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Review Article

From Discovery to Deployment: The Evolution of COVID-19 Treatment and Vaccination Strategies

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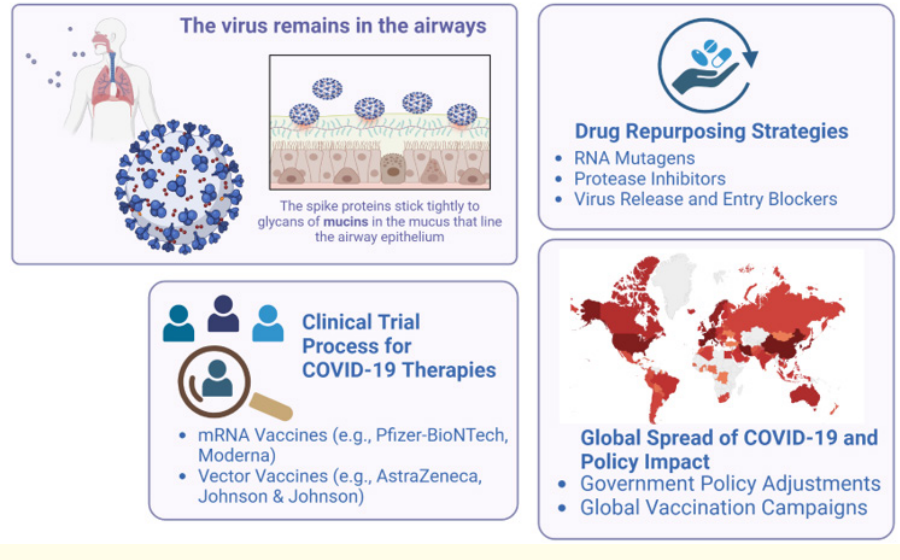
Abstract

In the relentless pursuit to control COVID-19, a diverse range of therapies has been under investigation, each with the potential for significant impact on the course of the pandemic. This review meticulously collates and examines data on these proposed treatments, highlighting the need for further drug development and clinical trials to enable their effective use in combating the virus. The potential medications discussed are RNA mutagens, virus entry and release blockers, and protease inhibitors. Additionally, this review provides a comprehensive overview of the mechanisms behind the currently available vaccines, offering insights into their role in fighting against the SARS-CoV-2 virus. This virus, identified as a single-stranded RNA beta-coronavirus, is notable for its complex genome that codes for accessory, non-structural, and structural proteins and for the emergence of new strains that pose ongoing challenges. The pervasive impact of SARS-CoV-2, characterized by its high transmissibility and capacity to induce widespread panic, underscores the urgency of addressing this global health crisis. The review advocates for policy shifts to prioritize the administration of booster doses to populations at heightened risk, including those with compromised immune systems, existing comorbidities, and other vulnerabilities, as a strategy to mitigate the severity of COVID-19 outcomes.

Keywords: Coronavirus; Clinical Trials; Drug Repurposing; Vaccine Development; COVID-19; Side Effects

Graphical Abstract



Introduction

SARS-CoV-2 is an efficiently transmitting and subsequently highly infectious third novel β-coronavirus. The genome of SARSCoV-2 is meticulously linked to the RaTG13 found in *Rhinolophus affinis* and RmYN02 viruses observed in *Rhinolophus malayanus*. The origin of SARS-CoV-2 is believed to be from bats [1].

The clinical syndrome occurs with specific ailments like gastrointestinal disease, hyperinflammatory syndrome, coagulopathy, and cardiac pathology, most often resulting in cardiac failure by the virus SARS-CoV-2 is known as coronavirus disease-19 (COVID-19) [2]. SARS-CoV-2 fatalities are most commonly linked with advanced age and comorbidities conditions that include hypertension, obesity, diabetes, and an immunocompromised state [3].

In December 2019, a wave of cases was disclosed with new diseases with symptoms such as pneumonia and respiratory failure caused by a novel coronavirus in the province of Hubei in China and an outburst of pneumonia cases in the city of Wuhan. The symptoms of pyrexia, restlessness, dry cough, and hyperventilation were diagnosed as viral pneumonia. The World Health Organization (WHO) momentarily named the new virus 2019 ''novel coronavirus (2019-nCoV)'' on 12 January 2020. This infectious disease was officially labeled ''coronavirus disease 2019 (COVID-19)'' on 12 February 2020. Later, the International Committee on Taxonomy of Viruses (ICTV). Official designation of the virus as ''SARS-CoV-2'' based on phylogeny taxonomy. It initially turned up in China and spread globally as a threat [4]. WHO made the judgment that COVID-19 could be identified as a pandemic, followed by the four pandemics these are; in 1918-Spanish flu (H1N1), in 1957-Asian flu (H2N2), in 1968-Hong Kong flu (H3N2), and 2009-Pandemic flu (H1N1). Tedros Adhanom Ghebreyesus, General Director of the WHO, held a world press conference and declared it a pandemic on 11 March 2020 [5].

