glomerular filtration rate (eGFR)	105.9 mL/min
Uric acid	7.1 mg/dL
Total Bilirubin	1.55 mg/dL
Glucose	85 mg/dL
Hemoglobin A1C	5.6 %
N-terminal-pro-brain natriuretic peptide (NT-proBNP)	9 pg/mL
C-Reactive Protein (CRP)	0.04 mg/dL
Procalcitonin	0.03 ng/mL
Thyroid-stimulating hormone (TSH)	3.09 μU/mL
Free triiodothyronine (FT3)	3.03 pg/mL
Free thyroxine (FT4)	1.69 ng/dL
Rapid plasma reagin (RPR)	(–)
Treponema pallidum latex agglutination test (TPLA-Ab)	(–)
Hepatitis B surface antigen (HBs-Ag)	(–)
Hepatitis C virus antibody (HCV-Ab)	(–)
Human immunodeficiency virus antibody (HIV-Ab)	(–)

risk of psychosis remain unclear.

Here, we report an adolescent case of new-onset schizophrenia after COVID-19 and discuss possible mechanisms by which SARS-CoV-2 infection may have triggered the disease.

The patient and the patient's family provided permission for the study and its publication, and patient privacy was duly protected.

Case Report

A 16-year-old boy with insomnia visited a psychiatrist before entrance examinations for high school 18 months before SARS-CoV-2 infection (at age 15 years). Neither psychotic nor developmental concerns were reported, and the patient's academic performance was normal. His insomnia resolved and he stopped seeing his psychiatrist after passing the examinations. He was able to continue schoolwork and maintain good relationships with his classmates. He reported having asthma from infancy to age 9 years but had no asthma attacks thereafter.

He stayed home when he contracted COVID-19, with fever and mild cough. Four days after onset, he began exhibiting incoherent behavior: rushing out of his house suddenly, bursting into laughter by himself, and sudden disruption of communication. He was admitted to our hospital when he entered a catatonic state and became incapable of moving on his own, 8 days after COVID-19 onset. He displayed fever, rigidity, catalepsy, intermittent tremor, and incoherent speech and behavior.

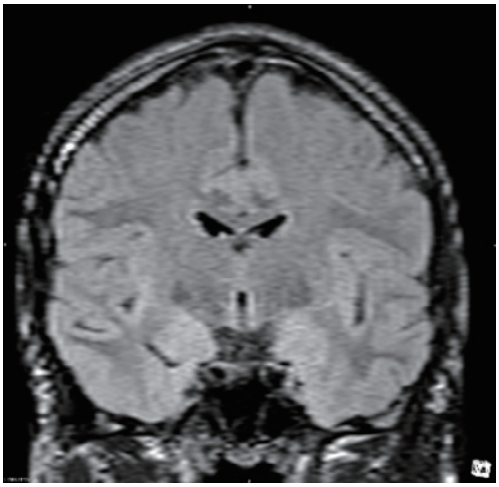

Fig. 1 Head magnetic resonance imaging (MRI) on admission revealed no abnormalities.

Blood tests (**Table 1A**) and head magnetic resonance imaging (MRI) (**Fig. 1**) did not suggest encephalitis or delirium. A cerebrospinal fluid examination ruled out infectious encephalitis. Anti-*N*-methyl-D-aspartate antibody, a representative autoantibody in autoimmune encephalitis, was not detected (**Table 1B**).

Real-time PCR testing of nasopharyngeal swabs obtained upon hospitalization (8 days after COVID-19 onset) showed that cycle threshold (Ct) values for the coronavirus were greater than 30 (**Table 1C**), which suggested that the virus titer was declining. The inflammatory response was not severe, and the patient did not develop pneumonia, asthma attack, or respiratory or circulatory failure. Severe deterioration in his general condition and infectious encephalitis due to SARS-CoV-2 were deemed unlikely (**Table 1A, 1B**); however, he received antiviral therapy (remdesivir), as well as anti-interleukin-6 (IL-6) receptor antibody (tocilizumab) and methylprednisolone sodium succinate, to limit the risk of encephalopathy due to SARS-CoV-2.

