Centers for Disease Control and Prevention
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COVID-19

Science Brief: COVID-19 Vaccines and Vaccination

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Summary of Recent Changes

Last updated July 27, 2021

- Data were added from studies published since the last update that demonstrate currently authorized mRNA vaccines provide protection against variants of concern, including the Delta strain that is now predominant in the United States. Vaccine effectiveness against hospitalization and death is high for all current SARS-CoV-2 variants; emerging data suggest lower effectiveness against confirmed infection and symptomatic disease caused by the Beta, Gamma, and Delta variants compared with the ancestral strain and the Alpha variant.

Key Points

- All COVID-19 vaccines currently authorized in the United States are effective against COVID-19, including serious outcomes of severe disease, hospitalization, and death.
- Available evidence suggests the currently authorized mRNA COVID-19 vaccines (Pfizer-BioNTech and Moderna) are highly effective against hospitalization and death for a variety of strains, including Alpha (B.1.1.7), Beta (B.1.351), Gamma (P.1), and Delta (B.1.617.2); data suggest lower effectiveness against confirmed infection and symptomatic disease caused by the Beta, Gamma, and Delta variants compared with the ancestral strain and Alpha variant. Ongoing monitoring of vaccine effectiveness against variants is needed.
- A growing body of evidence indicates that people fully vaccinated with an mRNA vaccine (Pfizer-BioNTech or Moderna) are less likely than unvaccinated persons to

acquire SARS-CoV-2 or to transmit it to others. However, the risk for SARS-CoV-2 breakthrough infection in fully vaccinated people cannot be completely eliminated as long as there is continued community transmission of the virus.

- Studies are underway to learn more about the effectiveness of Johnson & Johnson/Janssen vaccine.
- At this time, there are limited data on vaccine effectiveness in people who are immunocompromised. People with immunocompromising conditions, including those taking immunosuppressive medications, should discuss the need for personal protective measures after vaccination with their healthcare provider.
- This updated science brief synthesizes the scientific evidence supporting CDC's guidance for fully vaccinated people and will continue to be updated as more information becomes available.

Background

COVID-19 vaccination is a critical prevention measure to help end the COVID-19 pandemic. COVID-19 vaccines are now widely available in the United States, and CDC recommends all people 12 years and older be vaccinated against COVID-19. Three COVID-19 vaccines are currently authorized by the U.S. Food and Drug Administration (FDA) for emergency use: two mRNA vaccines (Pfizer-BioNTech, Moderna) and one adenoviral vector vaccine (Johnson & Johnson/Janssen vaccine). People are considered fully vaccinated if they are ≥2 weeks following receipt of the second dose in a 2-dose series (mRNA vaccines), or ≥2 weeks following receipt of a single-dose vaccine (Johnson & Johnson/Janssen).*

Public health recommendations for people fully vaccinated with authorized COVID-19 vaccines must consider evidence of vaccine effectiveness against symptomatic and asymptomatic COVID-19, as well as vaccine impact on SARS-CoV-2 transmission. Other individual and societal factors are also important when evaluating the benefits and potential harms of additional prevention measures among vaccinated individuals. The Advisory Committee on Immunization Practices and CDC routinely consider factors such as population values, acceptability, and feasibility of implementation when making vaccine recommendations.[1] These factors were also considered when developing CDC's interim public health recommendations for fully vaccinated people.

In this scientific brief, we summarize evidence available through July 24, 2021, for the currently authorized COVID-19 vaccines (administered according to the recommended schedules) and additional considerations used to inform public health recommendations for fully vaccinated people, including:

- Vaccine efficacy and effectiveness against SARS-CoV-2 infection
- Vaccine performance against emerging SARS-CoV-2 variant viruses
- Impact of other prevention measures in the context of vaccination

Accumulating evidence indicates that fully vaccinated people without immunocompromising conditions are able to engage in most activities with low risk of acquiring or transmitting SARS-CoV-2. The benefits of avoiding disruptions such as unnecessary quarantine and social isolation might outweigh the low residual risk of becoming ill with COVID-19, generally with mild disease.

COVID-19 vaccine efficacy and effectiveness

Vaccine efficacy refers to how well a vaccine performs in a carefully controlled clinical trial, whereas effectiveness describes its performance in real-world observational studies. Evidence demonstrates that the authorized COVID-19 vaccines are both efficacious and effective against symptomatic, laboratory-confirmed COVID-19, including severe forms of the disease. In addition, a growing body of evidence suggests that mRNA COVID-19 vaccines also reduce asymptomatic infection and transmission. Substantial reductions in SARS-CoV-2 infections (both symptomatic and asymptomatic) will reduce overall levels of disease, and therefore, viral transmission in the United States. However, investigations are ongoing to assess further the risk of transmission from fully vaccinated persons with breakthrough infections.

Animal challenge studies

Rhesus macaque challenge studies provided the first evidence of the potential protective effects of Pfizer-BioNTech, Moderna, and Johnson & Johnson/Janssen COVID-19 vaccines against SARS-CoV-2 infection, including both symptomatic and asymptomatic infection. Vaccinated macaques developed neutralizing antibodies that exceeded those in human convalescent sera and showed no or minimal signs of clinical disease after SARS-CoV-2 challenge.[2-4] In addition, COVID-19 vaccination prevented or limited viral replication in the upper and lower respiratory tracts, which may have implications for transmission of the virus among humans.[2-4]

Vaccine efficacy from human clinical trials

Clinical trials subsequently demonstrated the authorized COVID-19 vaccines to be efficacious against laboratory-confirmed, symptomatic COVID-19 in adults, including severe forms of the disease, with evidence for protection against both symptomatic and asymptomatic SARS-CoV-2 infection [5-11] (**Box**). Recent trial data demonstrated 100% efficacy of the Pfizer-BioNTech vaccine against laboratory-confirmed, symptomatic COVID-19 in adolescents 12–15 years old, although this estimate was based on small numbers of cases.[12]

Box 1. Summary of vaccine efficacy estimates for authorized COVID-19 vaccines

All authorized COVID-19 vaccines demonstrated efficacy (range 65% to 95%) against symptomatic, laboratory-confirmed COVID-19 in adults ≥18 years.

- For each authorized COVID-19 vaccine, efficacy was demonstrated across different populations, including elderly and younger adults, in people with and without underlying health conditions, and in people representing different races and ethnicities.
- The Pfizer-BioNTech COVID-19 vaccine also demonstrated high efficacy against symptomatic, laboratory-confirmed COVID-19 in adolescents aged 12-17 years.

All authorized COVID-19 vaccines demonstrated high efficacy (≥89%) against COVID-19 severe enough to require hospitalization.

All authorized COVID-19 vaccines demonstrated high efficacy against COVID-19-associated death.

- In the clinical trials, no participants who received a COVID-19 vaccine died from COVID-19; the Moderna and Johnson & Johnson/Janssen trials among adults ≥18 years each had COVID-19 deaths in the unvaccinated placebo arm.

Preliminary data from the clinical trials among adults ≥18 years old suggest COVID-19 vaccination protects against symptomatic infection and may also protect against asymptomatic infection.

- In the Moderna trial, among people who had received a first dose, the number of asymptomatic people who tested positive for SARS-CoV-2 at their second-dose appointment was approximately 67% lower among vaccinees than among placebo recipients (0.1% and 0.3%, respectively)
- Efficacy of Johnson & Johnson/Janssen COVID-19 vaccine against asymptomatic infection was 74% in a subset of trial participants.

No trials have compared efficacy between any of the authorized vaccines in the same study population at the same time, making comparisons of efficacy difficult.

- All Phase 3 trials differed by calendar time and geography.
- Vaccines were tested in settings with different background COVID-19 incidence and circulating variants.

Real-world vaccine effectiveness

Multiple studies from the United States and other countries have demonstrated that a two-dose COVID-19 mRNA vaccination series is highly effective against SARS-CoV-2 infection (including both symptomatic and asymptomatic infections) caused by ancestral and variant strains and sequelae including severe disease, hospitalization, and death. Early evidence for the Johnson & Johnson/Janssen vaccine also demonstrates effectiveness against COVID-19 in real-world conditions.

