Covid-19 Variants and a New Sub-Variant Jn-1- Sign, Symptoms, And Treatments

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***Abstract*—COVID-19, also known as coronavirus disease, is caused by a virus called severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Started spreading at the end of 2019, which is why it's called COVID-19, and became a pandemic disease in 2020. The prediction was that SARS-CoV-2 emerged from direct transmission of a bat coronavirus to humans. Since the beginning of the pandemic, we have seen several variants, including Alpha, Beta, Delta, and Omicron. SARS-CoV-2 continues to evolve into many variants and sub-variants. In the year 2025, the cases of COVID-19 started to rise again in parts of India, Thailand, Brazil, the UK, and Greece. According to the WHO report taken on the 18th of May 2025, these countries have more cases in comparison to Denmark, Ukraine, and Italy so far. In a significant development, the WHO has recently found a novel strain, JN-1, designating it as a "variant of interest" underlining its potential significance in the ongoing battle against the virus. The recent increase has been linked to the spread of a new subvariant of Omicron, JN-1. This paper is going to review how different variants behave and what precautions may be necessary. The paper will also reveal the new variant JN-1, including its symptoms, precautions, diagnosis, and treatment.**

***Index Terms*—SARS-CoV-2, Immune response, JN.1, Variants, Treatment**

I. INTRODUCTION

COVID-19 is an infectious disease caused by the newly identified coronavirus known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2 [1]. The virus and its disease were unknown before the outbreak that began in Wuhan, China, in December 2019 [2]. The source is believed to be a virus that has spilled over from an animal host to humans [3]. The first reported human case appeared on December 1, 2019, although some cases may have emerged as early as mid-November [4]. By late December 2019, several patients in Wuhan were admitted with viral pneumonia of unknown cause [2]. The pathogen was later identified as a novel coronavirus, provisionally named 2019-nCoV [1]. By January 26, 2020, more than 2000 cases had already been reported, most of which involved people living in or visiting Wuhan, and human-to-human transmission had been confirmed [5]. The rapid spread of the virus across continents led the World Health Organization (WHO) to declare COVID-19 a global pandemic in March 2020 [6].

1.1 Background

The novel coronavirus disease (COVID-19) outbreak, which began in late 2019, rapidly spread worldwide, causing significant disruptions to health, social, and economic systems [6]. Even after more than five years, its impact remains evident worldwide [7]. The pandemic highlighted two contrasting realities: while one group of individuals experienced only mild symptoms or remained asymptomatic, another group developed severe complications, sometimes leading to death [8]. Factors such as age, immune status, and underlying comorbidities have a significant influence on disease severity and clinical outcomes [9] [10].

1.2 Transmission

COVID-19 primarily spreads from person to person through respiratory droplets released when an infected individual coughs, sneezes, or talks [11]. People can become infected by inhaling these droplets or by touching contaminated surfaces and then touching their mouth, nose, or eyes [12]. In addition to droplet transmission, smaller aerosol particles can remain suspended in the air for extended periods, contributing to airborne transmission, especially indoors [13].

Transmission can also occur indirectly when individuals touch surfaces contaminated with the virus and subsequently touch their mouth, nose, or eyes, although this route is considered less common compared to respiratory transmission [14]. The risk of transmission is highest during close, prolonged contact with infected individuals, particularly during the early stages of infection when viral load is high [15]. The incubation period, which is the time between exposure to the virus and the onset of symptoms, ranges from 1 to 14 days, with an average of 5–6 days [16]. More than 97% of infected individuals develop symptoms within 14 days [17]. In mild to moderate cases, recovery usually occurs within 2 weeks, while severe cases may take 3–6 weeks [18]. Active viral replication primarily occurs in the upper respiratory tract and lungs [19]. Although COVID mainly affects the lungs, it can also affect other parts of the body, including the blood, heart, kidneys, liver, and skin [20].

