

Review Article

COVID-19 and its resurgence, public behavior, and global response: lessons learnt

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ABSTRACT

COVID-19 has caused significant damage to the social, emotional, and economic well-being of populations worldwide. Recent resurgences in several countries necessitate a focused review of the factors driving repeated waves of infection. This narrative review examines the evolution of the virus over time, behaviours of the public, and how governments implemented policies and systems to counter COVID-19. Key topics include the evolution of SARS-CoV-2 variants, the role of human behaviour in transmission, and the effectiveness and limitations of vaccines against rapidly evolving lineages. The review suggests that although vaccines have played a crucial role in mitigating the severity of symptoms and the spread of the virus, their effectiveness may decline over time due to waning immunity and the emergence of rapid viral mutations and newer strains. Moreover, asymptomatic infections can also exacerbate the spread of the virus without being recognized. Other social factors, including the spread of misinformation and behavioural complacency due to pandemic fatigue, also lead to an increase in the number of COVID cases. In 2025, given the emergence of new variants and the evolution of vaccines, this topic remains highly relevant. Understanding these patterns can help improve public health decisions and preparedness for future pandemics.

Keywords: COVID-19, Mutation, Vaccines, Public behaviour, Omicron, Delta

INTRODUCTION

The Coronavirus disease-2019 (COVID-19) virus, first detected in Wuhan, China, in November 2019, is transmitted through the release of airborne particles and droplets containing the SARS-CoV-2 virus, released by the bodily discharge of infected individuals. The world health organization (WHO) declared COVID-19 a global pandemic on 11 March 2020.¹ As of 11 May 2025, over 778 million cases and 7 million deaths have been reported globally.² Despite improved healthcare responses and mass vaccinations, recent trends have indicated a resurgence in the number of cases, driven by emerging variants such as XBB.1.5, EG.5, and BA.2.86.³ These strains exhibit increased transmissibility and partial immune escape, raising concerns about the long-term COVID situation.

MUTATION AND EVOLUTION OF SARS-COV-2

For clarity of terminology, a “variant” denotes a virus with one or more new mutations; “strain” is sometimes reserved for variants with distinct functional properties. In practice, major severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) lineages are discussed as variants.⁴ Where genetic changes result in clear functional differences, some authors use “strain”; however, for SARS-CoV-2, the WHO framework of variants of concern/use remains standard.⁴

As an RNA virus, SARS-CoV-2 accumulates replication errors; most are neutral, but mutations affecting the spike protein may alter receptor binding or antibody recognition, thereby increasing transmissibility or immune escape.³

Most mutations usually have little or no effect. However, occasionally a mutation can lead to a change in the structure of an essential protein, such as the spike protein that mediates cell entry. The virus may evolve to spread more efficiently, evade detection by existing antibodies,

and bypass immune defences. Gradual antigenic drift produced successive variants (Alpha, delta, omicron) with a higher spread potential and varying clinical patterns.^{3,5} Table 1 shows the evolution of different COVID-19 variants between September 2020 to February 2023.

Table 1: The evolution of various COVID-19 variants.⁵

Variants	Date detected	Origin	Key characteristics	Common symptoms
Alpha (B.1.1.7)	September 2020	United Kingdom	50% more transmissible than the original strain; mild increase in severity	Fever, persistent cough, fatigue, headache, loss of smell/taste
Beta (B.1.1351)	May 2020	South Africa	Immune escape properties: reduced vaccine efficacy observed	Fever, muscle aches, fatigue, sore throat, cough
Gamma (P.1)	November 2020	Brazil	Increased transmissibility; some immune escape	Fever, cough, fatigue, headache, shortness of breath
Delta (B.1.617.2)	October 2020	India	Highly transmissible; more severe disease; reduced vaccine effectiveness	Headache, sore throat, runny nose, fever, persistent cough
Omicron (B.1.1.529)	November 2021	South Africa	Extremely high transmissibility; milder symptoms; significant immune escape	Sore throat, runny nose, headache, fatigue, sneezing
XBB.1.5	October 2022	USA/Singapore	Subvariant of Omicron; even better at evading immunity; highly transmissible	Cough, sore throat, congestion, fatigue, headache
EG.5 (Eris)	February 2023	UK/Global	Omicron lineage; increased spread; mild symptoms; strong immune evasion	Runny nose, headache, fatigue, cough, sneezing

Exacerbating this challenge is the growing phenomenon of pandemic fatigue. These behavioral shifts, coupled with viral mutations and variable public health responses, underscore the need for a comprehensive assessment of the pandemic's evolution and its recurrent surges. This review aims to explore how viral adaptation, human behaviour, and global response strategies have interacted over time, and what these patterns reveal about strengthening preparedness and sustaining vigilance in the face of future public health threats.