Structure of coronavirus

- **Spike (S):** The S protein enters inside the cells by binding to cellular receptors and helps fuse the viral envelope with the host's cell membrane. There are two subunits of spike protein: S1, which is accountable for binding to the host cell receptor, and S2, which is responsible for merging the cell membrane and the virus. Cleavage of S protein occurs at the boundary between the subunits S1 and S2, which is suggested to activate protein for membrane fusion utilizing irreversible conformational modifications, and thereby, the virus enters the cells (figure 01).
- **Envelope (E):** In the assembly and morphogenesis of virions in the cell, envelope proteins are essential.
- **Membrane (M):** Golgi apparatus glycosylates the three transmembrane domains of the M protein. It regenerates virions into the cell. Nucleocapsid protein binds to RNA to create a complex. In this endoplasmic reticulum-Golgi apparatus intermediate compartment (ERGIC), the M protein causes the development of interacting virions with this complex.
- **Nucleocapsid (N):** N proteins are phosphoproteins that can bind to genomic RNA and are essential for coronavirus transcription and replication [6], as shown in Figure 1.

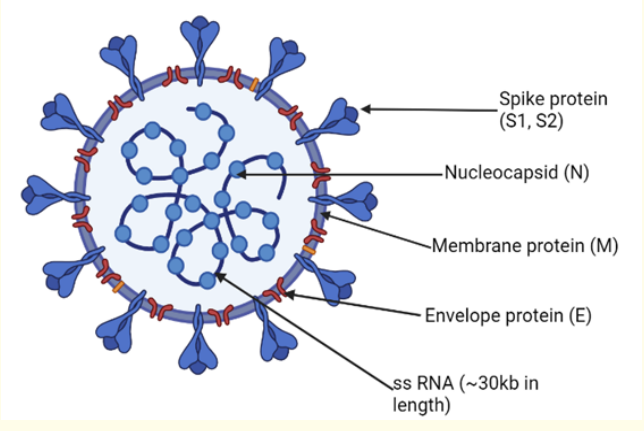


Figure 1: Structure of coronavirus [6-8].

Symptoms and other health complications

The infected person shows signs of COVID-19 from 2 to 14 days, but the illness prevails for 27 days. Researchers have shown that the incubation period, on average, is around 5.2 days [9]. The patient's age and the immunological system will determine the time. The symptoms of COVID-19 are pyrexia, cough, and fatigue, while other signs include dry cough, headache, hemoptysis, diarrhea, and lymphopenia. The compilation of symptoms is reviewed [10] (fig-

ure 2). Some factors, such as environmental conditions, also affect the current outbreak of COVID-19. A chest CT scan exhibited the manifestation of ground glass, which confirmed pneumonia. Some peripheral ground-glass opacity in subpleural portions of each of the lungs was a cause for immune responses (systemic as well as localized) that contributed to enhancement in inflammation. The COVID-19 symptoms are similar to early β-coronavirus, likewise, fever along with dry cough and dyspnea, as well as opacity observed in the ground-glass region within bilateral chest CT [11]. COVID-19 has also caused some atypical clinical symptoms like sore throat, runny nose, and sneezing, mainly related to the lower airway pathway. Certain cases showed dyspnea associated with hypoxemia in the upper lung lobe after admission [12]. Therefore, the percentages of symptoms reviewed and compiled for COVID-19 are given in Figure 3. The compilation of systemic symptoms/disorders is given in Figure 3.

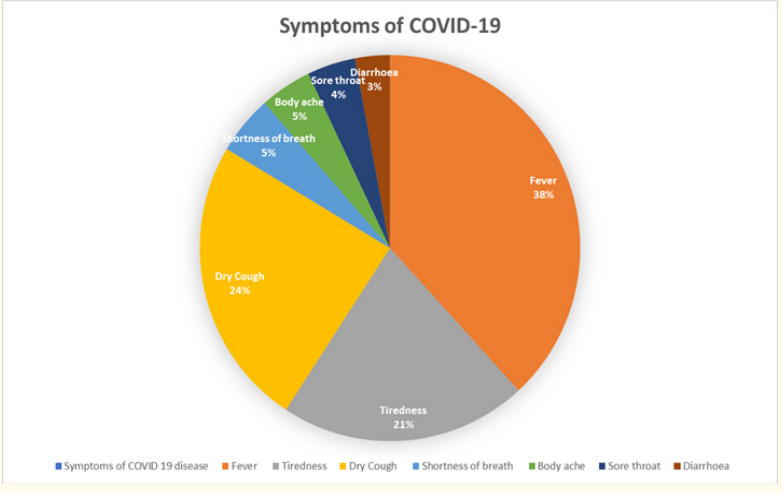


Figure 2: Percentages of symptoms reviewed and compiled of COVID 19 [10,12].

