The impacts of increased vaccine uptake in Colorado

07/28/2021

Prepared by the Colorado COVID-19 Modeling Group

Colorado School of Public Health: Elizabeth Carlton, Debashis Ghosh, Irina Kasarskis, Talia Quandelacy, Jonathan Samet; University of Colorado School of Medicine: Kathryn Colborn; University of Colorado-Boulder Department of Applied Mathematics: Sabina Altus, David Bortz; Colorado State University: Jude Bayham; Vanadata: Parker Jackson, David Jacobson

For Contact: Jon.Samet@CUAnschutz.edu

Summary

- We compared vaccination scenarios: increasing vaccination rates among adults and/or teens (80% of adults or 70% of 12-17 year olds with at least one shot by Labor Day). Vaccinating 80% of Colorado adults will require administering approximately 456,000 additional first doses. Vaccinating 70% of Colorado teens (age 12-17) will require administering approximately 90,500 first doses.
- Increasing vaccination rates among adults immediately will prevent substantial numbers of COVID-19 hospitalizations through the fall. If transmission control continues to decline, increased vaccinations could prevent 1000s of COVID-19 hospitalizations over the next three months.
- Vaccinating 80% of Colorado adults yields greater reduction in infection and severe COVID-19 than does vaccinating 70% of Colorado teens (age 12-17).
- On a per vaccination basis, vaccinating an adult prevents more hospitalizations than vaccinating a teen. The differential gains from vaccinating adults are reduced if mixing increases among children and teens.
- If vaccination uptake is low among adults in August and transmission control decreases substantially, Colorado could see a peak in COVD-19 hospitalizations this fall that approaches the December 2020 peak.

Introduction

The purpose of this report is to address two questions

1. What is the benefit of increasing the percentage of adults (age 18+) that have received at least one vaccine dose from 70%, where Colorado is now, to 80% by Labor Day?
2. What is the benefit of increasing the percentage of Colorado teens (age 12-17) vaccinated such that 70% have received first doses by Labor Day?

We examine the potential impact of vaccinations by estimating future COVID-19 hospital admissions, a proxy for severe COVID-19, and the prevalence of infection, which is an approximate measure of the infection risk for SARS-CoV-2. For this latter measure, we focus on infection prevalence in unvaccinated populations, which is higher than infection prevalence overall and in the vaccinated populations

To address the two questions, we used our age-structured SEIRV (susceptible-exposed-infected-recovered-vaccinated) model and real-time COVID-19 hospital census, vaccination, and case data to generate projections of the potential future course of SARS-CoV-2 in Colorado under different scenarios of vaccine uptake in the months ahead. We generate projections of the estimated numbers of SARS-CoV-2 infections, hospitalizations, hospital demand, and deaths under these different scenarios. We also generate estimates of the prevalence of infections for this fall under different scenarios of vaccination and transmission control.

About the model. The model has been parameterized to Colorado-specific data whenever possible. For example, the length of time a COVID-19 patient is assumed to spend in the hospital varies by age and over time and is based on data provided by Colorado hospitals. We use the model to estimate the current state of SARS-CoV-2 in Colorado and then use the most recent model fit to generate projections of the future course of infections under different scenarios. A description of the current model fit is provided in the appendix at the end of this report (See Current State of SARS-CoV-2 in Colorado). Links to model code and documentation are also provided in the appendix.

The estimates presented in this report are based on hospitalization census data through 07/26 and vaccination data through 7/25.

Vaccination in Colorado

In Colorado, the number of people vaccinated per day has been declining over time. Older populations have had the highest vaccination levels, and vaccinations in younger populations have been lower (Figure 1). Figure 1 shows weekly counts of vaccinations for different age groups. The numbers vaccinated over time decline in each age group. We estimate that at present, 85% of adults age 65+, 71% of adults age 40 to 64, 60% of adults age 20 to 39, and 49% of children and teens age 12 to 19 have been vaccinated with at least one dose of the COVID-19 vaccine as of July 25, 2021.