LITERATURE REVIEW

This review synthesizes evidence on COVID-19 resurgence, public behaviour, and global response strategies, drawing from both peer-reviewed and grey literature to ensure a comprehensive and balanced assessment. A systematic literature search was conducted across major bibliographic databases, including PubMed and Scopus, for studies published between January 2020 and June 2024. Boolean search strings were developed to capture relevant concepts, combining keywords and medical subject headings (MeSH) such as "COVID-19 resurgence", "COVID waves", "public compliance COVID", "pandemic public health response", and "lessons learned COVID-19". The search strategy was iteratively refined to improve sensitivity and specificity. Only English-language publications were included.

To supplement the scientific evidence and capture emerging, real-time developments, we also reviewed grey literature, including reports and technical briefs from WHO, national health agencies, policy briefs, press releases, credible news outlets, and publicly available data. This allowed us to incorporate policy updates, behavioral trends, and early observations that had not yet undergone peer review.

All sources were appraised for credibility and relevance. Peer-reviewed articles were prioritized for scientific evidence and analytical insights, while institutional and reputable media sources were used selectively to provide recent statistics, policy changes, and behavioral observations. Duplicates were removed and where overlapping information was found, peer-reviewed findings were given precedence. The extracted data were synthesized narratively, and the lessons learned, and recommendations were derived by integrating these findings, highlighting areas for improved preparedness and sustained vigilance in managing current and future pandemics.

DISCUSSION

The findings of this review are presented across three core domains: drivers of COVID-19 resurgence, including factors such as viral mutations, vaccine uptake,

seasonal variations, and policy gaps; public behaviours and compliance trends observed during successive phases of the pandemic; and global and national public health responses to resurgence events.

Resurgence and contributing factors

COVID-19 infections have demonstrated resurgence over

the past several years, even following periods of decline, despite the widespread rollout of vaccines that initially contributed to reduction in case numbers. Closer examination reveals that multiple, interrelated factors drive these repeated resurgences.

Figure 1 depicts various factors responsible for COVID-19 virus resurgence.

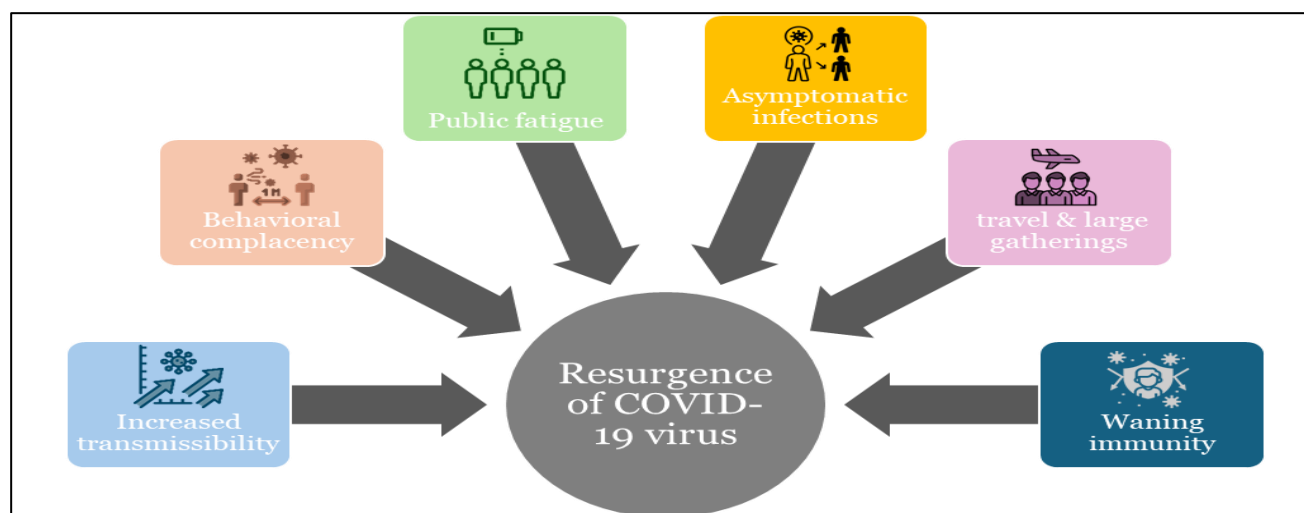


Figure 1: Factors leading to the COVID-19 virus resurgence.