Table 1a. Effectiveness of COVID-19 Vaccination Against SARS-CoV-2 Infection and Symptomatic Disease

Country	Population	Vaccine	Outcome	Vaccine Effectiveness*
United States[13]	General adult population	Pfizer-BioNTech or Moderna	SARS-CoV-2 infection	89%*[1]
United States[14]	General adult population	Pfizer-BioNTech or Moderna	SARS-CoV-2 infection	86%*[2]
United States[15]	General adult population	Pfizer-BioNTech or Moderna	Hospitalization	96%*[1]
United States[16]	Healthcare workers	Pfizer-BioNTech	SARS-CoV-2 infection	97%*[2]
		Moderna	SARS-CoV-2 infection	99%*[2]
United States[17]	Healthcare workers, first responders, and other essential and frontline workers	Pfizer-BioNTech or Moderna	SARS-CoV-2 infection	90%*[2]
United States[18]	Healthcare workers	Pfizer-BioNTech	SARS-CoV-2 infection	96%*[1]
United States[19]	Healthcare workers	Pfizer-BioNTech or Moderna	Symptomatic disease	94%*[1]
United States[20]	Healthcare workers and residents in a skilled nursing facility	Pfizer-BioNTech	Residents: symptomatic disease	87%*[2]

			Residents: hospitalization	94%*[2]
			Healthcare workers: symptomatic disease	87%*[2]
United States[21]	Hospitalized adults ≥65 years old	Pfizer-BioNTech or Moderna	Hospitalization	94%*[2]
United States[22]	Health system members ≥18 years old	Johnson & Johnson/Janssen	SARS-CoV-2 infection	77%*[2]
United Kingdom[23]	Healthcare workers	Pfizer-BioNTech or AstraZeneca	SARS-CoV-2 infection	90%*[2]
United Kingdom[24]	Healthcare workers	Pfizer-BioNTech	SARS-CoV-2 infection	86%*[1]
United Kingdom (Scotland)[25]	Healthcare workers	Pfizer-BioNTech or AstraZeneca	SARS-CoV-2 infection	92%*[2]
United Kingdom[26]	Adults aged ≥ 80 years, including those with multiple underlying conditions	Pfizer-BioNTech	Symptomatic disease	85%*[2]
Israel[27]	HMO members >16 years old	Pfizer-BioNTech	SARS-CoV-2 infection	89%*[1]
Israel[28]	Health system members	Pfizer-BioNTech	<60 years old: SARS-CoV-2 infection	93%*[2]
			≥60 years old: SARS-CoV-2 infection	92%*[2]
Israel[29]	General adult	Pfizer-BioNTech	SARS-CoV-2	92%*[1]

	population		infection	
			Symptomatic disease	94%*1
			Hospitalization	87%*1
			Severe disease	92%*1
Israel[30]	General population ≥16 years	Pfizer-BioNTech	SARS-CoV-2 infection	93%*1
			Hospitalization	94%*1
			Severe disease	94%*1
Israel[31]	General population ≥16 years	Pfizer-BioNTech	Symptomatic disease	97%*1
			Severe/critical disease	98%
			Hospitalization	97%
			Death	97%
Israel[32]	Healthcare workers	Pfizer-BioNTech	Symptomatic disease	97%*1
Israel[33]	Healthcare workers	Pfizer-BioNTech	Symptomatic disease	90%*3
Italy[34]	Healthcare workers	Pfizer-BioNTech	Symptomatic disease	95%*1
Denmark[35]	Long term care facility residents	Pfizer-BioNTech	SARS-CoV-2 infection	64%*1
	Long term care facility staff	Pfizer-BioNTech	SARS-CoV-2 infection	90%*1
Sweden[36]	General adult population	Pfizer-BioNTech	SARS-CoV-2 infection	86%*1

*Only studies including estimates of vaccine effectiveness ≥7 days following a completed vaccination series are included here. Studies examining multiple vaccines for which a single estimate of vaccine effectiveness is reported did not assess vaccine effectiveness by product type.

[1]≥7 days after second dose

[2]≥14 days after second dose

[3]≥11 days after second dose

In addition to the studies listed in Table 1a, further evidence of the impact of vaccination with Pfizer-BioNTech and Moderna COVID-19 vaccine has been demonstrated among healthcare workers, with major reductions in SARS-CoV-2 infections among those receiving two doses of COVID-19 vaccine even when community transmission was increasing. (37-39)

Table 1b. Effectiveness of COVID-19 Vaccination Against Asymptomatic SARS-CoV-2 Infection

Country	Population	Vaccine	Outcome	Vaccine effectiveness
United States[40]	General adult population	Pfizer-BioNTech or Moderna	Asymptomatic infection	80%*[1]
United States[18]	Healthcare workers	Pfizer-BioNTech	Asymptomatic infection	90%*[2]
Israel[31]	General adult population	Pfizer-BioNTech	Asymptomatic infection	92%*[2]
Israel[32]	Healthcare workers	Pfizer-BioNTech or AstraZeneca	Asymptomatic infection	86%*[2]
Israel[33]	Healthcare workers	Pfizer-BioNTech	Asymptomatic infection	65%*[3]

[1]≥0 days after second dose
[2]≥7 days after second dose
[3]≥11 days after second dose

Data from multiple studies in different countries suggest that people vaccinated with Pfizer-BioNTech COVID-19 vaccine who develop COVID-19 have a lower viral load than unvaccinated people.[41-44] This observation may indicate reduced transmissibility, as viral load has been identified as a key driver of transmission.[45] Two studies from the United Kingdom found significantly reduced likelihood of transmission to household contacts from people infected with SARS-CoV-2 who were previously vaccinated for COVID-19.[25, 46]

Vaccine effectiveness in immunosuppressed people

Evidence of reduced antibody response to or reduced immunogenicity of COVID-19 mRNA vaccination has been observed in the following groups: people taking certain immunosuppressive medications like rituximab [47-50] or mycophenolate [50-53], people with hematologic cancers [54, 55], and hemodialysis patients [56]. At this time, data on vaccine protection in people who are immunocompromised are limited; in addition, the impact of immune suppression on COVID-19 vaccine effectiveness may vary by condition.[55, 57] Complete data on which immunocompromising conditions might affect response to COVID-19 vaccination are not available; in addition, there is no established immune correlate of protection against SARS-CoV-2 so the risk of infection in people who respond incompletely to COVID-19 vaccination cannot be quantified using immunogenicity data. People with immunocompromising conditions, including those taking immunosuppressive medications, should discuss the need for personal protective measures after vaccination with their healthcare provider.

Emerging SARS-CoV-2 viral variants and vaccine performance

SARS-CoV-2 variants of concern (VOCs: Alpha (B.1.1.7), first detected in the United Kingdom; Beta (B.1.351), first detected in South Africa; Gamma (P.1), first detected in Japan/Brazil; and Delta (B.1.617.2), first detected in India) have emerged with mutations that alter the receptor binding domain of the spike protein and have a negative impact on vaccine effectiveness (notably the N501Y mutation occurring in Alpha, Beta and Gamma variants, the E484K and E417T/N mutations in Beta and Gamma, and the L452R mutation in Delta).[58]

Similar mutations also occur in SARS-CoV-2 variants of interest (VOIs: Epsilon (B.1.427/B.1.429), first detected in the United States-California; Iota (B.1.526), first detected in the United States-New York; Eta (B.1.525), first detected in the United Kingdom/Nigeria; and Kappa (B.1.617.1) and B.1.617.3, first detected in India)[58], but these variants currently have limited prevalence or expansion in the United States or other countries and still lack clear evidence of increased transmission, disease severity, or impact on available vaccines, therapeutics, or diagnostic tests.[58] Vaccine performance against emerging SARS-CoV-2 variants is an important consideration when evaluating the need for prevention measures in vaccinated people and will require continued monitoring. When evaluating risk, considering regional and local circulation of SARS-CoV-2 variants is also relevant; current data can be found on CDC's website.

Vaccine-induced neutralizing antibody activity

Sera from mRNA COVID-19 vaccine (both Pfizer-BioNTech and Moderna) recipients have demonstrated minimal to large reductions in antibody neutralization activity against a variety of mutations [59-126]; one related meta-analysis has been published [69]. Across studies of VOCs, the greatest reductions were observed for Beta, followed by Gamma and Delta; reductions for Alpha were minimal. A limited number of studies were available for some VOI that demonstrated greater reductions for Eta and Kappa, and minimal reductions for Epsilon and Iota. The E484K/Q and L452R mutations alone or in combination with other mutations in the receptor binding domain have been shown to account for the majority of reduction in vaccine-induced neutralizing antibody activity for the Beta, Gamma, and Delta variants.[71, 77, 91, 109, 112, 127, 128] Alpha and Iota variants with E484K mutations, which have been detected in the United Kingdom, United States, and other countries, have shown further reductions in neutralization above Alpha and Iota alone, respectively.[62, 68, 70, 71, 90, 114, 115, 118] For two-dose COVID-19 vaccines, multiple studies have shown greater neutralization against variants after the second dose (i.e. among fully vaccinated people) compared with the first dose (partially vaccinated).[59, 71, 72, 77, 78, 86, 99, 103, 105-107, 119, 129]

Two studies have shown that six months after receiving the Moderna vaccine, higher proportions of people had undetectable neutralization activity against Beta and Gamma compared with the ancestral strain.[130, 131] However, a recent study showed that people who received the Johnson & Johnson/Janssen vaccine had minimal decline in neutralizing titers against Beta, Gamma, and Delta at 8 months post-vaccination and that there was evidence of expanded breadth of neutralizing antibody response against variants over this time period, likely through B cell maturation.[64] Another study comparing antibody responses to different vaccines at 2.5–3 months post-vaccination showed comparatively lower neutralizing titers against Beta and Delta for Johnson & Johnson/Janssen (an adenovirus vector vaccine) compared with the mRNA vaccines.[132] More evidence is still needed in this area, including understanding potential differences in the kinetics of immune response related to different vaccine platforms.