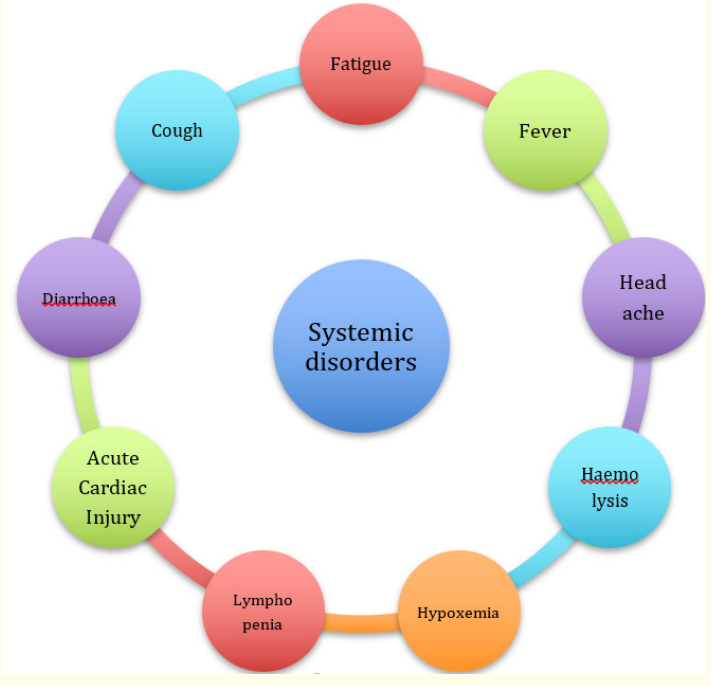


Figure 3: Compilation of systemic symptoms/disorders from review [13].

Pathogenesis and transmission of Covid 19

The COVID-19 zoonotic disease originated from SARS-CoV-2, which is possibly attained by the consuming of wild animals as food or maybe by the contact between rural and wildlife residents in those regions. Since the emergence of SARS-CoV and Middle East respiratory syndrome-coronavirus (MERS-CoV), bats have been suspects of evolving viruses [14].

Coronavirus vaccine design

Previous vaccine literature on SARS-CoV-1 and (MERS-CoV) shows that the S-protein on the virus's surface is a suitable target for vaccine design, which interacts with the receptor angiotensin I converting enzyme 2 (ACE2) [15].

There are a few vaccines investigated that are adequate but not able to instigate immunity, like recombinant S-protein-based vaccines, attenuated and whole-inactivated vaccines, and vectored vaccines for SARS-CoV-1, which are tested in preclinical models [16].

An effective coronavirus vaccine could be designed to produce an adequate antibody response, whereas some live virus-based vaccines produce severe problems such as granulocyte infiltration and lung and liver injuries [17].

Current studies have shown that neutralizing monoclonal antibodies isolated against SARS-CoV-1 could cross-react with the receptor-binding domains of SARS-CoV2. These studies suggested that the vaccines against SARS-CoV1 may be able to protect against SARS-CoV-2, but these vaccines are still being tested in Phase 1 [18]. Many vaccines developed targeting MERS-CoV S-protein are also in preclinical and clinical development. However, the chances seem to be less than strong cross-neutralizing antibodies produced from MERS-CoV vaccines to SARS-CoV2 because of the phylogenetic difference between these two viruses [19].

Drug repurposing of different drugs for Covid-19:

In drug repurposing, medicines that are safe for humans are redeveloped and used as a combination therapy for the clinical benefits of diseases. For COVID treatment, these drugs are considered favorable. Broad-spectrum antiviral agents (BSAAs) have been considered safe in early clinical trials [20].

Protease inhibitors like lopinavir/ritonavir are examples of drug combination therapy used for influenza and HIV and are considered in phase IV clinical trials.

RNA mutagen like remdesivir is considered in phase III clinical trials for antimalarial and favipiravir in combination, in phase II clinical trials for pneumonia, and are also considered for treatment in covid 19 [21,22].