Increased transmissibility of variants

The emergence of more transmissible/immune-evasive variants (R_0 and immune escape) has been observed. Recent research shows that the Delta variant has an estimated R_0 of 5-8, making it more transmissible than the *Alpha*, *Beta*, and *Gamma* variants by roughly 55%, 60%, and 34%, respectively. It has overtaken earlier strains to become the predominant variant in India.⁶ Major waves frequently coincided with the emergence of higher-transmissibility variants (e.g., Delta and omicron), consistent with increased effective reproduction numbers and antibody evasion.^{3,5}

Public behaviours and compliance trends

Behavioral complacency

Behavioral complacency is one of the primary factors contributing to the resurgence of COVID-19.⁶ Following COVID-19 vaccination, participants reported reduced adherence to handwashing and the use of sanitizer (70.2%), as well as social distancing (60.5%). In contrast, practices such as greeting with a handshake (58.8%) and using public transportation (45.9%) showed an increase.⁷ Across the globe, there has been a decline in preventive behaviours such as hand hygiene and mask-wearing. During the COVID-19 pandemic, more than 96% of respondents washed their hands between 6 and 12 times a day, with the majority washing them 8 times a day. However, after the COVID-19 pandemic, the frequency

declined; >92% of respondents washed their hands 4 to 7 times a day.⁸ As case numbers declined and daily life gradually returned to normal, pre-pandemic lapses in hygiene practices began to re-emerge. As pandemic restrictions eased, mask-wearing and handwashing declined, and people resumed participating in activities that involved frequent exposure to large crowds.^{6,8}

Public fatigue

Another reason for the resurgence was public fatigue coupled with rampant misinformation.⁹ Prolonged pandemic measures caused people to become less careful about safety measures and pay less attention to restrictions. Concurrently, social media amplified misinformation, promoting unsupported claims such as vaccines negatively affecting fertility or altering genetic makeup.⁹ A national survey (Annenberg public policy center, July 2024) found that 28% of Americans erroneously believe COVID-19 vaccines have caused thousands of deaths, up from 22% in June 2021, while 22% believe infection is safer than vaccination, more than doubling from 10% in April 2021.¹⁰ These beliefs contributed to heightened vaccine hesitancy and indirectly fueled continued COVID-19 transmission.

Asymptomatic infections

Asymptomatic infections were another issue.¹¹ A large meta-analysis of nearly 29.8 million tested individuals found that while only about 0.25% of entire tested

population were asymptomatic positives, a much larger proportion-40.5% of confirmed COVID-19 cases asymptomatic.¹² Feeling fine and completely unaware, they would continue their daily activities, thereby facilitating silent community transmission. This silent, unnoticed transmission enabled COVID-19 to circulate in communities even when it appeared that no one sick.¹¹

Vaccination and immunity

Vaccines leverage the principles of adaptive immunity. By presenting the spike antigen safely, they induce neutralizing antibodies and T-cell responses without causing disease. Table 2 provides a list of all the vaccines used in the treatment of COVID-19 infections.

Table 2: Different types of vaccines used in COVID-19 infections.

Vaccine type	Examples	Mechanism of action
mRNA vaccines	Pfizer-BioNTech, Moderna	Use a small piece of genetic code (mRNA) to instruct cells to produce a harmless spike protein, triggering an immune response. ^{13,14}
Viral vector vaccines	AstraZeneca, Johnson and Johnson	Use a modified (non-replicating) virus to deliver DNA instructions for making spike protein. ¹⁵
Inactivated vaccines	Sinopharm	Contain killed virus particles that cannot replicate but still stimulate the immune system to recognize the pathogen. ¹⁶

Vaccine effectiveness against severe disease has generally remained high across successive waves; however, protection against infection diminishes over time and is further reduced in the presence of immune-evasive variants.^{3,17} This trend also highlights the importance of timely booster doses and updated vaccine formulations.