1.3. Signs and Symptoms [21]

- Loss of smell
- Loss of taste
- Red eyes
- Rash
- Nausea/Vomiting
- Headache
- Sore throat
- Nasal congestion
- Diarrhea
- Shortness of breath
- Fever
- Congestion or Runny nose
- Cough

1.4. Risk Groups

- Low risks: Contact studies indicate that children and young adults do become infected and can transmit infection. However, children rarely progress to serious illness [22] [23].
- High risks: Older people have a high risk of several illnesses from COVID, especially for people in their 50s or older [22] [24]. People with compromised or weakened immune systems have a high risk of severe COVID-19. People having certain health issues, including Heart or lung disease, Diabetes, Asthma, Cancer, HIV infection, conditions of the kidneys or liver, etc. [24] [25].

1.5. Immunity

Short-term: Antibodies to SARS-CoV-2, including IgG and IgM, typically appear 6–12 days after symptom onset [26] [27]. Following this, antibody levels gradually decline [27]. Despite the immune response, patients may remain infectious during this period [15].

Long-term: Current evidence is insufficient to determine the effectiveness or duration of antibody-mediated immunity [28]. Therefore, it is unclear whether immunity guarantees long-term protection or supports the concept of "immunity passports" or "risk-free certificates [22] [28]."

1.6. Treatment

At present, no antiviral drug has been specifically approved for the treatment of COVID-19 [29]. Research efforts are focused on repurposing existing drugs to evaluate their efficacy against SARS-CoV-2 [30]. The World Health Organization (WHO) is conducting large, multi-country Solidarity Trials to assess four potential therapeutic candidates:

•Remdesivir: Originally developed for Ebola [30].

•Lopinavir/Ritonavir: An antiretroviral drug combination previously used against HIV [30].

•Chloroquine: An antimalarial drug with reported antiviral activity [31].

•Interferon Beta: An immune-modulating agent with antiviral properties [30].

II DIFFERENT VARIANTS OF COVID-19 – SIGNS AND SYMPTOMS

Since the beginning of the pandemic, we have seen several variants, including Alpha, Beta, Delta, and Omicron, each showing differences in transmissibility, immune escape, and clinical presentation [10]. We often hear terms like Alpha, Beta, Delta, and Omicron, but they can be confusing. Each COVID-19 variant comes with different symptoms—some cause loss of smell and taste, while others resemble allergies, bringing fatigue and headaches [32].

So, what are variants? COVID-19 is an RNA virus, and every time it infects someone, its genetic code changes slightly [33]. These small changes are called mutations. Most mutations don't matter, but sometimes one makes the virus stronger, like

spreading faster or avoiding the immune system. When that happens, we get a new variant [7].
To make them easier to track, the WHO named variants after Greek letters. Think of COVID-19 as a tree trunk, and its variants as branches. For example, Delta was different from Beta, and Omicron spread faster because of spike protein changes, though it usually caused milder illness [28].

2.1 Alpha (B.1.1.7) was the first of the variants and first appeared in Great Britain in November 2020 and soon spread throughout the world in December 2020 [34]. The Alpha faded away with the rise of the more aggressive Delta variant. 30-50% more contagious than the original SARS-CoV-2 strain [35].

2.2 Beta (B.1.351) was identified in South Africa at the end of 2020 and spread to other countries [36]. 50% more harmful than the coronavirus [37].

2.3 Delta (B.1.617.2) was first identified in India in late 2020, and soon it spread around the world [38]. Delta exhibited significantly higher transmissibility and was associated with increased viral loads and more severe clinical outcomes compared with previous variants [39]. Delta was one of the predominant variants of coronavirus until Omicron took over in mid-December 2021 [40].

2.4 Omicron and its subvariants have ranked as the predominant SARS-CoV-2 strains, while the original Omicron strain (BA.1) is no longer circulating, Omicron subvariants are now driving SARS-CoV-2 infections worldwide [41]. Omicron was first identified in Botswana and South Africa in late November 2021, and by the end of December [42].

III JN.1 VARIANT OF COVID-19: SYMPTOMS, PREVENTION, AND TREATMENT

3.1 Rising Cases of JN.1 Variant in India

Recent reports indicate a rise in COVID-19 cases in parts of India, with over 250 active cases linked to the newly identified JN.1 variant, a sub-lineage of Omicron [43]. Health authorities are closely monitoring this variant to assess changes in its transmissibility and clinical presentation. Although most infections reported so far have been mild, the increasing number of cases highlights the importance of understanding their characteristics and potential public health impact [44].