Elevated levels of creatine kinase (CK) in blood (hyperCKemia), a sign of malignant catatonia or neuroleptic malignant syndrome, were noted after injection of haloperidol to palliate restlessness (**Fig. 2**). Antipsychotics were avoided, and benzodiazepines (diazepam and clonazepam) and hydration by an intravenous drip alleviated catatonia and hyperCKemia. He initially had a fever, although C-reactive protein remained in the normal range (≤0.04 mg/dL). Fever subsided when catatonia and hyperCKemia improved.

Table 1B Cerebrospinal fluid examination upon hospitalization including reverse transcription-polymerase chain reaction (RT-PCR) for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and ordinary bacterial culture. There were no obvious signs of encephalitis or meningitis

Leucocyte	1 /μL
Protein	30 mg/dL
Glucose	61 mg/dL
Chloride	129 mEq/L
Anti-N-methyl-D-aspartate (NMDA)	(–)
antibody (cell-based Immunofluorescence Assay)	Titer <1
Reverse transcription-polymerase chain reaction (RT-PCR) for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)	(–)
Cycle threshold (Ct) (E)	0.0
Ct (N2)	0.0
Ordinary bacterial culture	(–)

Nevertheless, the patient began to develop hallucinations (visual hallucinations initially, after which auditory and verbal hallucination gradually became dominant), delusional mood ("I feel something terrible is happening"), and delusions ("I killed all these people"). Psychotic symptoms gradually progressed as delusions of control emerged, which is a Schneider's first-rank symptom (FRS).

Encephalitis caused by infection or autoimmunity, epilepsy, delirium, and other diseases that could induce aberrant behaviors, such as endocrine and metabolic diseases, were excluded by electroencephalography (EEG) (**Fig. 3**) and further blood testing (**Table 1D**). MRI using a voxel-based specific regional analysis system for Alzheimer disease (VSRAD) suggested diminished gray matter volume in the right medial temporal lobe (**Fig. 4 A, 4B, 4C, 4D**).

Table 1C The cycle threshold (Ct) of RT-PCR for SARS-CoV-2 from a nasopharyngeal swab on the day of hospitalization. The Ct value over 30 suggested a declining and low virus titer

RT-PCR for SARS-CoV-2	(+)
Ct (E)	32.1
Ct (N2)	34.8

Schizophrenia was diagnosed based on the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5), and olanzapine (10 mg/day) improved most of the positive symptoms. However, he could not concentrate on anything for longer than 10 minutes and had to receive repeated education upon discharge to memorize important points, suggesting cognitive impairment. He became stable and was discharged 3 months after hospitalization, at which point he was referred to a local clinic.

Discussion

In a systematic review of 40 case reports of psychosis, excepting delirium, after COVID-19, 92% of patients had delusions, 60% had auditory hallucinations, 23% had visual hallucinations, and 15% had catatonia[11]. The duration of the intervention for psychosis varied from 2 to 90 days, suggesting that both brief psychotic disorders and schizophrenia may have been included. However, a high incidence of visual hallucinations was noted despite the