Achieving herd-level protection has been challenged by multiple factors, including waning immunity, barriers to vaccine access, and the emergence of new variants. Persistent global inequities in vaccine distribution were evident throughout 2021 and 2022, with significant disparities observed across regions and income levels. These inequities not only delayed protection in vulnerable populations but also hindered global efforts to control transmission and reduce risk of new variant emergence.¹⁸

Other factors

Other factors contributing to the resurgence of the virus included increased travel and large gatherings.¹⁹ Public fatigue, increased travel, and large gatherings have also been significant contributors to the resurgence of virus.¹⁹ Periods such as holidays and summer vacations facilitated extensive inter-regional mixing, creating favorable conditions for viral transmission across communities.

High-density settings, including crowded events and busy travel hubs, amplified the risk, allowing a single infected individual to expose numerous others inadvertently.

Waning immunity represents another critical factor, as vaccine-induced protection diminishes over time.¹⁷ Studies show that effectiveness against SARS-CoV-2 infection drops substantially within months: for example, protection against symptomatic Omicron infection declined to approximately 20-30% at the twenty weeks post-vaccination, compared to over 80% at two to four weeks after booster doses.²⁰

Consequently, susceptibility to reinfection or breakthrough infection increases, especially in the presence of immune-evasive variants.^{3,17}

Global public health response

The rapid development and rollout of vaccines were unprecedented. Vaccines typically take many years due to constraints in research, development, and distribution. Through international collaboration and funding, a diverse portfolio of COVID-19 vaccines was developed within a year, a remarkable scientific achievement. Another milestone was the rapid sequencing of the viral genome, which enabled early tracking of mutations and informed the design of vaccines targeting the spike protein.²¹ In parallel, many countries implemented public health measures such as mask mandates and social distancing during the early phases of the pandemic, which contributed to slowing the initial spread of the virus.

Unfortunately, the unequal distribution of vaccines continued to be a significant problem. The Gini coefficients for the continents on June 7 and December 7, 2021, were 0.57 and 0.61, respectively, indicating severe inequality between the continents. Results show that North America had the highest Gini coefficient (0.91), while South America had the lowest Gini coefficient (0.61) as of December 7, 2021.¹⁸ Wealthier countries were able to stockpile expensive vaccines, whereas poor countries were left without protection from the virus. Moreover, the spread of misinformation continued to be a significant issue, leaving the public confused about what to do. Contradictory information on the internet, such as changing guidelines about mask usage or vaccine safety, led to growing scrutiny of health systems. On social media, erroneous claims about COVID-19 cures and conspiracy theories spread across the internet. This led to reduced compliance with the built-in safety systems designed to protect the public from the virus.⁹ Table 3 provides a comparative description of the public health responses implemented by various countries worldwide.

Table 3: Approaches of different countries to the spread.

Countries	Approaches	Measures	Unique features
Japan	Focused on identifying and controlling clusters of infections rather than broad lockdowns	Backward tracing of superspreading clusters; public guidance on avoiding closed, crowded, and close-contact settings	Science-led cluster control instead of blanket lockdowns. ¹¹
Singapore	Implemented a strict “circuit breaker” lockdown initially, followed by phased reopening.	Mask mandates; trace together (Bluetooth app/token); safe entry check-ins	First nationwide Bluetooth contact-tracing rollout; tightly sequenced reopening. ¹¹
United states	Combined rapid vaccine development with decentralized, state-level pandemic measures.	Federal funding for vaccine R and D/scale-up; state-level PHSM (masking, closures); phased vaccine rollout	Record-speed vaccine development; highly variable outcomes across states. ²²
India	Imposed an early nationwide lockdown and later focused on testing, treatment, vaccination, and public adherence to safety measures.	Nationwide lockdown (Mar 2020); “test-track-treat-vaccinate”; digital vaccine platform (CoWIN)	One of the strictest early lockdowns; world’s largest digital vaccination booking system. ²³
New Zealand	Pursued an early elimination strategy, aiming to keep COVID-19 out of the community until Delta emerged.	Rapid border closures; 4-level alert system; strict lockdowns; robust test-trace-isolate	Maintained near-zero community transmission through 2020; pivoted when Delta emerged. ²⁴

Lessons learned

The pandemic has taught us some difficult yet valuable lessons for both the public and public healthcare systems. Firstly, the importance of early action and preparation is evident. Those countries, such as New Zealand, that implemented strict early lockdown measures-such as swift travel restrictions, testing, and contact tracing-saw significantly fewer cases initially. This teaches how acting before a crisis escalates is far more effective than reacting afterwards. Moreover, early investments in pandemic preparedness, such as stockpiling personal protective equipment and establishing surveillance networks, proved their worth.