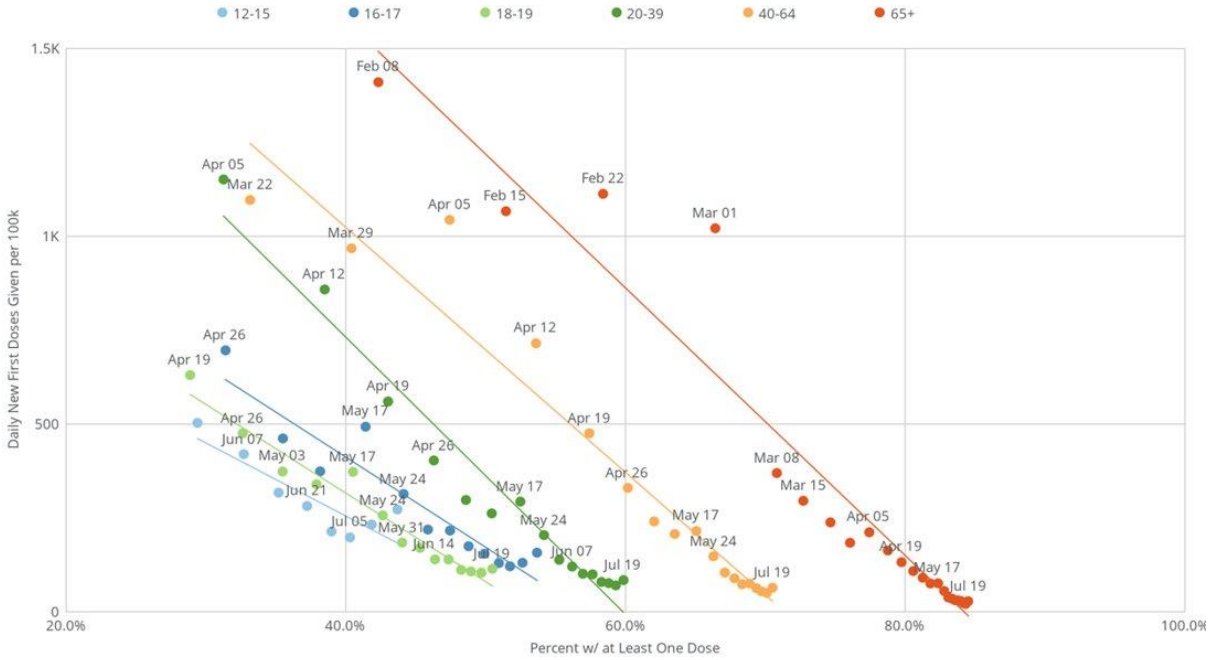


Figure 1. Vaccinations administered in Colorado by age group. Each dot represents the vaccinations administered in a week to people within a given age group.

To have 80% of adults, age 18+, and 70% of 12-17 year olds vaccinated with at least one dose by Labor Day will require a sharp increase in the number of vaccines administered per day. Hitting the target of 80% of adults vaccinated target will require administering approximately 456,000 more first dose vaccines between now and Labor Day. Hitting the target of 70% of 12-17 year olds vaccinated will require administering approximately 90,500, more first dose vaccines between now and Labor Day.

In order to estimate the potential impact of high vaccination uptake in Colorado in the weeks ahead, we generated four vaccination scenarios that reflect varying degrees of vaccine uptake between mid-July and Labor Day 2021. Details of the assumptions of vaccine distribution by age are provided in Table 1.

Scenario 1. Current vaccine trajectory. This scenario assumes we stay on the current vaccination trends by age and reflects our best guess at the percent vaccinated by Labor Day, if there are no major changes in vaccination campaigns and in the public's response to them. This is the reference scenario – we compare increased vaccine uptake to this scenario.

Scenario 2. 80% of adults 18+ vaccinated by Labor Day. This scenario would require major efforts to increase vaccine uptake in adults in Colorado. We assume vaccinations in 12-17 year olds are as outlined in Scenario 1. In this scenario, efforts are exclusively directed towards increasing vaccination uptake in adults.