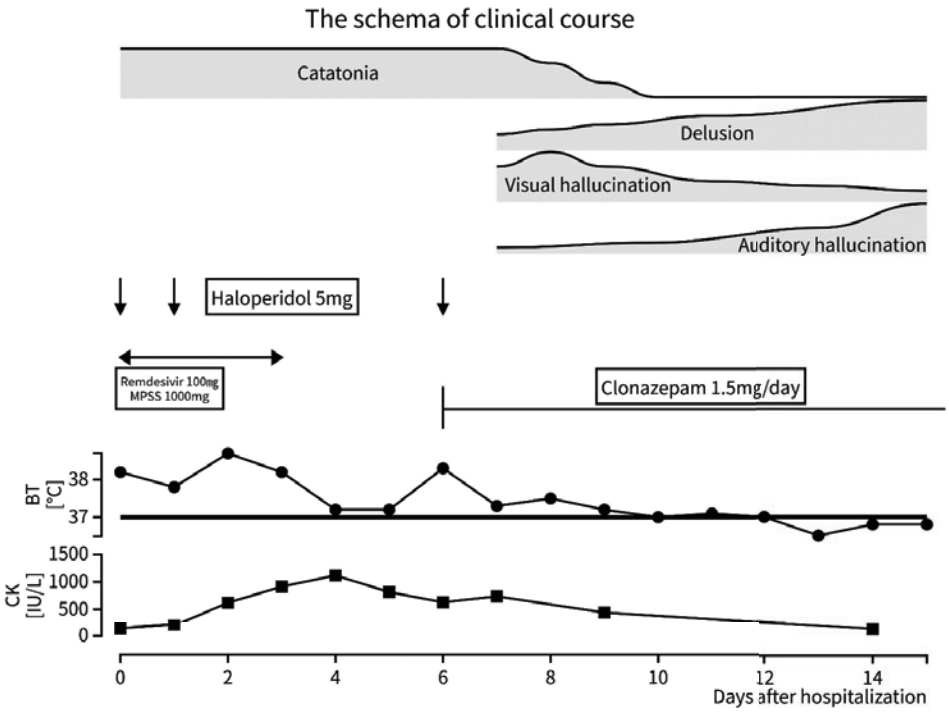

Fig. 2. The patient's acute clinical course. He developed HyperCKemia, which resolved after antipsychotic treatment was stopped and benzodiazepine treatment was started. Catatonia and fever also resolved but psychotic symptoms progressed.
MPSS: Methylprednisolone sodium succinate; BT: Body temperature; CK: Creatine kinase.

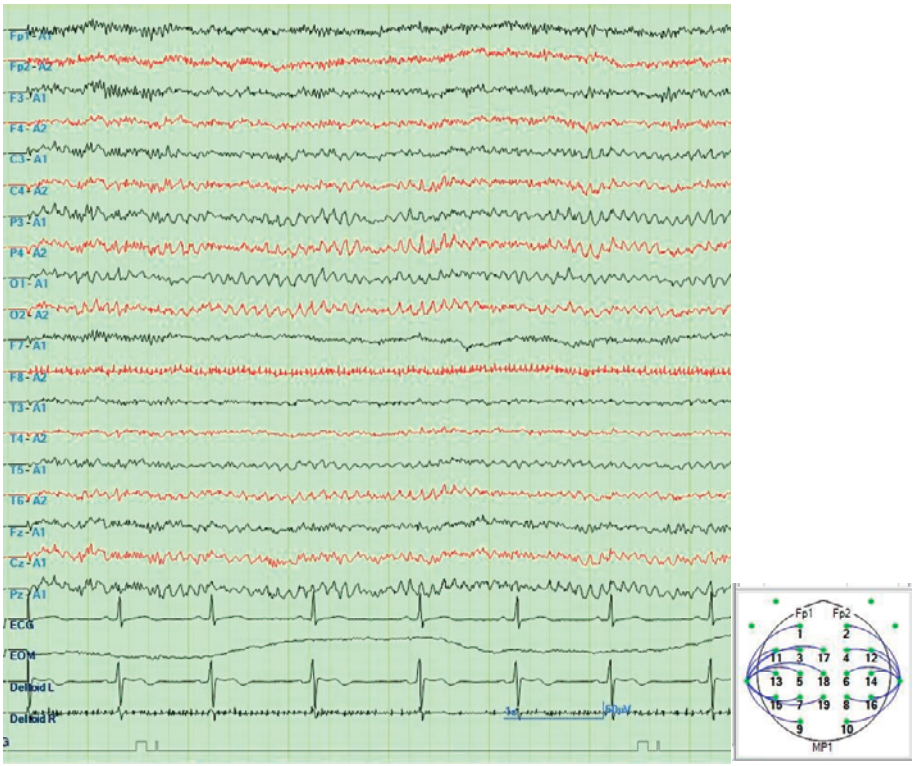

Fig. 3. An electroencephalogram (EEG) 8 days after admission showed no abnormal activity.

Table 1D Further blood workup. Autoimmune diseases, endocrine, metabolic, or nutritious problems were not indicated

Rheumatoid factor (RF)	<3 IU/mL
Immunoglobulin G (IgG)	934 mg/dL
Immunoglobulin A (IgA)	88 mg/dL
Immunoglobulin M (IgM)	120 mg/dL
Complement component 3 (C3)	83 mg/dL
Complement component 4 (C4)	8.4 mg/dL
50% hemolytic complement (CH50)	21 U
Anti-double stranded DNA	≤1.7 IU/mL
Proteinase 3 antineutrophil cytoplasmic antibody (PR3-ANCA)	<0.6 IU/mL
Myeloperoxidase Anti-neutrophil Cytoplasmic Antibody (MPO-ANCA)	0.2 IU/mL
Anti-thyroid peroxidase	<9.0 IU/mL
TSH Receptor antibody	<0.8 IU/L
Anti-thyroglobulin	<100 Times
Anti-ribonucleoprotein (Anti-RNP)	<0.5 U/mL
Adrenocorticotropic hormone (ACTH)	11.9 pg/mL
Cortisol	11.9 μg/dL
Prolactin	10.8 ng/mL
Vitamin B1	31.1 ng/mL
Vitamin B12	1,998 pg/mL