Robust correlation has been demonstrated between vaccine efficacy and neutralizing antibody levels induced by different vaccines.[133, 134] Based on evidence from clinical trials, the correlate of protection, or antibody threshold providing protection against severe disease, has been estimated to be much lower and less likely to be affected by differences in initial vaccine efficacy than that required for protection against confirmed infection.[134] However, in the absence of an accepted biological correlate of protection, it is difficult to fully predict how reduced neutralizing activity may affect COVID-19 vaccine effectiveness. Across studies, antibody neutralizing activity of sera from vaccinated people was generally higher than that observed for convalescent sera from people who have recovered from COVID-19.[71, 75, 80, 83, 101-103, 105, 107, 112, 118, 127, 128] However, some variants may reduce neutralizing antibody titers to near or below the protective threshold, resulting in lowered vaccine efficacy, increased breakthrough infections (i.e., infections in vaccinated persons), and shortened duration of immunity. For example, a modeling study estimated that a 5-fold lower neutralizing titer against a particular variant was predicted to reduce efficacy from 95% to 77% in a high efficacy vaccine, or from 70% to 32% for a lower efficacy

vaccine [134]; however, this assumes that antibody neutralization is the only major mechanism of protection, and this reduction may be mitigated where neutralization and cellular immunity both play a role in protection.

Vaccine-induced cellular immunity

Several studies have assessed CD4+ and CD8+ T cell responses from Moderna or Pfizer vaccine recipients to the ancestral SARS-CoV-2 strain compared with the Alpha, Beta, Gamma, and Epsilon variants; these studies observed modest or no defects in cellular immune recognition of the variants.[78, 85, 105, 135-139] Thus, cellular immunity may help limit disease severity in infections caused by variants that partially escape neutralizing antibodies. Polymorphisms in human leukocyte antigen alleles have been observed to result in variation of the T cell response to specific variants, which may impact different subpopulations differently based on higher genetic prevalence.[140-145]

Efficacy and effectiveness

A growing number of studies in Israel, Europe, and the United Kingdom have demonstrated high real-world effectiveness (>85%) of two doses of Pfizer-BioNTech COVID-19 vaccine while Alpha was prevalent.[24, 29-31, 33, 36, 146-148] Studies from Qatar have demonstrated high effectiveness against documented infection with Alpha and Beta ≥14 days after receiving the Pfizer-BioNTech vaccine (90% and 75%, respectively) and the Moderna vaccine (100% and 96%, respectively); importantly, both vaccines were 96%–100% effective against severe, critical, or fatal disease, regardless of strain.[149, 150] Clinical trial data suggest that the Johnson & Johnson/Janssen COVID-19 vaccine may have reduced overall efficacy against the Beta variant. Although sero-response rates were similar between U.S. clinical trial participants and those from Brazil and South Africa, vaccine efficacy after ≥14 days was 74% in the United States, 66% in Brazil (where ~69% of infections were due to Zeta [P.2]), and 52% in South Africa (~where 95% of infections were due to Beta). [151] Notably, Johnson & Johnson/Janssen vaccine showed good efficacy against severe or critical disease (73%–82%) across all sites. In three studies from Canada, one demonstrated 79% effectiveness for mRNA vaccines against confirmed infection during a time when Alpha and Gamma represented most infections, while another two demonstrated 84% and 88% effectiveness, respectively, against symptomatic infection caused by Gamma/Beta.[152-154]

For the Delta variant, recent studies from England and Scotland have noted reduced effectiveness of the Pfizer-BioNTech vaccine against confirmed infection (79%) and symptomatic infection (88%), compared with Alpha (92% and 93%, respectively).[146, 147] During two recent rounds of a national population survey in England when Delta was the dominant stain, 2-dose vaccine effectiveness against PCR-confirmed infection was 72% and 73%, respectively.[155] A study from Canada demonstrated 87% effectiveness against symptomatic illness ≥7 days after receipt of the Pfizer-BioNTech vaccine. [153] Press releases from Israel have noted further decreased effectiveness of vaccines against infection and illness caused by Delta; these differences may in part reflect differences in study methodology, but more technical information is needed to allow full interpretation. Notably, in the United Kingdom, Canada, and Israel, vaccine effectiveness against

hospitalization related to Delta was 93%–100% and comparable to that observed with Alpha.[148, 153] Data from the United Kingdom observed that the recent resurgence in COVID-19 cases is being driven by replacement of Alpha with the Delta variant and infections occurring in unvaccinated children and young adults.[155]

Breakthrough infections

Despite high efficacy, vaccine breakthrough cases are rare but inevitable, including infections caused by circulating variants. From January through May 2021, COVID-NET data from laboratory-confirmed COVID-19-associated hospitalizations in adults ≥18 years of age, for whom vaccination status is known, showed <3% of hospitalizations occurred in fully vaccinated persons. CDC conducts nationwide monitoring of vaccine breakthrough cases resulting in hospitalization or death. In general, symptoms and duration of illness in vaccine breakthrough infections have been attenuated compared with cases among unvaccinated people.[156] Among hospitalized or fatal breakthrough cases reported to CDC as of July 19, 2021, 74% were aged 65 years or older. One U.S. study observed that 44% of breakthrough infections were among people who were immunocompromised, similar to results reported from Israel.[157, 158] Breakthrough infections may boost immunity; four weeks after an outbreak in a long-term care facility, fully vaccinated residents who experienced breakthrough infections were found to have significantly higher antibody levels than vaccinated individuals who did not experience breakthrough infections.[159]

The proportions of VOCs observed among breakthrough cases has been similar to that observed in CDC's national genomic surveillance,[160] but interpretation of these data is challenging because of local variation and changes in variant proportions over time. An Israeli study of VOC infections in adults fully vaccinated with Pfizer-BioNTech compared with unvaccinated matched controls, during a time when Alpha was the dominant strain and Beta was detected in <1% of all specimens, found a higher proportion of Beta in fully vaccinated cases (matched odds ratio = 8.0) and a higher proportion of Alpha in partially vaccinated cases (matched odds ratio = 2.6), though small sample sizes, especially for Beta, were noted as a limitation.[161] A study from Houston, Texas observed that Delta caused a significantly higher rate of breakthrough infections in fully vaccinated people compared with infections from other variants, but noted that only 6.5% of all COVID-19 cases occurred in fully vaccinated individuals.[162] Studies from India with vaccines not authorized for use in the United States have noted relatively high viral loads and larger cluster sizes associated with infections with Delta, regardless of vaccination status.[96] These early data suggest that breakthrough Delta infections are transmissible. Unpublished data are consistent with this, and additional data collection and studies are underway to understand the level and duration of transmissibility from Delta vaccine breakthrough infections in the United States and other settings.

Impact of prevention measures in the context of vaccination

Individual and community-level prevention measures in addition to vaccination have been shown to help reduce the spread of SARS-CoV-2.[163-167] However, there can be individual and societal costs related to physical distancing, quarantine, school and business closures, and other prevention measures.[168-175]

Modeling studies suggest that adherence to other prevention measures, such as wearing masks and physical distancing, continues to be important in the context of vaccine implementation.[176-184] In one study, complete relaxation of prevention measures for the entire population prior to adequate vaccination coverage (60-80% depending on the population considered) resulted in essentially no reductions in SARS-CoV-2 infections.[178] However, in the context of rapid vaccine implementation, the benefit of non-pharmaceutical interventions decreases: preliminary data from one study found prevention measures in the United States could begin to be relaxed 2-3 months after vaccination began if a rate of 3 million doses administered daily were attained[185]. Correspondingly, preliminary data suggest that increasing vaccination rates may allow for the phasing out of some prevention measures as coverage increases.[184] With high vaccine effectiveness and increasing vaccination coverage, preliminary modeling studies conducted prior to emergence of the Delta variant predicted that vaccinated people returning to normal activities will have minimal impact on the course of the pandemic.[185, 186]

Conclusions

COVID-19 vaccines currently authorized in the United States have been shown to be effective against SARS-CoV-2 infections, including asymptomatic and symptomatic infection, severe disease, and death. These findings, along with the early evidence for reduced viral load in vaccinated people who develop COVID-19, suggest that any associated transmission risk is likely to be substantially reduced in vaccinated people. While vaccine effectiveness against emerging SARS-CoV-2 variants remains under investigation, available evidence suggests that the COVID-19 vaccines presently authorized in the United States offer protection against known emerging variants, including the Delta variant, particularly against hospitalization and death. Data suggest lower vaccine effectiveness against confirmed illness and symptomatic disease caused by the Beta, Gamma, and Delta variants compared with the ancestral strain and Alpha variant.

Evidence suggests the U.S. COVID-19 vaccination program has the potential to substantially reduce the burden of disease in the United States by preventing serious illness in fully vaccinated people and interrupting chains of transmission. The risks of SARS-CoV-2 infection in fully vaccinated people cannot be completely eliminated where community transmission of the virus is widespread. Vaccinated people can still become infected and spread the virus to others. Current efforts to maximize the proportion of the U.S. population that is fully vaccinated against COVID-19 remain critical to ending the COVID-19 pandemic.

*Note: CDC guidance for fully vaccinated people can also be applied to COVID-19 vaccines that have been listed for emergency use by the World Health Organization (e.g. AstraZeneca/Oxford). This brief summarizes evidence related to vaccines authorized for emergency use in the United States.

References

Note: Preprints have not been peer-reviewed. They should not be regarded as conclusive, guide clinical practice/health-related behavior, or be reported in news media as established information.