3.2 Distinct Features of JN.1

The JN.1 variant is a modified form of Omicron that carries an additional mutation in its spike protein, the viral component responsible for binding and entry into host cells [45]. This mutation may influence viral spread and immune response. Due to this, researchers are closely studying JN.1 to determine whether it differs from earlier variants in terms of transmissibility and symptom profile [45] [46].

3.3 Contagiousness and Severity

Preliminary evidence suggests that JN.1 may spread more efficiently than some earlier variants, potentially leading to a faster rise in cases [44]. However, the severity of illness associated with JN.1 remains largely low, with the majority of infections presenting as mild [45].

3.4 Signs and Symptoms

Most infections associated with the JN.1 variant have been reported to be mild. The clinical presentation is generally like that observed in earlier Omicron sub-variants, although symptom severity and combination may differ among individuals [47]. Frequently reported symptoms include mild, short-duration fever, dry or mildly productive cough, sore throat (often appearing early), nasal congestion or runny nose, fatigue, headache, and occasional muscle or body aches [48]. In some cases, gastrointestinal symptoms such as diarrhea and nausea have also been observed. In contrast to earlier SARS-CoV-2 variants, loss of taste or smell is reported less commonly in JN.1 infections [32]. Severe manifestations, including shortness of breath or chest pain, are rare; however, individuals with underlying medical conditions or compromised immune systems may remain at higher risk and should take additional precautions [24].

3.5 Prevention and Treatment

With COVID-19 cases increasing in several countries around the World, taking careful precautions remains essential to limit the spread of the virus [22] [29].

- Wear a mask in crowded or poorly ventilated places
- Wash your hands frequently with soap and water or use hand sanitizer

- Avoid touching your eyes, nose, and mouth with unclean hands
- Maintain physical distance in public places
- Avoid close contact with people who are sick
- Stay home and isolate if you have symptoms
- Cover mouth and nose while coughing or sneezing
- Ensure good ventilation in indoor spaces
- Keep vaccinations and booster doses up to date
- People with weak immunity or chronic illness should take extra care

Treatment for Mild Cases [29]

- Take enough rest and avoid heavy activity
- Drink plenty of fluids to prevent dehydration
- Use paracetamol for fever, headache, or body pain (as advised)
- Steam inhalation or warm salt-water gargles for a sore throat or a blocked nose
- Monitor body temperature and oxygen levels at home
- Stay isolated to prevent the spread of infection

Treatment for Severe Cases [29] [49]

- Hospital admission may be required
- Oxygen therapy if oxygen levels are low
- Use of antiviral or other medicines as prescribed by doctors
- Continuous monitoring of oxygen saturation and vital signs
- Intensive care support in very serious cases

3.6 Diagnosis of SARS-CoV-2 Variant JN-1

The diagnosis of the JN.1 variant follows the same approach used for other COVID-19 variants [50]. Diagnosis mainly focuses on detecting the genetic material of the virus or viral proteins from respiratory samples. Infection is first confirmed using standard COVID-19 tests that detect the presence of the SARS-CoV-2 virus. These tests help identify infected individuals early, allowing timely isolation and treatment.

Methods Used for Diagnosis

- RT-PCR Test [50]
- A swab sample is collected from the nose or throat
- The virus present in the sample contains RNA (genetic material)
- This viral RNA is first converted into DNA using an enzyme called reverse transcriptase
- The DNA is then amplified (copied many times) using PCR
- Special fluorescent markers produce a signal when viral DNA is present
- The machine detects this signal, and the result is reported as positive or negative
- RT-PCR is highly sensitive and accurate

- Rapid Antigen Test (RAT) [51]
- A nasal or throat swab sample is collected
- The test detects specific viral proteins (antigens) instead of genetic material
- The sample is placed on a test strip containing antibodies
- If viral antigens are present, they bind to antibodies and form a visible line
- Results are available within 15–30 minutes
- This test is faster but less sensitive than RT-PCR

IV. IMMUNE RESPONSE TO THE SARS-COV-2 JN-1 VARIANT

The JN.1 variant is a sub-lineage of the Omicron family of SARS-CoV-2 and shows several mutations, particularly in the spike protein [52]. These mutations influence how the virus interacts with the host immune system. Overall, JN.1 is associated with increased immune escape, meaning it can partially evade immune responses generated by previous infection or vaccination [53].