exclusion of delirium. Our patient also initially experienced visual hallucinations. SARS-CoV-2 infection might cause subclinical consciousness disturbance, even without obvious delirium, or might affect broad areas of the brain, including the occipital lobe, thus leading to visual hallucinations[12].

A retrospective study comparing the symptoms of schizophrenia and autoimmune encephalitis suggested that Schneider's FRS may help differentiate schizophrenia from autoimmune encephalitis[13]. A systematic review

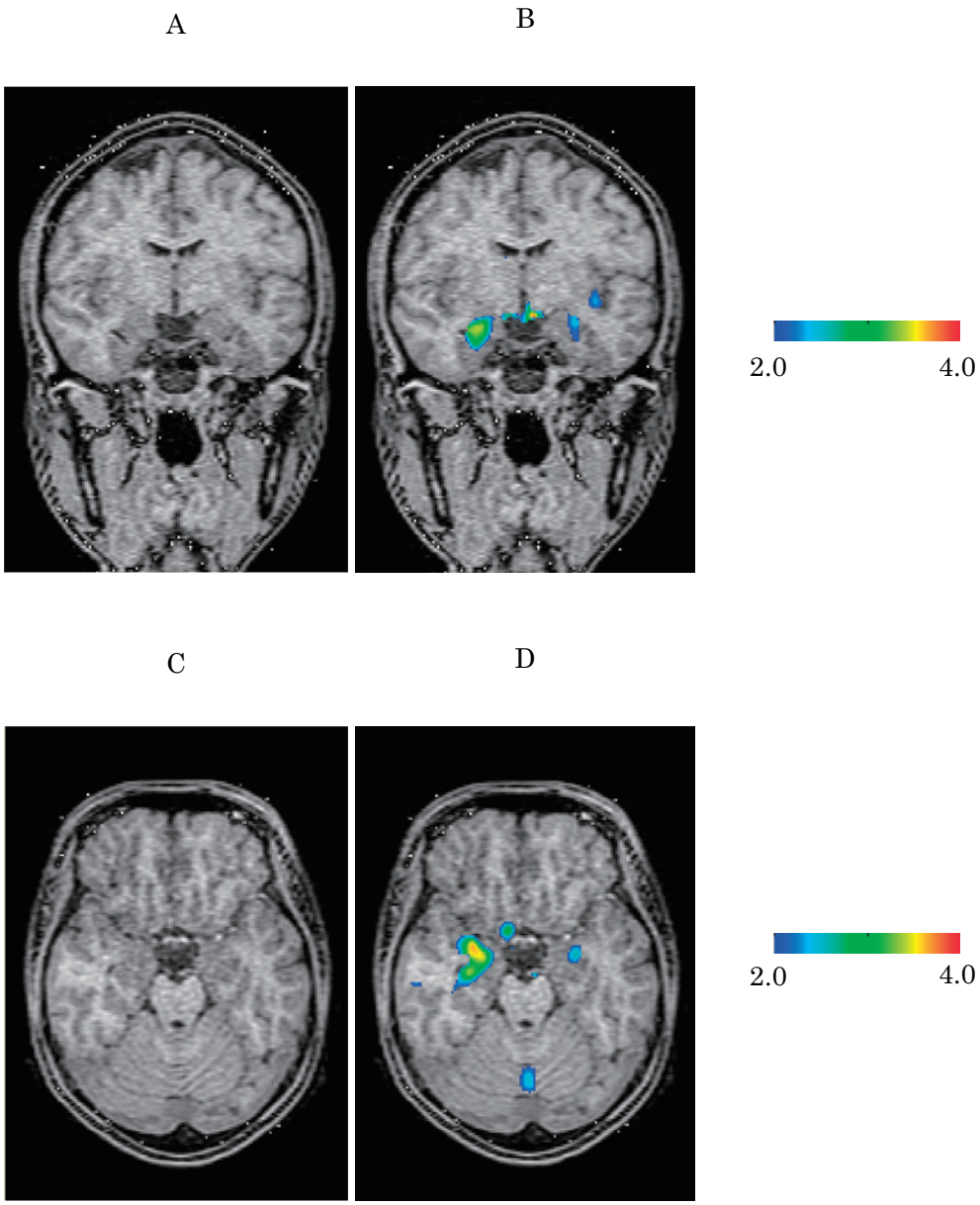

Fig. 4. A shows a coronal section of the brain on T1-weighted MRI image (T1WI). B shows a Z-score map of decreases in gray matter volume in the section, as determined by a voxel-based specific regional analysis system for Alzheimer disease (VSRAD). C is an axial T1WI of the brain. D is overlaid with a Z-score map. The volume of gray matter in the right medial temporal lobe appears diminished.

showed that Schneider's FRS differentiates schizophrenia from other psychiatric diagnoses with a sensitivity of 57.0-61.8% and a specificity of 74.7-94.1%, suggesting a high specificity, and a positive test result indicates that the disease is likely present[14]. Moreover, the International Statistical Classification of Diseases and Related Health Problems-11 incorporated some of Schneider's FRS (self-experiences; experiences of being controlled), whereas the DSM-5 does not include them as criteria for schizophrenia. Therefore, a diagnosis of schizophrenia was more likely for our patient, as he reported the experience of being controlled.