1. Lee G, Carr W, Group AE-BRW, Group AEBRW. Updated Framework for Development of Evidence-Based Recommendations by the Advisory Committee on Immunization Practices. MMWR Morb Mortal Wkly Rep. 2018;67(45):1271-2.
2. Corbett KS, Flynn B, Foulds KE, Francica JR, Boyoglu-Barnum S, Werner AP, et al. Evaluation of the mRNA-1273 Vaccine against SARS-CoV-2 in Nonhuman Primates. N Engl J Med. 2020;383(16):1544-55.
3. Mercado NB, Zahn R, Wegmann F, Loos C, Chandrashekar A, Yu J, et al. Single-shot Ad26 vaccine protects against SARS-CoV-2 in rhesus macaques. Nature. 2020;586(7830):583-8.
4. Vogel AB, Kanevsky I, Che Y, Swanson KA, Muik A, Vormehr M, et al. BNT162b vaccines protect rhesus macaques from SARS-CoV-2. Nature. 2021.
5. Baden LR, El Sahly HM, Essink B, Kotloff K, Frey S, Novak R, et al. Efficacy and Safety of the mRNA-1273 SARS-CoV-2 Vaccine. N Engl J Med. 2021;384(5):403-16.
6. Food and Drug Administration. Pfizer-BioNTech COVID-19 Vaccine. Vaccines and Related Biological Products Advisory Committee Briefing Document – Sponsor. https://www.fda.gov/media/144246/download .
7. Food and Drug Administration. Moderna COVID-19 Vaccine. Vaccines and Related Biological Products Advisory Committee December 17, 2020 Meeting Briefing Document- Sponsor. https://www.fda.gov/media/144452/download .
8. Food and Drug Administration. Moderna COVID-19 Vaccine. Vaccines and Related Biological Products Advisory Committee December 17, 2020 Meeting Briefing Document Addendum- Sponsor. https://www.fda.gov/media/144453/download .
9. Food and Drug Administration. Janssen COVID-19 Vaccine. Vaccines and Related Biological Products Advisory Committee February 26, 2021 Meeting Briefing Document – Sponsor. https://www.fda.gov/media/146219/download .
10. Food and Drug Administration. Janssen COVID-19 Vaccine. Vaccines and Related Biological Products Advisory Committee February 26, 2021 Meeting Briefing Document Addendum – Sponsor.

https://www.fda.gov/media/146218/download .

11. Polack FP, Thomas SJ, Kitchin N, Absalon J, Gurtman A, Lockhart S, et al. Safety and Efficacy of the BNT162b2 mRNA Covid-19 Vaccine. N Engl J Med. 2020;383(27):2603-15.
12. Food and Drug Administration. Emergency Use Authorization (EUA) Amendment for an Unapproved Product Review Memorandum. https://www.fda.gov/media/148542/download .
13. Pawlowski C LP, Puranik A, et. al. FDA-authorized COVID-19 vaccines are effective per real-world evidence synthesized across a multi-state health system. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.02.15.21251623v1.full.pdf .
14. Andrejko K. PJ, Myers JF., et al. Early evidence of COVID-19 vaccine effectiveness within the general population of California. MedRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.04.08.21255135v1 .
15. Vahidy FS. PL, Tano ME., et al. Real World Effectiveness of COVID-19 mRNA Vaccines against Hospitalizations and Deaths in the United States. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.04.21.21255873v1 .
16. Swift MD, Breeher LE, Tande AJ, Tommaso CP, Hainy CM, Chu H, et al. Effectiveness of mRNA COVID-19 vaccines against SARS-CoV-2 infection in a cohort of healthcare personnel. Clin Infect Dis. 2021.
17. Thompson MG BJ, Naleway AL, et al. Interim Estimates of Vaccine Effectiveness of BNT162b2 and mRNA-1273 COVID-19 Vaccines in Preventing SARS-CoV-2 Infection Among Health Care Personnel, First Responders, and Other Essential and Frontline Workers — Eight U.S. Locations, December 2020–March 2021. MMWR Morb Mortal Wkly Rep. 2021;ePub: 29 March 2021. DOI: http://dx.doi.org/10.15585/mmwr.mm7013e3 .
18. Tang L, Hijano DR, Gaur AH, Geiger TL, Neufeld EJ, Hoffman JM, et al. Asymptomatic and Symptomatic SARS-CoV-2 Infections After BNT162b2 Vaccination in a Routinely Screened Workforce. JAMA. 2021.
19. Pilishvili T. F-DK, Farrar JL., et al. Interim Estimates of Vaccine Effectiveness of Pfizer-BioNTech and Moderna COVID-19 Vaccines Among Health Care Personnel — 33 U.S. Sites, January–March 2021. MMWR Morb Mortal Wkly Rep. 2021;https://www.cdc.gov/mmwr/volumes/70/wr/mm7020e2.htm.
20. Cavanaugh AM, Fortier S, Lewis P, Arora V, Johnson M, George K, et al. COVID-19 Outbreak Associated with a SARS-CoV-2 R.1 Lineage Variant in a Skilled Nursing Facility After Vaccination Program – Kentucky, March 2021. MMWR Morb Mortal Wkly Rep. 2021;70(17):639-43.
21. Tenforde MW, Olson SM, Self WH, Talbot HK, Lindsell CJ, Steingrub JS, et al. Effectiveness of Pfizer-BioNTech and Moderna Vaccines Against COVID-19 Among Hospitalized Adults Aged >/=65 Years – United States, January-March 2021. MMWR Morb Mortal Wkly Rep. 2021;70(18):674-9.
22. Corchado-Garcia J. P-ZD, Hughes T., et al. Real-world effectiveness of

Ad26.COV2.S adenoviral vector vaccine for COVID-19. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.04.27.21256193v1 .

23. Lumley SF RG, Costantindes B., et al. An observational cohort study on the incidence of SARS-CoV-2 infection and B.1.1.7 variant infection in healthcare workers by antibody and vaccination status medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.03.09.21253218v1.full.pdf .
24. Hall VJ, Foulkes S, Saei A, Andrews N, Oguti B, Charlett A, et al. COVID-19 vaccine coverage in health-care workers in England and effectiveness of BNT162b2 mRNA vaccine against infection (SIREN): a prospective, multicentre, cohort study. Lancet. 2021;397(10286):1725-35.
25. Shah A GC, Bishop J, et al. Effect of vaccination on transmission of COVID-19: an observational study in healthcare workers and their households. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.03.11.21253275v1 .
26. Lopez Bernal J, Andrews N, Gower C, Robertson C, Stowe J, Tessier E, et al. Effectiveness of the Pfizer-BioNTech and Oxford-AstraZeneca vaccines on covid-19 related symptoms, hospital admissions, and mortality in older adults in England: test negative case-control study. BMJ. 2021;373:n1088.
27. Heymann AD. ZG, Shasha D., et. al. BNT162b2 Vaccine Effectiveness in Preventing Asymptomatic Infection with SARS-CoV-2 Virus: A Nationwide Historical Cohort Study. Lancet (preprint). 2021;https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3796868 .
28. Aran D. Estimating real-world COVID-19 vaccine effectiveness in Israel using aggregated counts. Github. 2021;https://github.com/dviraran/covid_analyses/blob/master/Aran_letter.pdf .
29. Dagan N, Barda N, Kepten E, Miron O, Perchik S, Katz MA, et al. BNT162b2 mRNA Covid-19 Vaccine in a Nationwide Mass Vaccination Setting. N Engl J Med. 2021.
30. Goldberg Y MM, Woodbridge Y, et al. Protection of previous SARS-CoV-2 infection is similar to that of BNT162b2 vaccine protection: A three-month nationwide experience from Israel. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.04.20.21255670v1 .
31. Haas EJ, Angulo FJ, McLaughlin JM, Anis E, Singer SR, Khan F, et al. Impact and effectiveness of mRNA BNT162b2 vaccine against SARS-CoV-2 infections and COVID-19 cases, hospitalisations, and deaths following a nationwide vaccination campaign in Israel: an observational study using national surveillance data. Lancet. 2021.
32. Angel Y. SA, Henig O., et al. Association Between Vaccination With BNT162b2 and Incidence of Symptomatic and Asymptomatic SARS-CoV-2 Infections Among Health Care Workers. JAMA (preprint). 2021;https://pubmed.ncbi.nlm.nih.gov/33956048/ .
33. Regev-Yochay G AS, Bergwerk M, et al. Decreased Infectivity Following BNT162b2 Vaccination. Lancet (preprint).

2021;https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3815668 .