Scenario 3. 70% of 12-17 year olds vaccinated by Labor Day. In this scenario, 12-17 year olds mirror the vaccine uptake of their parents, such that 70% are vaccinated by Labor Day. We assume vaccinations in adults are as outlined in Scenario 1. In this scenario, efforts are exclusively directed towards increasing vaccination uptake in 12-17 year olds.

Scenario 4. 70% of 12-17 year olds AND 80% of adults vaccinated by Labor Day. Under this scenario, vaccine uptake in all age groups from 12 to 64 increases rapidly in the weeks ahead.

Table 1. Percent of eligible population vaccinated with at least one dose. Vaccine uptake scenarios by age. Percentages show the percent of the population that has received at least one dose of a COVID-19 vaccine by Labor Day 2021 (9/6/2021)

	Age 12-17	Adults (18+)	Age 0-19	Age 20-39	Age 40-64	Age 65+
Current estimated percent vaccinated						
July 25, 2021	48%	69%	21%	60%	71%	85%
Labor Day projections						
Scenario 1. Current trajectory	50%	70%	22%	62%	72%	85%
Scenario 2. 80% of adults vaccinated	50%	79%	22%	76%	80%	87%
Scenario 3. 70% of 12-17 yr olds vaccinated	70%	71%	30%	62%	72%	85%
Scenario 4. 70% of 12-17 yr olds and 80% of adults vaccinated	69%	79%	30%	76%	80%	87%

Transmission Control

The impact of vaccinations depends on the level of what we term "transmission control" (Colorado COVID-Modeling team, 6/30/2020 report). Transmission control is an estimate of the collective impact of behaviors and policies such as mask-wearing, physical distancing, case isolation, contact tracing, improved ventilation and moving activities outside. Transmission control may also capture seasonal changes in transmission. When transmission control is 0%, spread of infections is uncontrolled, as in the very early days of the pandemic. When transmission control is close to 100%, the spread of the virus from an infected person to others is rare. At high levels of transmission control, the estimated impact of vaccines is relatively low because spread of infections is prevented by other measures. As transmission control declines, vaccines play a key role in preventing infections, severe disease and deaths.

In addition to changes in policy and behavior, variants of concern can also accelerate the spread of infections. We estimate the level of transmission control due to policies and behaviors, a term we call TC_{pb}. To describe the impact of variants, we also estimate a transmission control value that accounts for policies, behaviors, and variants (TC). This

value accounts for the proportion of total infections presumed to be caused by B.1.1.7 (Alpha), B.1.427/429, and B.1.617.2 (Delta) variants each week, and the infectiousness of these variants. The difference between TC_{pb} and TC represents the consequences of the more transmissible variants.

Throughout the pandemic, there has been uncertainty about future levels of transmission control as the estimated level reflects a complex and still incompletely understood combination of behavior, policy, new variants and, perhaps, weather. To capture the uncertainty regarding the course of the pandemic in the months ahead, we generated projections using a set of transmission control scenarios. These scenarios are grounded in recent levels of transmission control observed in Colorado (Figure 2). In these scenarios, we implement changes in TC_{pb} and assume Delta variant accounts for approximately 90% of infections in Colorado as of mid-July.