In a prospective study in Germany (the ABC Schizophrenia Study), most patients exhibited a prodromal phase that lasted several years before the first psychotic episode. Mild psychotic symptoms below the threshold intensified during an approximately 1-year interval before onset (psychotic pre-phase), culminating in the first psychotic episode[15]. Our patient experienced insomnia and visited a psychiatrist for several months during the high school entrance exam period, 18 months before hospitalization. However, his insomnia subsided, and con-

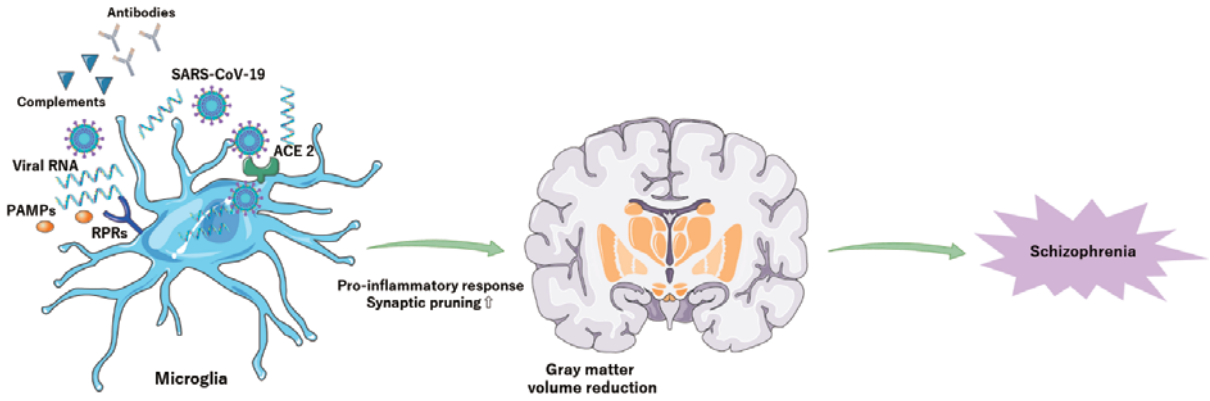

Fig. 5. COVID-19 infection may have triggered new-onset schizophrenia by affecting immunity, synaptic pruning, the renin–angiotensin system (RAS), and brain gray matter.
PAMPs: pathogen-associated molecular pattern molecules; PRRs: pattern recognition receptors.
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sultation was concluded after he passed the examination. He entered an advanced school and led a normal school life. Because he did not exhibit prodromal signs of schizophrenia and did not fall into the ultra-high-risk category[16], it is unlikely that schizophrenia would have developed in the absence of COVID-19 infection.

Immunological responses to COVID-19 are associated with T helper 2 (Th2)[17], which promotes antibody production and complement activation. Patients with COVID-19 produce more autoantibodies[18] and exhibit excess complement activation[19], which may promote synaptic pruning. Our patient might have had Th2-shifted immunity, as he had a history of asthma. Schizophrenia also exhibits a Th2 tendency, a potential biomarker of the disease[20] and may be induced by COVID-19. Pattern recognition receptors, such as Toll-like receptor 3 on microglia, recognize pathogen-associated molecular pattern molecules, such as viral RNA, and induce microglial activation[21].