Mechanism of Drugs in Clinical Trials is systematically given in Figure 4, and types of drug/treatment and mechanism are given in Table 1.

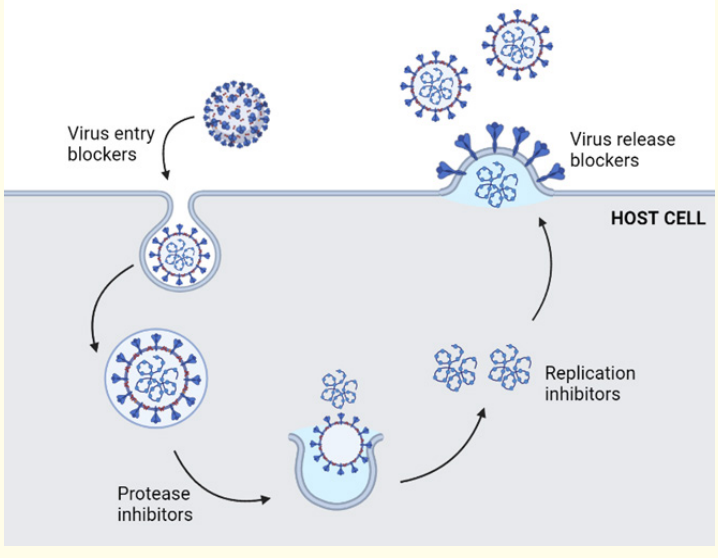


Figure 4: Mechanism of drugs in clinical trials [22].

RNA mutagens

Referring to Table 1, Remdesivir is a 1′-cyano-substituted adenosine nucleotide analogue prodrug. Its triphosphate competes with ATP, terminates the RNA chain, and treats COVID-19.

Favipiravir triphosphate mimics the ATP and GTP and hence incorporates with rdrp. It gives relief to pyrexia and cough and has fewer adverse effects. Ribavirin had the exact mechanisms. An underway clinical trial suggested that a combination of nitazoxanide, ribavirin, and ivermectin can be used to treat COVID-19 [40].

Protease inhibitors

Ritonavir-Lopinavir and Darunavir inhibit the protease of HIV, as given in Figure 5. In one of the studies, fifty patients were divided into two groups, the ritonavir-lopinavir group, and the Arbidol group, and it was observed that compared to the ritonavir-lopinavir group, viral clearance load was faster in the Arbidol group [41]. Common gastrointestinal side effects of ritonavir-Lopinavir are diarrhea, nausea, and vomiting. Darunavir was used for patients with HIV suffering from COVID-19, but it does not protect COVID-19-infected patients from respiratory function affected by SARS-Cov-2 [42] (table 1).

Virus-entry blockers, chloroquine

Entry of the virus involves S-protein binding to ACE2 receptor along with host gangliosides, and hence chloroquine creates interference with the binding process by competing with the S-protein to bind with gangliosides. In a clinical study, chloroquine phosphate appreciably decreased the recovery time from the disease compared to ritonavir-lopinavir treatment [43]. One of the studies suggests that combination therapy of hydroxychloroquine and azithromycin may show improvement in COVID patients, but hydroxychloroquine also showcases a higher amount of adverse effects [44]. It includes neurological, metabolic, and cardiac symptoms and should be consumed cautiously. Chloroquine and hydroxychloroquine safety issues were established by the FDA that included liver problems and failure, severe heart rhythm problems, kidney injuries, and blood and lymph system disorders, and cautioned against the use of these drugs outside hospitals [45] (table 1).

Virus-release blockers

Studies performed on the influenza viruses suggests that oseltamivir can bind and inhibit the neuraminidase enzyme in the virus responsible for virus release from the infected cell [46]. Clinical trial data for oseltamivir's efficacy in treating COVID-19 are insufficient [4] (table 1).

Non-virus-targeting treatment

Referring to Table 1, Cytokine storm leads to acute respiratory distress syndrome followed by multiple organ failure, which may also be fatal. Therefore, inhibiting the storm of cytokine is a critical parameter in the treatment of COVID-19. Drugs that fall under this category include inhibitors of interleukin-6 (IL-6). Therefore, treatments that directly target cytokines can decrease adverse events [47].