4.1 Immune Escape Mechanism

The spike protein is the main target of neutralizing antibodies produced after infection or vaccination [54]. In the JN.1 variant, multiple mutations alter the structure of the spike protein [52] [53]. As a result, antibodies that were effective against earlier variants bind less efficiently to JN.1 [55]. This reduced antibody recognition allows the virus to escape neutralization, increasing the risk of reinfection even in individuals with prior immunity.

4.2 Reduced Neutralizing Antibody Effectiveness
Studies using convalescent and vaccinated sera have shown that neutralizing antibody activity against JN.1 is lower compared to earlier Omicron subvariants [56]. Although antibodies are still produced, their ability to block viral entry into host cells is diminished [57]. This explains why breakthrough infections may occur, although severe disease is still generally prevented.

4.3 T-Cell–Mediated Immunity Remains Largely Intact
While antibody responses are partially compromised, T-cell–mediated immunity is less affected by JN.1 mutations [58]. T cells recognize different viral regions that are more conserved [59]. As a result, cellular immune responses continue to play an important role in controlling infection, limiting viral replication, and reducing disease severity.

4.4 Increased Infectivity and Host Cell Entry
JN.1 shows higher infectivity compared to some related variants. It can bind effectively to the ACE2 receptor on host cells and shows enhanced adaptation to certain host proteases such as TMPRSS2 [60]. This improved entry efficiency allows the virus to infect cells more easily, even in the presence of partial immune protection [61].

4.5 Inflammation and Immune Response
In most individuals, JN.1 infection triggers a typical antiviral immune response involving cytokine release and activation of innate immunity [62]. However, excessive immune activation is uncommon, which may explain why most cases remain mild. In individuals with weakened immunity or underlying conditions, immune responses may be insufficient, increasing the risk of complications [63].

4.6 Implications for Reinfection and Vaccination
Due to its immune escape properties, JN.1 increases the likelihood of reinfection [55]. However, existing vaccines still protect against severe disease by activating memory B cells and T cells. Booster doses help strengthen immune responses and improve protection against JN.1 [64].

Key Points to Remember
- JN.1 has mutations in the spike protein
- These mutations reduce antibody binding (immune escape)
- Neutralizing antibody activity is decreased
- T-cell immunity remains mostly preserved
- Reinfection risk is higher, but severe disease is uncommon
- Vaccines still protect against severe illness

V. CONCLUSION

The continuous evolution of SARS-CoV-2 has led to the emergence of several variants, with the JN.1 sub-variant of Omicron gaining attention due to its increasing spread in different parts of the world. This review highlights that JN.1 carries additional mutations in the spike protein, which contribute to increased transmissibility and partial immune escape. Despite this, most reported infections remain mild, especially among individuals with existing immunity from vaccination or prior infection.

The clinical features of JN.1 largely resemble those of earlier Omicron sub-variants, with symptoms such as fever, cough, sore throat, nasal congestion, fatigue, and occasional gastrointestinal issues. Severe disease is uncommon but may occur in elderly individuals or those with weakened immune systems or underlying health conditions. Current diagnostic methods, including RT-PCR and rapid antigen tests, remain effective for detecting JN.1 infections.

Although JN.1 shows reduced sensitivity to neutralizing antibodies, T-cell-mediated immunity continues to play a key role in limiting disease severity. Existing vaccines, particularly with booster doses, still provide strong protection against severe illness, hospitalization, and death. Preventive measures such as mask use, hand hygiene, proper ventilation, and early isolation remain essential in controlling transmission. In conclusion, while the JN.1 variant presents a challenge due to its immune escape properties, it does not appear to cause more severe disease than previous Omicron variants. Continuous surveillance, public awareness, vaccination efforts, and adherence to preventive strategies are crucial to minimizing its public health impact and managing future waves of COVID-19.