34. Fabiani M, Ramigni M, Gobbetto V, Mateo-Urdiales A, Pezzotti P, Piovesan C. Effectiveness of the Comirnaty (BNT162b2, BioNTech/Pfizer) vaccine in preventing SARS-CoV-2 infection among healthcare workers, Treviso province, Veneto region, Italy, 27 December 2020 to 24 March 2021. Euro Surveill. 2021;26(17).
35. Moustsen-Helms I EH, Nielsen J, et. al. Vaccine effectiveness after 1st and 2nd dose of the BNT162b2 mRNA Covid-19 Vaccine in long-term care facility residents and healthcare workers – a Danish cohort study medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.03.08.21252200v1.full.pdf(March 24, 2021).
36. Björk J. IM, Moghaddassi M., et al. Effectiveness of the BNT162b2 vaccine in preventing COVID-19 in the working age population – first results from a cohort study in Southern Sweden. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.04.20.21254636v1 .
37. Benenson S, Oster Y, Cohen MJ, Nir-Paz R. BNT162b2 mRNA Covid-19 Vaccine Effectiveness among Health Care Workers. N Engl J Med. 2021.
38. Daniel W, Nivet M, Warner J, Podolsky DK. Early Evidence of the Effect of SARS-CoV-2 Vaccine at One Medical Center. N Engl J Med. 2021.
39. Keehner J, Horton LE, Pfeffer MA, Longhurst CA, Schooley RT, Currier JS, et al. SARS-CoV-2 Infection after Vaccination in Health Care Workers in California. N Engl J Med. 2021.
40. Tande AJ, Pollock BD, Shah ND, Farrugia G, Virk A, Swift M, et al. Impact of the COVID-19 Vaccine on Asymptomatic Infection Among Patients Undergoing Pre-Procedural COVID-19 Molecular Screening. Clin Infect Dis. 2021.
41. Jones NK, Rivett L, Seaman S, Samworth RJ, Warne B, Workman C, et al. Single-dose BNT162b2 vaccine protects against asymptomatic SARS-CoV-2 infection. Elife. 2021;10.
42. Levine-Tiefenbrun M, Yelin I, Katz R, Herzel E, Golan Z, Schreiber L, et al. Initial report of decreased SARS-CoV-2 viral load after inoculation with the BNT162b2 vaccine. Nat Med. 2021;27(5):790-2.
43. McEllistrem MC, Clancy CJ, Buehrle DJ, Lucas A, Decker BK. Single dose of a mRNA SARS-CoV-2 vaccine is associated with lower nasopharyngeal viral load among nursing home residents with asymptomatic COVID-19. Clin Infect Dis. 2021.
44. Petter E MO, Zuckerman N, et al. Initial real world evidence for lower viral load of individuals who have been vaccinated by BNT162b2. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.02.08.21251329v1 .
45. Marks M, Millat-Martinez P, Ouchi D, Roberts CH, Alemany A, Corbacho-Monne M, et al. Transmission of COVID-19 in 282 clusters in Catalonia, Spain: a cohort study. Lancet Infect Dis. 2021.
46. Harris RJ HJ, Zaidi A, et al. Impact of vaccination on household transmission of SARS-COV-2 in England. khubnet.

2021;https://khub.net/documents/135939561/390853656/Impact+of+vaccination+on+household+transmission+of+SARS-COV-2+in+England.pdf/35bf4bb1-6ade-d3eb-a39e-9c9b25a8122a .

47. Boyarsky BJ, Ruddy JA, Connolly CM, Ou MT, Werbel WA, Garonzik-Wang JM, et al. Antibody response to a single dose of SARS-CoV-2 mRNA vaccine in patients with rheumatic and musculoskeletal diseases. Ann Rheum Dis. 2021.
48. Boyarsky BJ, Werbel WA, Avery RK, Tobian AAR, Massie AB, Segev DL, et al. Antibody Response to 2-Dose SARS-CoV-2 mRNA Vaccine Series in Solid Organ Transplant Recipients. JAMA. 2021.
49. Chavarot N. OA, Olivier M, et.al. Poor Anti-SARS-CoV-2 Humoral and T-cell Responses After 2 Injections of mRNA Vaccine in Kidney Transplant Recipients Treated with Belatacept. Transplantation. 2021;https://journals.lww.com/transplantjournal/Citation/9000/Poor_Anti_SARS_CoV_2_Humoral_and_T_cell_Responses.95281.aspx .
50. Rozen-Zvi B, Yahav D, Agur T, Zingerman B, Ben-Zvi H, Atamna A, et al. Antibody response to mRNA SARS-CoV-2 vaccine among kidney transplant recipients – Prospective cohort study. Clin Microbiol Infect. 2021.
51. Grupper A, Rabinowich L, Schwartz D, Schwartz IF, Ben-Yehoyada M, Shashar M, et al. Reduced humoral response to mRNA SARS-CoV-2 BNT162b2 vaccine in kidney transplant recipients without prior exposure to the virus. Am J Transplant. 2021.
52. Itzhaki Ben Zadok O, Shaul AA, Ben-Avraham B, Yaari V, Ben Zvi H, Shostak Y, et al. Immunogenicity of the BNT162b2 mRNA vaccine in heart transplant recipients – a prospective cohort study. Eur J Heart Fail. 2021.
53. Rabinowich L GA, Baruch R, et al. Low immunogenicity to SARS-CoV-2 vaccination among liver transplant recipients. J Hepatol (online ahead of print). 2021;https://pubmed.ncbi.nlm.nih.gov/33892006/ .
54. Herishanu Y, Avivi I, Aharon A, Shefer G, Levi S, Bronstein Y, et al. Efficacy of the BNT162b2 mRNA COVID-19 Vaccine in Patients with Chronic Lymphocytic Leukemia. Blood. 2021.
55. Monin L, Laing AG, Munoz-Ruiz M, McKenzie DR, Del Molino Del Barrio I, Alaguthurai T, et al. Safety and immunogenicity of one versus two doses of the COVID-19 vaccine BNT162b2 for patients with cancer: interim analysis of a prospective observational study. Lancet Oncol. 2021.
56. Simon B RH, Treipl A, et al. Hemodialysis Patients Show a Highly Diminished Antibody Response after COVID-19 mRNA Vaccination Compared to Healthy Controls. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.03.26.21254259v1 .
57. Yelin I KR, Herzel E, et al. Associations of the BNT162b2 COVID-19 vaccine effectiveness with patient age and comorbidities. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.03.16.21253686v1 .
58. Centers for Disease Control and Prevention. SARS-CoV-2 Variant Classifications and Definitions [Available from: https://www.cdc.gov/coronavirus/2019-

ncov/cases-updates/variant-surveillance/variant-info.html

59. Alenquer M FF, Lousa D, et al. Amino acids 484 and 494 of SARS-CoV-2 spike are hotspots of immune evasion affecting antibody but not ACE2 binding. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.04.22.441007v2 .
60. Alter G, Yu J, Liu J, Chandrashekar A, Borducchi EN, Tostanoski LH, et al. Immunogenicity of Ad26.COV2.S vaccine against SARS-CoV-2 variants in humans. Nature. 2021.
61. Anichini G, Terrosi C, Gori Savellini G, Gandolfo C, Franchi F, Cusi MG. Neutralizing Antibody Response of Vaccinees to SARS-CoV-2 Variants. Vaccines (Basel). 2021;9(5).
62. Annavajhala MK, Mohri H, Zucker JE, Sheng Z, Wang P, Gomez-Simmonds A, et al. A Novel SARS-CoV-2 Variant of Concern, B.1.526, Identified in New York. medRxiv. 2021;https://www.ncbi.nlm.nih.gov/pubmed/33655278 .
63. Arora P KA, Nehlmier I, et. al. Increased lung cell entry of B.1.617.2 and evasion of antibodies induced by infection and BNT162b2 vaccination. BioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.06.23.449568v1 .
64. Barouch DH SK, Sadoff J, et al. Durable Humoral and Cellular Immune Responses Following Ad26.COV2.S Vaccination for COVID-19. MedRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.07.05.21259918v1 .
65. Bates T LH, Lyski ZL, et al. Neutralization of SARS-CoV-2 variants by convalescent and vaccinated serum. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.04.04.21254881v1 .
66. Becker M DA, Junker D, et al. Immune response to SARS-CoV-2 variants of concern in vaccinated individuals. medRxiv. 2021;https://doi.org/10.1101/2021.03.08.21252958 .
67. Caniels TG BI, van der Straten K, et al. Emerging SARS-CoV-2 variants of concern evade humoral immune responses from infection and vaccination. MedRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.05.26.21257441v1 .
68. Carreno JM AH, Singh G, et al. Reduced neutralizing activity of post-SARS-CoV-2 vaccination serum against variants B.1.617.2, B.1.351, B.1.1.7+E484K and a sub-variant of C.37. medRxiv. 2021;https://doi.org/10.1101/2021.07.21.21260961
69. Chen X CZ, Azman AS, et al. Comprehensive mapping of neutralizing antibodies against SARS-CoV-2 variants induced by natural infection or vaccination. medRxiv. 2021;https://doi.org/10.1101/2021.05.03.21256506 .
70. Choi A KM, Wu K, et al. Serum Neutralizing Activity of mRNA-1273 against SARS-CoV-2 Variants. MedRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.06.28.449914v1 .
71. Collier DA, De Marco A, Ferreira I, Meng B, Datir R, Walls AC, et al. Sensitivity of SARS-CoV-2 B.1.1.7 to mRNA vaccine-elicited antibodies. Nature. 2021.
72. Davis C LN, Tyson G, et al. Reduced neutralisation of the Delta (B.1.617.2)

SARS-CoV-2 variant of concern following vaccination. MedRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.06.23.21259327v1 .