Tocilizumab

The severity of COVID-19 disease is highly positively related to IL-6 level. The monoclonal antibody tocilizumab acts as an antagonist for the IL-6 receptor. Some adverse effects are also observed and should be careful hypertriglyceridemia during the usage of tocilizumab Dexamethasone, an approved synthetic corticosteroid, a first-line treatment for immune-related complications mainly responsible for suppressing the immune system by inhibiting naive T cell proliferation and differentiation. It does not decrease the death rate in patients not requiring oxygen support. Adverse results include an increase in blood glucose levels, mood and behavior change, neuropsychological side effects and, ocular hypertension and cataracts, osteoporosis. Nevertheless, the above-mentioned adverse effects are only seen in the long term [48].

Clinical studies for COVID-19 based on selected monoclonal antibodies

Antibodies can combat viral infection by many mechanisms. Antibodies can prevent viral glycoproteins of envelope virus/protein shell non-enveloped virus by binding to the host cell. The primary function of these viral proteins is to initiate the fusion of viral and cellular membranes either by binding to cellular receptors (in the case of enveloped viruses) or by penetrating the cytosol directly (in the case of non-enveloped viruses). So, antibodies prevent these functions of viral proteins [49]. Compilation of Clinical studies for

COVID-19 based on selected monoclonal antibodies originating as B cells (from patients infected with SARS-COV-2) is given in Table 2.

Vaccination [30-34]

Human vaccinations with its vaccine type, side effects, inventor company and manufacturing country is reviewed and compiled in table 3.

Table 2: Clinical studies for COVID-19 based on selected monoclonal antibodies [50,52].

Drug names	Engineering	Omicron VOC neutralization
Casirivimab and Imdevimab	Unmodified	No neutralizing activity, *in vitro* study
Bamlanivimab and Etesevimab	Bamlanovimab is unmodified and Etesevimab is modified in (crystallizable fragment) FC domain that increases half-life.	No neutralizing activity, *in vitro* study
Sotrovimab	Modified in (crystallizable fragment) FC domain that increases half-life.	Partial neutralizing activity, *in-vitro* study.
Tixagevimab and cilgavimab	Modified in (crystallizable fragment) FC domain that increases half-life.	Partial neutralizing activity, *in-vitro* study.
Bebtelovimab	Unmodified	Potent neutralizing activity, *in vitro* study.
Regdanvimab	Modified in (crystallizable fragment) FC domain that increases half-life.	No neutralizing activity, *in-vitro* study
Amubarvimab and Romlusevimab	Modified in (crystallizable fragment) FC domain that increases half-life.	Partial neutralizing activity, *in-vitro* study.
Adintrevimab	Modified in (crystallizable fragment) FC domain that increases half-life.	Partial neutralizing activity, *in-vitro* study.

COVID 19 VACCINES							
Sr No	**Vaccine**	**Inventor (Company)**	**Manufacturing Country**	**No. of doses**	**Side effects**	**Age group**	**Vaccine type**
1	ZyCoV - D	Zydus Cadila	India	3	Negligible side effects	12yrs and above	DNA
2	mRNA - 1273 (also known as Spikevax)	Moderna	USA	2	Mild fever, muscle ache	12yrs and above	RNA
3	Sputnik V	Gamaleya	Russia	2	Fever, body pain, nausea, headache, sore throat, runny nose, fatigue, diarrhea, pain or swelling at site of injection	18yrs and above	Non Replicating Viral Vector
4	Ad26.COV2.S	Janssen (Johnson and Johnson)	Netherlands	1	Headache, fatigue, nausea, pain at site of injection	18yrs and above	Non Replicating Viral Vector
5	AZD1222	Oxford/ AstraZeneca	United Kingdom	1	Mild fever, body pain, pain at site of injection	18yrs and above	Non Replicating Viral Vector
6	Covishield	Oxford/Astra-Zeneca	India	2	Mild fever, body pain, pain at site of injection	18yrs and above	Non Replicating Viral Vector
7	Covaxin	Bharat Biotech	India	2	Headache, fatigue, body pain, pain at site of injection	12yrs and above	Inactivated
8	iNCOVACC Nasal spray (needle free)	Bharat Biotech	India			Restricted use Adults	adenovirus vector
9	Fabispray (first Nasal spray vaccine)(needle free)	Glenmark and SaNOtize	India	Two spray in Each nostril Six times a day for 7 days		Emergency use Adults	Nitric Oxide Nasal Spray (NONS): antimicrobial properties with a direct virucidal effect

Table 3: Human Vaccination, Vaccines approved for COVID-19 [53, 57].

Types of vaccines

mRNA vaccines

mRNA vaccines are innovative types of vaccines used to protect against infectious diseases. These mRNA vaccines instruct our cells to make a protein or a small piece of a protein that triggers/activates an immune response. If the coronavirus enters our body, the immune response enhances antibodies and protects us from getting infected [58].