WORKS CITED

[1] "Coronavirus disease (COVID-19)," 2020. [Online]. Available: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/global-research-on-novel-coronavirus-2019-ncov.

[2] W. Y. L. X. Huang C, "Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China.," The Lancet, [Online]. Available: https://www.thelancet.com/article/S0140-6736(20)30183-5/fulltext. [Accessed 30 January 2020].

[3] Y. X. W. X. e. Zhou P, "A pneumonia outbreak associated with a new coronavirus of probable bat origin.," Nature, [Online]. Available: https://www.nature.com/articles/s41586-020-2951-z. [Accessed 03 February 2020].

[4] R. A. L. W. H. E. G. R. Andersen KG, "The proximal origin of SARS-CoV-2.," Nature Medicine, [Online]. Available: https://www.nature.com/articles/s41591-020-0820-9. [Accessed 17 March 2020].

[5] G. X. W. P. e. Li Q, "Early Transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia.," New England of Journal Medicine, [Online]. Available: https://www.nejm.org/doi/full/10.1056/NEJMoa2001316. [Accessed 29 January 2020].

[6] W. H. Organizationn, "WHO- Director General's opening remarks at the media briefing on COVID-19," WHO, [Online]. Available: https://www.who.int/news-room/speeches/item/who-director-general-s-opening-remarks-at-the-media-briefing---5-may-2023#:~:text=It%20is%20therefore%20with%20great,the%20deaths%20we%20know%20about. [Accessed 11 March 2020].

[7] C. A. J. B. e. Harvey WT, "SARS-CoV-2 variants, spike mutations and immune escape.," Nature Reviews Microbiology, [Online]. Available: https://www.nature.com/articles/s41579-021-00573-0. [Accessed 01 June 2021].

[8] M. J. Wu Z, "Characteristics and important lessons from the coronavirus disease 2019 outbreak in China.," JAMA Network, [Online]. Available: https://jamanetwork.com/journals/jama/fullarticle/2762130#244003562. [Accessed 24 February 2020].

[9] W. A. B. K. e. Williamson EJ, "Factors associated with COVID-19-related death using OpenSAFELY.," Nature, [Online]. Available: https://www.nature.com/articles/s41586-020-2521-4. [Accessed 08 July 2020].

[10] C. E., "The coronavirus is mutating-does it matter?," Nature, [Online]. Available: https://www.nature.com/articles/d41586-020-02544-6. [Accessed 16 September 2020].

[11] "Transmission of SARS-CoV-2: implications for infection prevention precautions.," World Health Organization(WHO), [Online]. Available: https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions. [Accessed 09 July 2020].

[12] "How COVID-19 spreads.," Centers for Disease Control and Prevention., [Online]. Available: https://stacks.cdc.gov/view/cdc/85271. [Accessed 17 February 2021].

[13] M. D. Morawska L, "It is time to address airborne transmission of COVID-19.," National Library of Medicine., [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/32628269/. [Accessed 03 December 2020].

[14] G. E., "Exaggerated risk of transmission of COVID-19 by fomites.," The Lancet Infectious Disease, [Online]. Available: https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(20)30561-2/fulltext. [Accessed 30 July 2020].

[15] L. E. W. P. e. a. He X, "Temporal dynamics in viral shedding and transmissibility of COVID-19.," Nature Medicine, [Online]. Available: https://www.nature.com/articles/s41591-020-0869-5#citeas. [Accessed 15 March 2020].

[16] G. K. B. Q. e. a. Lauer SA, "The incubation period of coronavirus disease 2019 (COVID 19).," Ann Intern Med.. [Online]. [Accessed 2020].

[17] K. D. W. J. Backer JA, "Incubation period of 2019 novel coronavirus infections.," Euro Surveil.. [Online]. [Accessed 25 May 2020].

[18] R. A. C. A. P. S. P. H. Wiersinga WJ, "Pathophysiology, transmission, diagnosis, and treatment of COVID-19.," JAMA. [Online]. [Accessed August 2020].