The renin-angiotensin system (RAS) is important in the pathogenesis of schizophrenia, as it affects dopaminergic, glutamatergic, and GABAergic neurons[22]. SARS-CoV-2 infects cells via angiotensin-converting enzyme 2 and inhibits its function, leading to excessive angiotensin II signals, which induce microglial activation and a pro-inflammatory response. In human brain organoids, SARS-CoV-2 consistently promotes synapse elimination via microglial activation and upregulates neurodegenerative markers[23].

COVID-19 affects expressions of molecular markers associated with schizophrenia[24]. Differential gene expression pattern analysis revealed many overlapping immune-related genes between COVID-19 and schizophrenia[25].

SARS-CoV-2 shrinks the prefrontal and temporal cortices[12]. Lower mean volumes of the medial temporal, frontal, and anterior cingulate cortices are features of early psychosis[26]. A reduction in gray matter volume is related to microglial activation[27]. In our patient, gray matter volume in the right medial temporal lobe appeared to be diminished on VSRAD analysis of MRI. VSRAD analysis was used to detect selective atrophy of the medial temporal lobe. The result was obtained by global normalization, which allowed for correction of the absolute amount of gray matter to the individual total brain volume. Care should be taken with net Z-scores, as the standard VSRAD database comprises data from older individuals (age >53 years) and the present patient was only 16 years of age. Mean (SD) normalized gray matter volume in each region may differ between young and old subjects[28]. Nevertheless, our findings suggest that COVID-19 affected our patient's brain and caused psychotic symptoms and cognitive impairment. Thus, COVID-19 may have triggered the patient's first episode of schizophrenia by affecting immunity, synaptic pruning, RAS, gene expression, and brain gray matter (**Fig. 5**).

A limitation of this study was that only conventional examinations were performed. Emerging evidence of the pathological similarity of schizophrenia and encephalitis makes differentiating them technically challenging. No previous brain-imaging data were available for comparison. Moreover, long-term follow-up was not possible because he was referred to a local clinic after discharge.

Conclusion

By causing neuroinflammation, COVID-19 may have triggered new-onset schizophrenia in an adolescent. Infectious diseases during adolescence should be carefully managed, to prevent neuroinflammation and limit the risk of schizophrenia.

Conflict of Interest: M.S. received grants from Jusendo General Hospital. The other authors declare no conflicts of interest.