Viral vector vaccines

Viral vector vaccines are modified versions of a different type of virus (the vector) to transfer significant directives to our defense cells. The vector (not the virus causing COVID-19, but a different, harmless virus) will enter a cell and then, by utilizing the cell's machinery, may produce a harmless piece of the virus which is only found on the surface of the virus that causes COVID-19 is known as a spike protein [59].

The cell shows the S-protein on its surface, and our immune system recognizes it and activates the immune system. Then, our body starts producing antibodies and energizes other immune cells to protect our body from the infection.

At the end of the process, our bodies have trained to combat future infection with the COVID-19 virus.

Whole virus vaccines

These vaccines are based on regular technology in which a version of the virus (virus-like particles) is inactivated by being exposed to heat, radiation, or chemicals. These virus-like particles created artificially resemble the real virus but do not have any genetic material and thus can not cause infection [60].

Protein subunit vaccines

In this innovative recombinant vaccine, a small piece of the protein with the virus's genetic code is inserted into a different cell host, and the code contains directions for this cell to develop the virus S-protein[61]. These cells act as producers for large quantities of the protein subunits extracted and purified and are later used as active ingredients in the vaccine along with adjuvants. When these are injected, our bodies learn how to recognize the viral protein to generate an immune response in case of future Covid 19 attacks.

Booster dose

A booster dose is a dose of vaccine that improves or restores protection offered by the first immunization, which may diminish over time.

Following is a summary of clinical studies showing the impact of booster doses against Omicron variants:

- Pfizer BioNTech or Moderna booster dose vaccine after either the Oxford–AstraZeneca) or Pfizer BioNTech primary course increased immunity against Omicron [62].
- A phase 2 trial of the third dose booster vaccination, COV-BOOST, was initiated. It was reported that antibodies and cellular immune responses were enhanced after Oxford–AstraZeneca's initial course, and all, except one, after BNT/BNT (Pfizer BioNTech [62].
- Increased nAb titers were observed in patients who received booster doses. Expands neutralization against the Omicron variant and boosts nAb levels were observed.
- When booster dose recipients were compared with those who were vaccinated with two doses, Promising results were mentioned, as the likelihood of contracting SARS-CoV-2 was reduced by 86% [63].
- After two immunizations, a booster vaccination considerably boosted titers against Omicron to levels comparable to those reported against the ancestral (D614G) variety. Differences in post-vaccination antibody responses were not linked to age or gender [64].
- When compared to a two-dose mRNA vaccination (CoronaVac) with a BNT162b2 booster, neutralization of Omicron was undetectable in those who received the vaccine, but a 1.4-fold increase in neutralization response against Omicron was observed with a booster dose [65].
- The convalescents' immunity against the Omicron variants was dramatically improved after three vaccination injections.
- Adults who took a primary COVID-19 immunization regimen at least 12 weeks prior exhibited a satisfactory safety profile and were found immunogenic after receiving homologous and heterologous booster doses [66].

Side effects of vaccines in different countries

India had very low cases of Adverse Events Following Immunisation (AEFI) of Thrombosis and Thrombocytopenia syndrome (TTS) while administrating 220 crore doses of covid -19 vaccines, which is a small fraction of TTS cases in Canada, Australia, and the United Kingdom [67].

Table 4: Countrywide TTS cases [68].

Country Name	TTS cases	Incidence rate of TTS cases after vaccine administration
India	26	0.001 per lakh doses administered
Canada	105	2.27 per lakh doses administered
Australia	173	1.66 per lakh doses administered
United Kingdom	39	0.06 per lakh doses administered

The vaccine used was AstraZeneca (covishield).Total number of AEFI cases reported after the administration of 219.9 crore doses was 92,114, of which 89,332 were minor AEFI cases, whereas 2,782 were major cases [69].

Effectiveness of mixing of covid vaccines against new subvariant omicron BF.7.

A rise in cases of a new subvariant omicron BF.7 in China and other parts of the world has spread concern in India and throughout the world [70].

According to a new AIG study, Hyderabad-based Biological E's Corbevax booster in individuals already vaccinated with Covishield can offer maximum protection against Omicron variants, and corbevax showed higher levels of antibodies. According to the Indian Council Of Medical Research (ICMR), the study has found that a mix and match of different vaccines had no adverse effect and could actually be more effective and provide a better shield against different variants of Coronavirus [71]. Mixing of vaccines, which is also called heterologous boosting, can be a prominent strategy against the pandemic. Mixing shots like vector-based vaccine (Covishield) followed by mRNA bases(Pfizer) can give better immune protection. The mRNA-based vaccine generates antibodies, and the vector-based gives a better T-cell response. The side effects can vary from individual to individual. In a Spanish study, 448 individuals who received a mix of AstraZeneca dose followed By Pfizer BioNTech dose, the robust immune response was noted with fewer side effects [72].