[19] C. V. G. W. e. a. Wolfel R, "Virological assessment of hospitalized patients with COVID-2019.," Nature. [Online]. [Accessed 2020].
[20] M. M. S. K. e. a. Gupta A, "Extrapulmonary manifestations of COVID-19.," Nature Medicine. [Online]. [Accessed 26 July 2020].
[21] C. f. D. C. a. Prevention., "Symptoms of COVID-19.," CDC. [Online]. [Accessed 2025].
[22] "Coronavirus disease (COVID-19): advice for the public/Q&A and guidance pages (COVID-19 health topics)," WHO. [Online].
[23] M. O. B. C. e. a. Viner RM, "Susceptibility to SARS-CoV-2 infection among children and adolescents compared with adults: a systematic review and meta-analysis.," JAMA. [Online]. [Accessed 2021].
[24] C. f. D. C. a. Prevention (CDC)., "People with certain medical conditions and COVID-19.," CDC. [Online]. [Accessed 2020].
[25] W. A. B. K. e. a. Williamson EJ, "Factors associated with COVID-19-related death.," Nature. [Online]. [Accessed 2020].
[26] L. B. D. H. e. a. Long QX, "Antibody responses to SARS-CoV-2 in patients with COVID-19.," Nature Medicine. [Online]. [Accessed 26 June 2020].
[27] M. J. K. Y. e. a. Dan JM, "Immunological memory to SARS-CoV-2 assessed for upto 8 months after infection.," Science. [Online]. [Accessed 2021].
[28] "Tracking SARS-CoV-2 variants/variant updates and risk evaluations (including JN.1 risk evaluation).," WHO, [Online]. Available: World Health Organization.
[29] WHO, "Living guideline: therapeutics and COVID-19.," World Health Organization. [Online]. [Accessed 2023].
[30] W. S. T. Consortium., "Repurposed antiviral drugs for COVID-19-interim WHO Solidarity trial results.," New England J. Medicine. [Online]. [Accessed 2021].
[31] G. C. RECOVERY., "Effect of hydroxychloroquine in hospitalized patients with COVID-19.," New England J. Medicine... [Online]. [Accessed 2020].
[32] V. A. P. L. e. a. Menni C, "Symptom, prevalence, duration, and risk of hospital admission in individuals infected with SARS-CoV-2 during periods of different variant dominance.," Lancet. [Online]. [Accessed 2022].
[33] D. S., "Why are RNA virus mutation rates so damn high?," PLoS Biol.. [Online]. [Accessed 16 August 2018].
[34] M. S. C. M. e. a. Volz E, "Transmission of SARS-CoV-2 lineage B.1.1.7 in England.," Nature. [Online]. [Accessed 2021].
[35] A. S. B. R. e. a. Davies NG, "Estimated transmissibility and impact of SARS-CoV-2 lineage B.1.1.7 in England.," Science. [Online]. [Accessed 2021].
[36] W. E. G. M. e. a. Tegally H, "Detection of a SARS-CoV-2 variant of concern in South Africa.," Nature. [Online]. [Accessed 2021].
[37] A. F. H. T. e. a. Wibmer CK, "SARS-CoV-2 501Y.V2 escapes neutrilization by South African COVID-19 donor plasma.," Nature Medicine. [Online]. [Accessed 27 April 2021].
[38] P. V. J. S. e. a. Cherian S, "SARS-CoV-2 spike mutations, L452R, T478K, E484Q AND P681R, in the second wave of COVID-19 in Maharasthra, India," Microorganisms. [Online]. [Accessed July 09 2021].
[39] N. T. Z. A. e. a. Twohig KA, "Hospital admission and emergency care attendance risk for SARS-CoV-2 Delta variant.," Lancet Infectious Disease. [Online]. [Accessed 22 January 2022].
[40] O. H. World, "Weekly epidemiological update on COVID-19.," WHO. [Online]. [Accessed 2021].
[41] O. H. World., "Statement on Omicron sub-lineages.," WHO. [Online]. [Accessed 2023].
[42] M. S. A. D. e. a. Viana R, "Rapid epidemic expansion of the SARS-CoV-2 Omicron variant in southern Africa.," Nature. [Online]. [Accessed 2022].
[43] O. H. World, "SARS-CoV-2 variant JN.1: risk evaluation.," WHO. [Online]. [Accessed 2024].
[44] E. C. f. D. P. a. Control., "Epidemiological update: SARS-CoV-2 variants.," ECDC. [Online]. [Accessed 2024].
[45] W. J. J. F. e. a. Cao Y, "Omicron escapes the majority of existing SARS-CoV-2 neutralizing antibodies.," Nature. [Online]. [Accessed 2022].
[46] C. N. L. Z. e. a. Starr TN, "SARS-CoV-2 RBD antibodies that maximize breadth and resistance to escape.," Nature. [Online]. [Accessed 2021].
[47] C. f. D. C. a. Prevention., "COVID-19 symptoms by variant.," Atlanta:CDC. [Online]. [Accessed 2024].