73. Dejnirattisai W, Zhou D, Supasa P, Liu C, Mentzer AJ, Ginn HM, et al. Antibody evasion by the P.1 strain of SARS-CoV-2. Cell. 2021.
74. Deng X, Garcia-Knight MA, Khalid MM, Servellita V, Wang C, Morris MK, et al. Transmission, infectivity, and neutralization of a spike L452R SARS-CoV-2 variant. Cell. 2021.
75. Edara VV, Hudson WH, Xie X, Ahmed R, Suthar MS. Neutralizing Antibodies Against SARS-CoV-2 Variants After Infection and Vaccination. JAMA. 2021.
76. Emary KRW, Golubchik T, Aley PK, Ariani CV, Angus B, Bibi S, et al. Efficacy of ChAdOx1 nCoV-19 (AZD1222) vaccine against SARS-CoV-2 variant of concern 202012/01 (B.1.1.7): an exploratory analysis of a randomised controlled trial. Lancet. 2021;397(10282):1351-62.
77. Garcia-Beltran WF, Lam EC, St Denis K, Nitido AD, Garcia ZH, Hauser BM, et al. Multiple SARS-CoV-2 variants escape neutralization by vaccine-induced humoral immunity. Cell. 2021.
78. Geers D, Shamier MC, Bogers S, den Hartog G, Gommers L, Nieuwkoop NN, et al. SARS-CoV-2 variants of concern partially escape humoral but not T-cell responses in COVID-19 convalescent donors and vaccinees. Sci Immunol. 2021;6(59).
79. Gonzalez C. Saade C BA, et al. Live virus neutralisation testing in convalescent patients and subjects vaccinated against 19A, 20B, 20I/501Y.V1 and 20H/501Y.V2 isolates of SARS-CoV-2. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.05.11.21256578v1.full.pdf .
80. Hoffmann M, Arora P, Gross R, Seidel A, Hornich BF, Hahn AS, et al. SARS-CoV-2 variants B.1.351 and P.1 escape from neutralizing antibodies. Cell. 2021;184(9):2384-93 e12.
81. Hoffmann M H-WH, Kruger N, et al. SARS-CoV-2 variant B.1.617 is resistant to Bamlanivimab and evades antibodies induced by infection and vaccination. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.05.04.442663v1 .
82. Jongeneelen M KK, Veldman D, et al. Ad26.COV2.S elicited neutralizing activity against Delta and other SARS-CoV-2 variants of concern. BioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.07.01.450707v1 .
83. Kuzmina A KY, Voloshin O, et al. SARS CoV-2 Escape Variants Exhibit Differential Infectivity and Neutralization Sensitivity to Convalescent or Post-Vaccination Sera. Cell Host & Microbe. 2021.
84. Leier HC BT, Lyski ZL, et al. Previously infected vaccinees broadly neutralize SARS-CoV-2 variants. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.04.25.21256049v1 .
85. Lilleri D VI, Bergami F, et al. SARS-CoV-2 mRNA vaccine BNT162b2 elicited a robust humoral and cellular response against SARS-CoV-2 variants. Research

Square. 2021;https://www.researchsquare.com/article/rs-396284/v1 .

86. Liu C, Ginn HM, Dejnirattisai W, Supasa P, Wang B, Tuekprakhon A, et al. Reduced neutralization of SARS-CoV-2 B.1.617 by vaccine and convalescent serum. Cell. 2021.
87. Liu J, Liu Y, Xia H, Zou J, Weaver SC, Swanson KA, et al. BNT162b2-elicited neutralization of B.1.617 and other SARS-CoV-2 variants. Nature. 2021.
88. Liu J BB, Wang X, et al. Correlation of vaccine-elicited antibody levels and neutralizing activities against SARS-CoV-2 and its variants. BioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.05.31.445871v1 .
89. Liu Y, Liu J, Xia H, Zhang X, Fontes-Garfias CR, Swanson KA, et al. Neutralizing Activity of BNT162b2-Elicited Serum. N Engl J Med. 2021.
90. Liu Y, Liu J, Xia H, Zhang X, Zou J, Fontes-Garfias CR, et al. BNT162b2-Elicited Neutralization against New SARS-CoV-2 Spike Variants. N Engl J Med. 2021.
91. Lucas C VC, Yildirim I, et al. Impact of circulating SARS-CoV-2 variants on mRNA vaccine-induced immunity in uninfected and previously infected individuals. medRxiv. 2021;https://doi.org/10.1101/2021.07.14.21260307
92. Lustig Y, Zuckerman N, Nemet I, Atari N, Kliker L, Regev-Yochay G, et al. Neutralising capacity against Delta (B.1.617.2) and other variants of concern following Comirnaty (BNT162b2, BioNTech/Pfizer) vaccination in health care workers, Israel. Euro Surveill. 2021;26(26).
93. Madhi SA, Baillie V, Cutland CL, Voysey M, Koen AL, Fairlie L, et al. Efficacy of the ChAdOx1 nCoV-19 Covid-19 Vaccine against the B.1.351 Variant. N Engl J Med. 2021.
94. McCallum M BJ, De Marco A, et al. SARS-CoV-2 immune evasion by variant B.1.427/B.1.429. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.03.31.437925v1 .
95. Miyakawa K JS, Kato H, et al. Rapid detection of neutralizing antibodies to SARS-CoV-2 variants in post-vaccination sera. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.05.06.21256788v1 .
96. Mlcochova P KS, Dhar MS, et al. . SARS-CoV-2 B.1.617.2 Delta variant emergence and vaccine breakthrough. Research Square. 2021 https://www.researchsquare.com/article/rs-637724/v1 .
97. Moore PL M-GT, Hermanus T, et al. Neutralizing antibodies elicited by the Ad26.COV2.S COVID-19 vaccine show reduced activity against 501Y.V2 (B.1.351), despite protection against severe disease by this variant. BioRxiv. 2021 https://www.biorxiv.org/content/10.1101/2021.06.09.447722v2 .
98. Muik A, Wallisch AK, Sanger B, Swanson KA, Muhl J, Chen W, et al. Neutralization of SARS-CoV-2 lineage B.1.1.7 pseudovirus by BNT162b2 vaccine-elicited human sera. Science. 2021;371(6534):1152-3.
99. Planas D, Bruel T, Grzelak L, Guivel-Benhassine F, Staropoli I, Porrot F, et al. Sensitivity of infectious SARS-CoV-2 B.1.1.7 and B.1.351 variants to neutralizing antibodies. Nat Med. 2021;27(5):917-24.
100. Planas D VD, Baidaliuk A, et al. Reduced sensitivity of infectious SARS-CoV-2

variant B.1.617.2 to monoclonal antibodies and sera from convalescent and vaccinated individuals. BioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.05.26.445838v1 .

101. Rathnasinghe R, Jangra S, Cupic A, Martinez-Romero C, Mulder LCF, Kehrer T, et al. The N501Y mutation in SARS-CoV-2 spike leads to morbidity in obese and aged mice and is neutralized by convalescent and post-vaccination human sera. medRxiv. 2021;https://www.ncbi.nlm.nih.gov/pubmed/33501468 .
102. Sahin U MA, Vogler I, et al. BNT162b2 induces SARS-CoV-2-neutralising antibodies and T cells in humans. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2020.12.09.20245175v1 .
103. Shen X, Tang H, McDanal C, Wagh K, Fischer W, Theiler J, et al. SARS-CoV-2 variant B.1.1.7 is susceptible to neutralizing antibodies elicited by ancestral spike vaccines. Cell Host Microbe. 2021.
104. Shen X, Tang H, Pajon R, Smith G, Glenn GM, Shi W, et al. Neutralization of SARS-CoV-2 Variants B.1.429 and B.1.351. N Engl J Med. 2021.
105. Skelly D HA, Gilbert-Jaramillo J, et al. Vaccine-induced immunity provides more robust heterotypic immunity than natural infection to emerging SARS-CoV-2 variants of concern. Research Square. 2021;https://www.researchsquare.com/article/rs-226857/v1 .
106. Stamatatos L, Czartoski J, Wan YH, Homad LJ, Rubin V, Glantz H, et al. mRNA vaccination boosts cross-variant neutralizing antibodies elicited by SARS-CoV-2 infection. Science. 2021.
107. Supasa P, Zhou D, Dejnirattisai W, Liu C, Mentzer AJ, Ginn HM, et al. Reduced neutralization of SARS-CoV-2 B.1.1.7 variant by convalescent and vaccine sera. Cell. 2021.
108. Tada T ZH, Dcosta BM, et al. The Spike Proteins of SARS-CoV-2 B.1.617 and B.1.618 Variants Identified in India Provide Partial Resistance to Vaccine-elicited and Therapeutic Monoclonal Antibodies. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.05.14.444076v1 .
109. Tada T ZH, Dcosta BM, et al. SARS-CoV-2 Lambda Variant Remains Susceptible to Neutralization by mRNA Vaccine-elicited Antibodies and Convalescent Serum. BioRxiv. 2021;https://doi.org/10.1101/2021.07.02.450959 .
110. Wall EC, Wu M, Harvey R, Kelly G, Warchal S, Sawyer C, et al. Neutralising antibody activity against SARS-CoV-2 VOCs B.1.617.2 and B.1.351 by BNT162b2 vaccination. Lancet. 2021;397(10292):2331-3.
111. Wang P, Casner RG, Nair MS, Wang M, Yu J, Cerutti G, et al. Increased resistance of SARS-CoV-2 variant P.1 to antibody neutralization. Cell Host Microbe. 2021;29(5):747-51 e4.
112. Wang P, Nair MS, Liu L, Iketani S, Luo Y, Guo Y, et al. Antibody Resistance of SARS-CoV-2 Variants B.1.351 and B.1.1.7. Nature. 2021.
113. Wang Z, Schmidt F, Weisblum Y, Muecksch F, Barnes CO, Finkin S, et al. mRNA vaccine-elicited antibodies to SARS-CoV-2 and circulating variants. Nature. 2021.