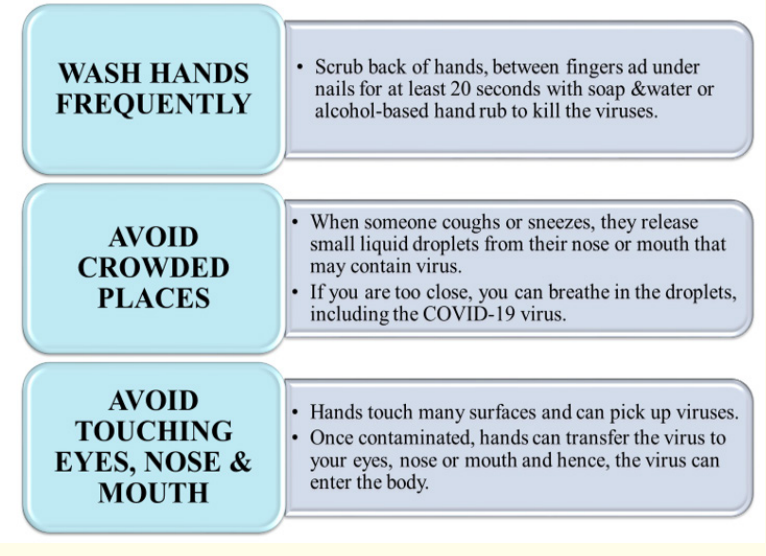


Figure 5: Measures to be taken [73,74].

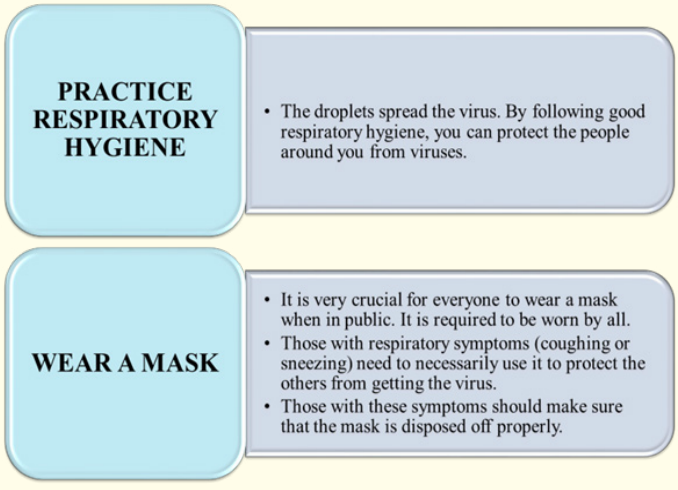


Figure 6: Precautions to be taken [75].

Measures to be taken to prevent the disease are given in Figure 5. Precautions to be taken to prevent the disease are given in Figure 6.

Different types of variants of COVID-19

Variants of concerns (VOCs)

A variant in which there is increased transmissibility, mortality rate or hospitalization, reduction of neutralization by antibodies that are generated during previous infection or vaccination, reduced efficacy of treatments or vaccines, or diagnostic detection failure is as follows [76].

- Alpha (α)
- Beta (β)
- Gamma (γ)
- Delta (δ)

Variants of interest (VOIs)

A variant with particular genetic markers related to changes to receptor binding and reduced neutralization by antibodies is likely to have a diagnostic impact or enhancement in the transmissibility or severity of the disease [77].

- Epsilon. (£)
- Zeta (ζ)
- Eta (η)
- Theta (θ)
- Iota (ι)
- Kappa (κ)

Strains

As per current studies, viruses are very likely to avoid transmission barriers, particularly when infections are widespread. It's important to note that the higher the infection rate, the higher the mutations occur [78]. The virus will be able to live and spread in this fashion. Many SARS-COV-2 variants have lately appeared worldwide as a result of virus transmission. Several causes are responsible for the various amounts of genetic changes, one of which is the universal lack of protection against this novel virus. A new study estimated COVID-19 gene sequences to check if there were any mutations [79]. The discovery says that 26,844 single mutations were tracked in 203,346 SARS-CoV-2 human genomes, with S proteins and NSP3 being the most common mutations. Around 5000 mutations in the S protein had been located by the end of December 2020 [80]. Omicron (B.1.1.529) in South Africa and Delta (lineage B.1.1617) in India are two new variants that have lately appeared. The first case of delta's was reported in October 2020, and the variant has a faster rate of transmission and infection than other identified variants. Omicron was reported on November 9, 2021; because of the larger number of mutations, it has a considerably higher transmission rate than previously existing variations. The same can be reviewed in table 4. The penetration of virus into human cells is responsible for the variant features, has multiple spike protein alterations, and shows more than 30 changes in the virus region. The emerging stains of COVID-19 are given in Table 5.