[48] H. I. C. P. e. a. Cheung KS, “Gastrointestinal manifestations of SARS-CoV-2 infection.,” Gastroenterology. [Online]. [Accessed 2020].
[49] N. C.-1. T. G. Panel., “COVID-19 treatment guidelines.,” NIH. [Online]. [Accessed 2025].
[50] L. O. K. M. e. a. Corman VM, “Detection of 2019 novel coronavirus by real-time RT-PCR.,” Euro Surveill.. [Online]. [Accessed 25 March 2020].
[51] A. A. B. M. e. a. Scohy A, “Low performance of rapid antigen detection test for SARS-CoV-2.,” Clinical Virology. [Online]. [Accessed 2020].
[52] WHO, “SARS-CoV-2 variant JN.1: updated risk assessment.,” Geneva: WHO. [Online]. [Accessed 2024].
[53] J. F. W. J. e. a. Cao Y, “Imprinted SARS-CoV-2 humoral immunity induces convergent Omicron RBD evolution.,” Nature. [Online]. [Accessed 2023].
[54] P. Y. T. M. e. a. Piccoli L, “Mapping neutralizing and immunodominant sites on the SARS-CoV-2 spike receptor-binding domain.,” Cell. [Online]. [Accessed 2020].
[55] v. S. C. G. N. e. a. Pulliam JRC, “Increased risk of SARS-CoV-2 reinfection associated with Omicron emergence.,” Science. [Online]. [Accessed 2022].
[56] S. N. M. P. e. a. Planas D, “Considerable escape of SARS-CoV-2 Omicron to antibody neutralization.,” Nature. [Online]. [Accessed 2022].
[57] P. M. A. S. e. a. Goel RR, “mRNA vaccines induce durable immune memory to SARS-CoV-2 and variants.,” Science. [Online]. [Accessed 2021].
[58] W. D. R. S. e. a. Grifoni A, “Targets of T cell responses to SARS-CoV-2 coronavirus in humans.,” Cell. [Online]. [Accessed 2020].
[59] S. J. M. N. e. a. Tarke A, “Impact of SARS-CoV-2 variants on the total CD+4 and CD+8 T cell reactivity.,” Cell Rep Medicine. [Online]. [Accessed July 02 2021].
[60] K.-W. H. P. S. Hoffmann M, “A multibasic cleavage site in the spike protein of SARS-CoV-2 is essential for infection of human lung cells.,” Molecular Cell. [Online]. [Accessed 2020].
[61] G. D. Z. J. e. a. Peacock TP, “The furin cleavage site of SARS-CoV-2 spike protein is a key determinant for transmission.,” Nature Microbiology. [Online]. [Accessed 06 July 2021].
[62] B. G. G. C. e. a. Vabret N, “Immunology of COVID-19: current state of the science.,” Immunity. [Online]. [Accessed 2020].
[63] N.-P. B. L. W. e. a. Blanco-Melo D, “Imbalanced host response to SARS-CoV-2 drives development of COVID-19.,” Cell. [Online]. [Accessed 2020].
[64] A. H. S. UK., “COVID-19 vaccine surveillance report (Omicron and sub-lineages).,” [Online]. [Accessed 2024].