References

1. Hafner H, Riecher-Rossler A, An Der Heiden W, Maurer K, Fatkenheuer B, Loffler W. Generating and testing a causal explanation of the gender difference in age at first onset of schizophrenia. Psychol Med. 1993;23(4):925–40.
2. Zubin J, Spring B. Vulnerability: a new view of schizophrenia. J Abnorm Psychol. 1977;86(2):103–26.
3. Al-Haddad BJS, Oler E, Armistead B, et al. The fetal origins of mental illness. Am J Obstet Gynecol. 2019;221(6): 549–62.
4. Khandaker GM, Zimbron J, Dalman C, Lewis G, Jones PB. Childhood infection and adult schizophrenia: a meta-analysis of population-based studies. Schizophr Res. 2012; 139(1-3):161–8.
5. Khandaker GM, Zammit S, Lewis G, Jones PB. A population-based study of atopic disorders and inflammatory markers in childhood before psychotic experiences in adolescence. Schizophr Res. 2014;152(1):139–45.
6. Paolicelli RC, Bolasco G, Pagani F, et al. Synaptic pruning by microglia is necessary for normal brain development. Science. 2011;333(6048):1456–8.
7. Inta D, Lang UE, Borgwardt S, Meyer-Lindenberg A, Gass P. Microglia activation and schizophrenia: lessons from the effects of minocycline on postnatal neurogenesis, neuronal survival and synaptic pruning. Schizophr Bull. 2017;43(3):493–6.
8. Mongan D, Sabherwal S, Susai SR, Focking M, Cannon M, Cotter DR. Peripheral complement proteins in schizophrenia: a systematic review and meta-analysis of serological studies. Schizophr Res. 2020;222:58–72.
9. Shiwaku H, Katayama S, Kondo K, et al. Autoantibodies against NCAM1 from patients with schizophrenia cause schizophrenia-related behavior and changes in synapses in mice. Cell Rep Med. 2022;3(4):100597.
10. Taquet M, Sillett R, Zhu L, et al. Neurological and psychiatric risk trajectories after SARS-CoV-2 infection: an analysis of 2-year retrospective cohort studies including 1 284 437 patients. Lancet Psychiatry. 2022;9(10):815–27.
11. Smith CM, Gilbert EB, Riordan PA, et al. COVID-19-associated psychosis: a systematic review of case reports. Gen Hosp Psychiatry. 2021;73:84–100.
12. Kumar PR, Shilpa B, Jha RK. Brain disorders: impact of mild SARS-CoV-2 may shrink several parts of the brain. Neurosci Biobehav Rev. 2023;149:10515.
13. Funayama M, Koreki A, Takata T, et al. Differentiating autoimmune encephalitis from schizophrenia spectrum disorders among patients with first-episode psychosis. J Psychiatr Res. 2022;151:419–26.
14. Soares-Weiser K, Maayan N, Bergman H, et al. First rank symptoms for schizophrenia. Cochrane Database Syst Rev. 2015;1(1):CD010653.
15. Hafner H, Maurer K, Ruhrmann S, et al. Early detection and secondary prevention of psychosis: facts and visions. Eur Arch Psychiatry Clin Neurosci. 2004;254(2):117–28.
16. Yung AR, Nelson B. Young people at ultra high risk for psychosis: a research update. Early Interv Psychiatry. 2011;5 Suppl 1:52–7.
17. Aleebrahim-Dehkordi E, Molavi B, Mokhtari M, et al. T helper type (Th1/Th2) responses to SARS-CoV-2 and influenza A (H1N1) virus: from cytokines produced to immune responses. Transpl Immunol. 2022;70:101495.
18. Wang EY, Mao T, Klein J, et al. Diverse functional autoantibodies in patients with COVID-19. Nature. 2021;595 (7866):283–8.
19. Pires BG, Calado RT. Hyper-inflammation and complement in COVID-19. Am J Hematol. 2023;98 Suppl 4:S74–81.
20. Galinska-Skok B, Waszkiewicz N. Markers of schizophrenia-a critical narrative update. J Clin Med. 2022;11(14):3964.
21. Awogbindin IO, Ben-Azu B, Olusola BA, et al. Microglial Implications in SARS-CoV-2 Infection and COVID-19: Lessons From Viral RNA Neurotropism and Possible Relevance to Parkinson's Disease. Front Cell Neurosci. 2021;15:670298.
22. Oh SJ, Fan X. The possible role of the angiotensin system in the pathophysiology of schizophrenia: implications for pharmacotherapy. CNS Drugs. 2019;33(6):539–47.
23. Samudyata, Oliveira AO, Malwade S, et al. SARS-CoV-2 promotes microglial synapse elimination in human brain organoids. Mol Psychiatry. 2022;27(10):3939–50.
24. Quincozes-Santos A, Rosa RL, Tureta EF, et al. COVID-19 impacts the expression of molecular markers associated with neuropsychiatric disorders. Brain Behav Immun Health. 2021;11:100196.
25. Xia J, Chen S, Li Y, et al. Immune response is key to genetic mechanisms of SARS-CoV-2 infection with psychiatric disorders based on differential gene expression pattern analysis. Front Immunol. 2022;13:798538.
26. Howes OD, Cummings C, Chapman GE, Shatalina E. Neuroimaging in schizophrenia: an overview of findings and their implications for synaptic changes. Neuropsychopharmacology. 2023;48(1):151–67.
27. Selvaraj S, Bloomfield PS, Bo C, Veronese M, Turkheimer F, Howes OD. Brain TSPO imaging and gray matter volume in schizophrenia patients and in people at ultra high risk of psychosis: an [^{11}C]PBR28 study. Schizophr Res. 2018;195:206–14.
28. Matsuda H, Mizumura S, Nemoto K, et al. Automatic voxel-based morphometry of structural MRI by SPM8 plus diffeomorphic anatomic registration through exponentiated lie algebra improves the diagnosis of probable Alzheimer disease. AJNR Am J Neuroradiol. 2012;33(6): 1109–14.

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