114. West AP WJ, Wang JC, et al. Detection and characterization of the SARS-CoV-2 lineage B.1.526 in New York. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.02.14.431043v3 .
115. Wu K, Werner AP, Koch M, Choi A, Narayanan E, Stewart-Jones GBE, et al. Serum Neutralizing Activity Elicited by mRNA-1273 Vaccine. N Engl J Med. 2021.
116. Xie X, Liu Y, Liu J, Zhang X, Zou J, Fontes-Garfias CR, et al. Neutralization of SARS-CoV-2 spike 69/70 deletion, E484K and N501Y variants by BNT162b2 vaccine-elicited sera. Nat Med. 2021.
117. Zhou D, Dejnirattisai W, Supasa P, Liu C, Mentzer AJ, Ginn HM, et al. Evidence of escape of SARS-CoV-2 variant B.1.351 from natural and vaccine-induced sera. Cell. 2021.
118. Zhou H DB, Samanovic M, et al. . B.1.526 SARS-CoV-2 variants identified in New York City are neutralized by vaccine-elicited and therapeutic monoclonal antibodies. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.03.24.436620v1.full.pdf .
119. Becker M, Dulovic A, Junker D, Ruetalo N, Kaiser PD, Pinilla YT, et al. Immune response to SARS-CoV-2 variants of concern in vaccinated individuals. Nat Commun. 2021;12(1):3109.
120. Edara VV, Pinsky BA, Suthar MS, Lai L, Davis-Gardner ME, Floyd K, et al. Infection and Vaccine-Induced Neutralizing-Antibody Responses to the SARS-CoV-2 B.1.617 Variants. N Engl J Med. 2021.
121. Ferreira I, Kemp S, Datir R, Saito A, Meng B, Rakshit P, et al. SARS-CoV-2 B.1.617 mutations L452 and E484Q are not synergistic for antibody evasion. J Infect Dis. 2021.
122. Tada T, Dcosta BM, Samanovic MI, Herati RS, Cornelius A, Zhou H, et al. Convalescent-Phase Sera and Vaccine-Elicited Antibodies Largely Maintain Neutralizing Titer against Global SARS-CoV-2 Variant Spikes. mBio. 2021;12(3):e0069621.
123. Trinite B, Pradenas E, Marfil S, Rovirosa C, Urrea V, Tarres-Freixas F, et al. Previous SARS-CoV-2 Infection Increases B.1.1.7 Cross-Neutralization by Vaccinated Individuals. Viruses. 2021;13(6).
124. Marot S, Malet I, Leducq V, Abdi B, Teyssou E, Soulie C, et al. Neutralization heterogeneity of United Kingdom and South-African SARS-CoV-2 variants in BNT162b2-vaccinated or convalescent COVID-19 healthcare workers. Clin Infect Dis. 2021.
125. Edara VV, Norwood C, Floyd K, Lai L, Davis-Gardner ME, Hudson WH, et al. Infection- and vaccine-induced antibody binding and neutralization of the B.1.351 SARS-CoV-2 variant. Cell Host Microbe. 2021;29(4):516-21 e3.
126. Stankov MV, Cossmann A, Bonifacius A, Dopfer-Jablonka A, Ramos GM, Godecke N, et al. Humoral and cellular immune responses against SARS-CoV-2 variants and human coronaviruses after single BNT162b2 vaccination. Clin Infect Dis. 2021.

127. Jangra S, Ye C, Rathnasinghe R, Stadlbauer D, Personalized Virology Initiative study g, Krammer F, et al. SARS-CoV-2 spike E484K mutation reduces antibody neutralisation. Lancet Microbe. 2021.

128. Tada T, Dcosta BM, Samanovic-Golden M, Herati RS, Cornelius A, Mulligan MJ, et al. Neutralization of viruses with European, South African, and United States SARS-CoV-2 variant spike proteins by convalescent sera and BNT162b2 mRNA vaccine-elicited antibodies. bioRxiv. 2021;https://www.ncbi.nlm.nih.gov/pubmed/33564768 .

129. Marot S MI, Jary A, et al. Neutralization heterogeneity of United Kingdom and South-African SARS-CoV-2 variants in BNT162b2-vaccinated or convalescent COVID-19 healthcare workers. bioRxiv. 2021;https://doi.org/10.1101/2021.03.05.434089 .

130. Pegu A OCS, Schmidt SD, et al. Durability of mRNA-1273-induced antibodies against SARS-CoV-2 variants. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.05.13.444010v1 .

131. Wu K, Choi A, Koch M, et al. Preliminary Analysis of Safety and Immunogenicity of a SARS-CoV-2 Variant Vaccine Booster. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.05.05.21256716v1 .

132. Tada T ZH, Samanovic MI, et al. Comparison of Neutralizing Antibody Titers Elicited by mRNA and Adenoviral Vector Vaccine against SARS-CoV-2 Variants. BioRxiv. 2021;https://doi.org/10.1101/2021.07.19.452771

133. Earle KA, Ambrosino DM, Fiore-Gartland A, Goldblatt D, Gilbert PB, Siber GR, et al. Evidence for antibody as a protective correlate for COVID-19 vaccines. Vaccine. 2021;39(32):4423-8.

134. Khoury DS, Cromer D, Reynaldi A, Schlub TE, Wheatley AK, Juno JA, et al. Neutralizing antibody levels are highly predictive of immune protection from symptomatic SARS-CoV-2 infection. Nat Med. 2021;27(7):1205-11.

135. Gallagher KME, Leick MB, Larson RC, Berger TR, Katsis K, Yam JY, et al. SARS-CoV-2 T-cell immunity to variants of concern following vaccination. bioRxiv. 2021.

136. Neidleman J LX, McGregor M, et al. mRNA vaccine-induced SARS-CoV-2-specific T cells recognize B.1.1.7 and B.1.351 variants but differ in longevity and homing properties depending on prior infection status. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.05.12.443888v1 .

137. Stankov MV CA, Bonifacius A, et al. Humoral and cellular immune responses against SARS-CoV-2 variants and human coronaviruses after single BNT162b2 vaccination. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.04.16.21255412v1 .

138. Tarke A SJ, Methot N, et al. Negligible impact of SARS-CoV-2 variants on CD4+ and CD8+ T cell reactivity in COVID-19 exposed donors and vaccinees. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.02.27.433180v1 .

139. Woldemeskel BA, Garliss CC, Blankson JN. SARS-CoV-2 mRNA vaccines induce broad CD4+ T cell responses that recognize SARS-CoV-2 variants and HCoV-

NL63. J Clin Invest. 2021;131(10).

140. Motozono C TM, Zahradnik J, et al. An emerging SARS-CoV-2 mutant evading cellular immunity and increasing viral infectivity. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.04.02.438288v1 .
141. Pretti MAM GR, Farias AS, et al. New SARS-CoV-2 lineages could evade CD8+ T-cells response. bioRxiv. 2021;https://www.biorxiv.org/content/10.1101/2021.03.09.434584v2 .
142. Reynolds CJ, Pade C, Gibbons JM, Butler DK, Otter AD, Menacho K, et al. Prior SARS-CoV-2 infection rescues B and T cell responses to variants after first vaccine dose. Science. 2021.
143. Dolton G RC, Hasan MS, et al. Emergence of immune escape at dominant SARS-CoV-2 killer T-cell epitope. MedRxiv. 2021;https://doi.org/10.1101/2021.06.21.21259010
144. Agerer B, Koblischke M, Gudipati V, Montano-Gutierrez LF, Smyth M, Popa A, et al. SARS-CoV-2 mutations in MHC-I-restricted epitopes evade CD8(+) T cell responses. Sci Immunol. 2021;6(57).
145. Buckley PR LC, Pinho MP, et al. HLA-dependent variation in SARS-CoV-2 CD8+ T cell cross-reactivity with human coronaviruses. bioRxiv. 2021;https://doi.org/10.1101/2021.07.17.452778
146. Lopez Bernal J, Andrews N, Gower C, Gallagher E, Simmons R, Thelwall S, et al. Effectiveness of Covid-19 Vaccines against the B.1.617.2 (Delta) Variant. N Engl J Med. 2021.
147. Sheikh A, McMenamin J, Taylor B, Robertson C, Public Health S, the EIIC. SARS-CoV-2 Delta VOC in Scotland: demographics, risk of hospital admission, and vaccine effectiveness. Lancet. 2021;397(10293):2461-2.
148. Stowe J AN, Gower C, et al. Effectiveness of COVID-19 vaccines against hospital admission with the Delta (B.1.617.2) variant. khubnet. 2021;https://khub.net/web/phe-national/public-library/-/document_library/v2WsRK3ZlEig/view/479607266 .
149. Chemaitelly H, Yassine HM, Benslimane FM, Al Khatib HA, Tang P, Hasan MR, et al. mRNA-1273 COVID-19 vaccine effectiveness against the B.1.1.7 and B.1.351 variants and severe COVID-19 disease in Qatar. Nat Med. 2021.
150. Abu-Raddad LJ, Chemaitelly H, Butt AA, National Study Group for C-V. Effectiveness of the BNT162b2 Covid-19 Vaccine against the B.1.1.7 and B.1.351 Variants. N Engl J Med. 2021.
151. Sadoff J, Gray G, Vandebosch A, Cardenas V, Shukarev G, Grinsztejn B, et al. Safety and Efficacy of Single-Dose Ad26.COV2.S Vaccine against Covid-19. N Engl J Med. 2021;384(23):2187-201.
152. Chung H HS, Nasreen S, et al. Effectiveness of BNT162b2 and mRNA-1273 COVID-19 vaccines against symptomatic SARS-CoV-2 infection and severe COVID-19 outcomes in Ontario, Canada. medRxiv. 2021;https://khub.net/web/phe-national/public-library/-/document_library/v2WsRK3ZlEig/view/479607266 .