Table 5: Emerging strains of COVID-19 [81,82].

Strain/Variant name	Mutations
B.1.1.7	N501Y, P681H
P.1 or B.1.1.2 48	N501Y and K417T, escape mutant- E484K
1.351	N501Y, K417N, E484K
B.1.526	E484K and S477N
B.1.427/B.1.429	L452R

AI-Fueled Acceleration in COVID-19 Drug Repurposing

The COVID-19 pandemic necessitated a rapid response to developing effective treatments. Traditional drug discovery, a painstaking process often taking over a decade, proved inadequate. Drug repurposing, leveraging existing medications for new uses, emerged as a promising alternative. Artificial intelligence (AI) has become a game-changer in this field. AI can analyze massive datasets of biological information, drug-target interactions, and disease mechanisms. Techniques like machine learning and network analysis enable researchers to identify drugs approved for other conditions that might target SARS-CoV-2 or its associated pathways [83]. This streamlines the process, and leverages established safety profiles, potentially accelerating clinical trials.

A prime example is Baricitinib, a JAK inhibitor initially developed for rheumatoid arthritis. Through AI-powered analysis, researchers identified its potential to mitigate the cytokine storm, a hallmark of severe COVID-19 cases [84]. Subsequent clinical trials confirmed Baricitinib's efficacy in reducing inflammation and improving patient outcomes [85]. Disulfiram, used for alcohol dependence, is another example identified by AI virtual screening as a potential inhibitor of a protein crucial for viral entry [86]. While Disulfiram's effectiveness requires further investigation, it exemplifies AI's ability to explore unconventional avenues in drug repurposing.

The significance of AI in COVID-19 drug repurposing is undeniable. It has significantly reduced the time and resources needed to identify potential treatments. This rapid response has the potential to save countless lives and alleviate the global burden of the pandemic. However, it is crucial to remember that AI-driven predictions require validation through laboratory and clinical studies. The case of Lopinavir/Ritonavir, an HIV treatment initially investigated for COVID-19 based on its broad-spectrum antiviral properties but later found to have limited efficacy in large-scale trials [87], underscores the importance of a combined approach. AI-powered drug repurposing research will likely explore combination therapies targeting different stages of the viral lifecycle, further optimizing treatment strategies [87].

Conclusion

The emergence of SARS-CoV-2 as a global health menace has catapulted the scientific community into an unprecedented race towards finding viable therapeutic and preventive measures. Throughout the pandemic, the virus has demonstrated a remarkable ability to infect and spread swiftly across continents, creating a sense of urgency and sometimes, panic, around the globe. The collective response has led to the rapid development and authorization of vaccines, presenting a beacon of hope amidst the crisis. However, as we navigate the evolutionary trajectory of the virus, characterized by the emergence of new variants, it becomes increasingly crucial to adapt our strategies accordingly.

Global cooperation and adaptive policy making are imperative in ensuring that vaccine coverage extends to the most susceptible segments of the population. The prioritization of booster vaccines for individuals with underlying health conditions, immunocompromised states, and the aged can significantly reduce the severity of outbreaks and alleviate the load on healthcare systems. Furthermore, continued research into novel therapeutic agents and vaccine platforms will equip us with a more robust arsenal against not only the current virus but also future pathogens that may arise. Ultimately, the fight against SARS-CoV-2 is a testament to the resilience and ingenuity of the global scientific community, highlighting the importance of preparedness, collaboration, and innovation in overcoming public health challenges.

Ethical Approval

Not applicable.

Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Competing Interests

Authors have no competing interests amongst each other.

Availability of Data and Materials

Not applicable.

Funding

Funding have not utilized so it has declared not applicable.

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Not applicable.

Authors Contributions

Dr. Bandoo C. Chatale, Dr. Swati Mutha, Madhuri B. Goswami, Bhairavi Murkute, Kashmira R. Chaudhari, have written the main review article and Akshata Yashwant Patne, Dr. Prashant R Murumkar have reviewed the article for plagiarism, figure designing and content.

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