Secondly, the importance of public trust and communication between the public and authorities is paramount. The pandemic has shown us that without public cooperation, scientific knowledge and medical tools cannot overcome the pandemic. When global leaders are transparent and clear, they achieve higher compliance with measures such as vaccinations and masking. By contrast, mixed messaging fuels skepticism and resistance, thereby undermining the effectiveness of interventions. It is crucial that authorities combat misinformation proactively-for example, by collaborating with community leaders and utilizing social media to disseminate accurate information, thereby maintaining public understanding of why specific measures such as restrictions are necessary.

Lastly, the pandemic has highlighted the inequity in resource distribution and response efforts. Delays in distributing vaccines, equipment, or even basic supplies prolong the pandemic, allowing new strains to continue

emerging. Variants emerging from areas of uncontrolled transmission can threaten global gains. Therefore, a more equitable approach (for instance, sharing vaccine technology and doses, or supporting low-resource health systems) is not only ethically right but scientifically prudent. Since no country can fully insulate itself from a global pandemic, providing aid to other countries to curb the spread is in everyone’s self-interest.

Importantly, COVID-19 has highlighted the need for robust surveillance and quick response to pathogen evolution. We have learned that even after an epidemic wave subsides, continued vigilance is necessary. Surveillance systems, including genomic sequencing of viral samples, need to be expanded and networked globally so that new variants or outbreaks are quickly detected and assessed. Alongside this, regulatory agility is necessary to update vaccines or therapeutics when the pathogen changes. During the COVID-19 pandemic, we witnessed the introduction of booster shots and updated vaccine formulations as a response to waning immunity and the emergence of new variants. In the future, this kind of nimble adjustment will be crucial for the long-term management of an evolving virus.

Recommendations for pandemic preparedness-Every country should develop and maintain robust response plans that can be activated on short notice, as new pathogens can emerge at any time. Nurturing the public’s trust through transparency and education will be just as important as developing drugs and vaccines. Prioritize global equity in resource distribution, including vaccines, treatments, and technical support, to ensure faster, coordinated responses and reduce the risk of prolonged

transmission and variant emergence in future pandemics. Strengthen global genomic surveillance and regulatory agility to enable rapid detection of pathogen evolution and timely updates of vaccines and therapeutics in future pandemics.

Limitations

This review is limited to English-language sources available as of mid-2024 and may not reflect subsequent developments. Access restrictions also prevented inclusion of some high-quality, paywalled studies. The scope was intentionally focused on viral evolution, public behaviors, and public health responses, excluding areas such as long COVID, psychological impacts, and detailed economic analyses. Additionally, the generalizability of findings may be constrained. These limitations should be taken into account when interpreting the conclusions.

CONCLUSION

The COVID-19 pandemic has underscored that controlling a rapidly evolving virus requires a combination of scientific innovation, agile policies, and strong public engagement. While vaccines, public health measures, and global collaboration significantly reduced mortality and morbidity, waning immunity, behavioral fatigue, and inequities in access have repeatedly fueled resurgence. This review highlights that sustained vigilance, through continuous genomic surveillance, timely updates on vaccines and therapeutics, and robust communication strategies, is critical to staying ahead of emerging variants. Equally important is fostering public trust and ensuring equitable resource distribution across countries, as uncontrolled transmission anywhere poses a threat everywhere. Lessons from diverse national responses show that early action, transparent leadership, and community engagement yield better outcomes, whereas delayed or fragmented approaches magnify harm.

Moving forward, the focus must be on building resilient systems, scalable surveillance networks, rapid regulatory pathways, and frameworks for fair resource allocation. These measures will not only strengthen preparedness for future pandemics but also enhance global health security. COVID-19 has been a stark reminder that preparedness, cooperation, and adaptability are not optional; they are essential for managing present and future public health crises.

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