153. Nasreen S CH, He S, et al. Effectiveness of COVID-19 vaccines against variants of concern in Ontario, Canada. medRxiv. 2021;https://doi.org/10.1101/2021.06.28.21259420 .

154. Yassi A GJ, Lockhart K, et al. Infection control, occupational and public health measures including mRNA-based vaccination against SARS-CoV-2 infections to protect healthcare workers from variants of concern: a 14-month observational study using surveillance data. medRxiv. 2021;Effectiveness of BNT162b2 and mRNA-1273 COVID-19 vaccines against symptomatic SARS-CoV-2 infection and severe COVID-19 outcomes in Ontario, Canada.

155. Riley S EO, Haw D, et al. REACT-1 round 13 interim report: acceleration of SARS-CoV-2 Delta epidemic in the community in England during late June and early July 2021. medRxiv. 2021 https://doi.org/10.1101/2021.07.08.21260185 .

156. Thompson MG, Burgess JL, Naleway AL, Tyner H, Yoon SK, Meece J, et al. Prevention and Attenuation of Covid-19 with the BNT162b2 and mRNA-1273 Vaccines. N Engl J Med. 2021;385(4):320-9.

157. Brosh-Nissimov T, Orenbuch-Harroch E, Chowers M, Elbaz M, Nesher L, Stein M, et al. BNT162b2 vaccine breakthrough: clinical characteristics of 152 fully vaccinated hospitalized COVID-19 patients in Israel. Clin Microbiol Infect. 2021.

158. Tenforde MW PM, Ginde AA, et al. Effectiveness of SARS-CoV-2 mRNA Vaccines for Preventing Covid-19 Hospitalizations in the United States. MedRxiv. 2021;https://doi.org/10.1101/2021.07.08.21259776

159. Muller L AM, Ostermann PN, et al. SARS-CoV-2 infection in fully vaccinated individuals of old age strongly boosters the humoral immune response. medRxiv. 2021;https://doi.org/10.1101/2021.07.19.21260563

160. Centers for Disease Control and Prevention. COVID-19 Vaccine Breakthrough Infections Reported to CDC — United States, January 1–April 30, 2021 [Available from: https://www.cdc.gov/mmwr/volumes/70/wr/mm7021e3.htm?s_cid=mm7021e3_w.

161. Kustin T, Harel N, Finkel U, Perchik S, Harari S, Tahor M, et al. Evidence for increased breakthrough rates of SARS-CoV-2 variants of concern in BNT162b2-mRNA-vaccinated individuals. Nat Med. 2021.

162. Musser JM CP, Olsen RJ, et al. . Delta variants of SARS-CoV-2 cause significantly increased vaccine breakthrough COVID-19 cases in Houston, Texas. medRxiv. 2021;https://www.nature.com/articles/s41591-021-01413-7

163. Gallaway MS, Rigler J, Robinson S, Herrick K, Livar E, Komatsu KK, et al. Trends in COVID-19 Incidence After Implementation of Mitigation Measures – Arizona, January 22-August 7, 2020. MMWR Morb Mortal Wkly Rep. 2020;69(40):1460-3.

164. Haug N, Geyrhofer L, Londei A, Dervic E, Desvars-Larrive A, Loreto V, et al. Ranking the effectiveness of worldwide COVID-19 government interventions. Nat Hum Behav. 2020;4(12):1303-12.

165. Honein MA, Christie A, Rose DA, Brooks JT, Meaney-Delman D, Cohn A, et al. Summary of Guidance for Public Health Strategies to Address High Levels of

Community Transmission of SARS-CoV-2 and Related Deaths, December 2020. MMWR Morb Mortal Wkly Rep. 2020;69(49):1860-7.

166. Kanu FA, Smith EE, Offutt-Powell T, Hong R, Delaware Case I, Contact Tracing T, et al. Declines in SARS-CoV-2 Transmission, Hospitalizations, and Mortality After Implementation of Mitigation Measures- Delaware, March-June 2020. MMWR Morb Mortal Wkly Rep. 2020;69(45):1691-4.
167. Kucharski AJ, Klepac P, Conlan AJK, Kissler SM, Tang ML, Fry H, et al. Effectiveness of isolation, testing, contact tracing, and physical distancing on reducing transmission of SARS-CoV-2 in different settings: a mathematical modelling study. Lancet Infect Dis. 2020;20(10):1151-60.
168. Alexander A RJ, Smetters K, et al. Epidemiological and Economic Effects of Lockdown. Brookings Papers on Economic Activity. 2020;https://www.brookings.edu/wp-content/uploads/2020/09/Arnon-et-al-conference-draft.pdf .
169. Boserup B, McKenney M, Elkbuli A. Alarming trends in US domestic violence during the COVID-19 pandemic. Am J Emerg Med. 2020;38(12):2753-5.
170. Brooks SK, Webster RK, Smith LE, Woodland L, Wessely S, Greenberg N, et al. The psychological impact of quarantine and how to reduce it: rapid review of the evidence. Lancet. 2020;395(10227):912-20.
171. Czeisler ME, Lane RI, Petrosky E, Wiley JF, Christensen A, Njai R, et al. Mental Health, Substance Use, and Suicidal Ideation During the COVID-19 Pandemic – United States, June 24-30, 2020. MMWR Morb Mortal Wkly Rep. 2020;69(32):1049-57.
172. Holland KM, Jones C, Vivolo-Kantor AM, Idaikkadar N, Zwald M, Hoots B, et al. Trends in US Emergency Department Visits for Mental Health, Overdose, and Violence Outcomes Before and During the COVID-19 Pandemic. JAMA Psychiatry. 2021.
173. McGinty EE, Presskreischer R, Han H, Barry CL. Psychological Distress and Loneliness Reported by US Adults in 2018 and April 2020. JAMA. 2020;324(1):93-4.
174. Orben A, Tomova L, Blakemore SJ. The effects of social deprivation on adolescent development and mental health. Lancet Child Adolesc Health. 2020;4(8):634-40.
175. UNESCO. Adverse consequences of school closures. https://en.unesco.org/covid19/educationresponse/consequences .
176. Alvarez MM B-GS, Trujillo-de Santiago, G Modeling the effect of vaccination strategies in an Excel spreadsheet: The rate of vaccination, and not only the vaccination coverage, is a determinant for containing COVID-19 in urban areas. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.01.06.21249365v1.full .
177. Borchering RK, Viboud C, Howerton E, Smith CP, Truelove S, Runge MC, et al. Modeling of Future COVID-19 Cases, Hospitalizations, and Deaths, by

Vaccination Rates and Nonpharmaceutical Intervention Scenarios – United States, April-September 2021. MMWR Morb Mortal Wkly Rep. 2021;70(19):719-24.

178. Galanti M PS, Yamana TK, et al. The importance of continued non-pharmaceutical interventions during the upcoming SARS-COV-2 vaccination campaign. medRxiv. 2020;https://www.medrxiv.org/content/10.1101/2020.12.23.20248784v1 .
179. Gozzi N BP, Perra N, et al. The importance of non-pharmaceutical interventions during the COVID-19 vaccine rollout. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.01.09.21249480v1.full.pdf .
180. Gumel A IE, Ngonghala C, et al. Towards achieving a vaccine-derived herd immunity threshold for COVID-19 in the U.S. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2020.12.11.20247916v3 .
181. Iboi EA, Ngonghala CN, Gumel AB. Will an imperfect vaccine curtail the COVID-19 pandemic in the U.S.? Infect Dis Model. 2020;5:510-24.
182. Li J, Giabbanelli P. Returning to a Normal Life via COVID-19 Vaccines in the United States: A Large-scale Agent-Based Simulation Study. JMIR Med Inform. 2021;9(4):e27419.
183. Love J KL, Angulo F, et al. Continued need for non-pharmaceutical interventions after COVID-19 vaccination in long-termcare facilities. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.01.06.21249339v1.full.pdf .
184. Tang B LP, Yang J. The challenges of the coming mass vaccination and exit strategy in prevention and control of COVID-19, a modelling study. medRxiv. 2020;https://www.medrxiv.org/content/10.1101/2020.12.18.20248478v1 .
185. Kraay ANM GM, Ge Y, et al. Modeling the use of SARS-CoV-2 vaccination to safely relax non-pharmaceutical interventions. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.03.12.21253481v1.full.pdf .
186. Shayak B SM, Mishra AK. COVID-19 Spreading Dynamics in an Age-Structured Population with Selective Relaxation of Restrictions for Vaccinated Individuals : a Mathematical Modeling Study. medRxiv. 2021;https://www.medrxiv.org/content/10.1101/2021.02.22.21252241v1.full.pdf .

Previous Updates

As of May 27, 2021

- Data were added from studies published since the last update that further demonstrate currently authorized COVID-19 vaccines are effective against SARS-CoV-2 infection, symptomatic and severe disease, and hospitalization with COVID-19.
- Data were added suggesting that currently authorized mRNA vaccines provide protection against variants of concern, including the B.1.1.7 strain that is predominant in the United States.
- Data were added from studies published since the last update that further demonstrate people who are fully vaccinated with a currently authorized mRNA vaccine are protected against asymptomatic infection and, if infected, have a lower viral load than unvaccinated people.

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