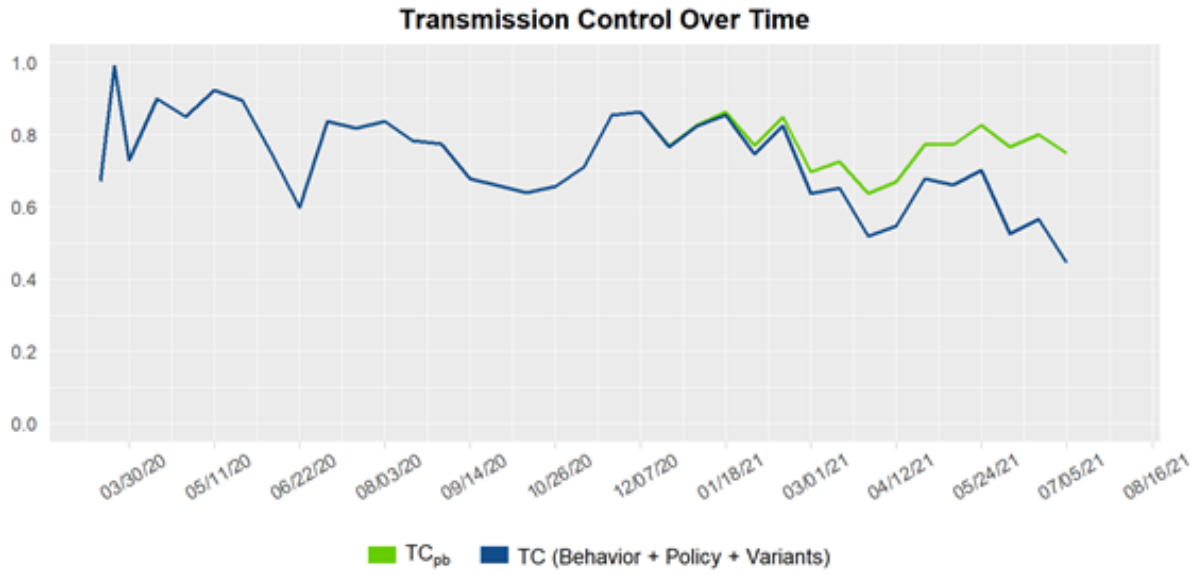


Figure 2. The estimated transmission control value for each two-week period since March 2020 in Colorado. The green line shows the estimated value of transmission control due to policy and behavior (TC_{pb}). The blue line shows the estimated transmission control accounting for behavior, policy, and variants. In the scenarios, below, changes are made to TC_{pb}. On the graph, the value is shown for the mid-point of each two-week period.

Transmission control scenarios considered

A. Remain on current trajectory (TC_{pb}=75%).
B. Transmission control gradually declines over the month of August, leading to a net 5% decline in TC_{pb} by Labor Day (TC_{pb}=70% starting 9/06/2021). This reflects

further increases in contact rates as people return to work and resume pre-pandemic activities. TC_{pb} is assumed to remain constant after Labor Day.

C. Transmission control declines over the month of August, leading to a net 10% decline in TC_{pb} per week on Labor Day (TC_{pb}=65%). This reflects further increases in contact rates as people return to work and resume pre-pandemic activities. TC_{pb} is assumed to remain constant after Labor Day.
D. Scenario B plus an additional 15% drop in TC_{pb} among those under age 20 on August 15. This is intended to capture increased mixing among younger populations when schools re-open. In reality, we do not know how contact rates will change in younger populations this fall – the level of transmission control in this age group will depend on factors such as masking, ventilation, testing and contact tracing in this population. Recent CDC guidance recommending universal masking in schools this fall may prevent large increases in transmission-relevant contacts among young populations.
E. Scenario C plus an additional 15% drop in TC_{pb} among those under age 20 on August 15.

What is the potential impact of increasing vaccinations in Colorado?

Impact of vaccination on severe COVID-19. Increased vaccinations in teens and adults between mid-July and Labor Day will prevent COVID hospitalizations, an indicator of severe COVID-19 (Tables 2 & 3). The impact of vaccinations is greater if we reach the goal of 80% of adults vaccinated compared to 70% of teens. The impact of vaccinations is also higher if transmission control declines. For example, if 80% of Colorado adults are vaccinated by Labor Day, approximately 839 COVID-19 hospitalizations will be avoided assuming we remain at current levels of transmission control and variants. If transmission control declines by 10%, the impact of vaccination nearly triples: over 2,113 hospitalizations will be avoided by vaccinating 80% of adults. If 70% of teens are vaccinated by Labor Day, the number of hospitalizations avoided ranges from 165 (if transmission control and variants remain at current levels) to 435 (if transmission control declines by 10%).

If the contact rates in children and teens increase in the fall, leading to greater declines in transmission control in these age groups, vaccinating 80% of Colorado adults will prevent thousands of hospitalizations, vaccinating 70% of Colorado teens could prevent nearly 1,000 hospitalizations.

Table 2. Estimated number of COVID-19 hospitalizations from mid-July to November 1 under different vaccine scenarios and levels of transmission control.

Transmission control level	Current trajectory (Reference)	80% of adults vaccinated (Scenario 2)	70% of teens (age 12-17) vaccinated (Scenario 3)	80% of adults and 70% of teens vaccinated (Scenario 4)
Current trajectory	4,720	3,881	4,555	3,781
TC_{pb} reduced by 5%	6,313	4,921	6,010	4,766
TC_{pb} reduced by 10%	8,512	6,399	8,077	6,135
TC_{pb} reduced by 5% and increased mixing in children/teens	9,439	7,247	8,869	6,812
TC_{pb} reduced by 10% and increased mixing in children/teens	13,129	9,784	12,164	9,140

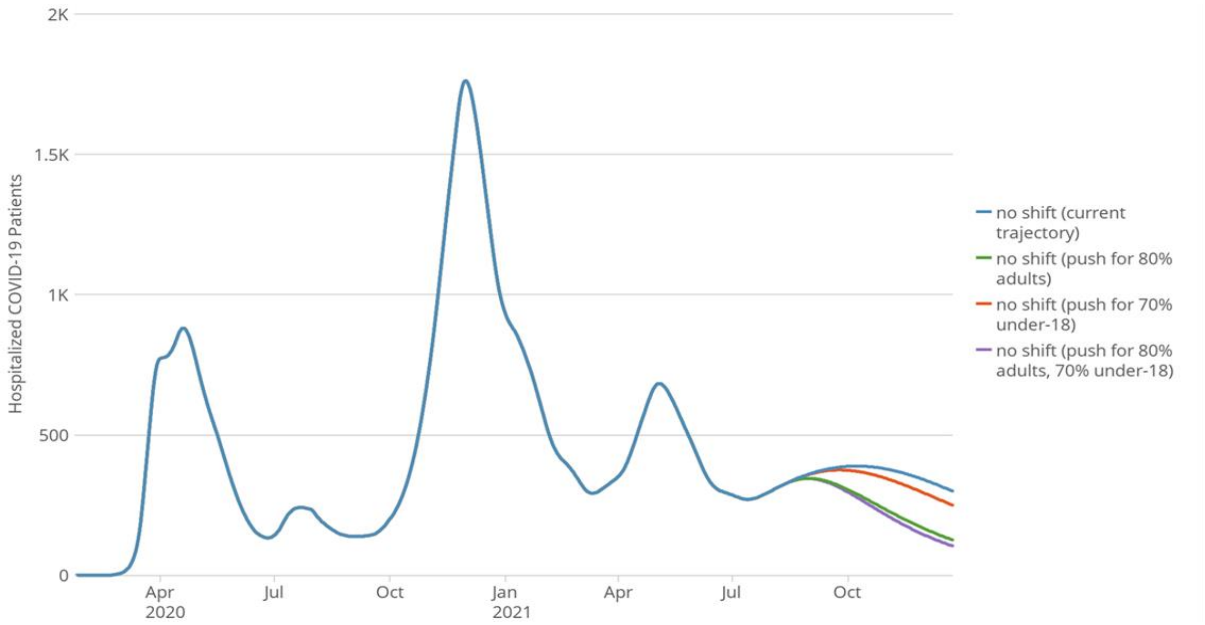
Table 3. Estimated number of COVID-19 hospitalizations avoided from mid-July to November 1 due to vaccinations from mid-July to Labor Day under different levels of transmission control.

Transmission control level	Current trajectory (Reference)	80% of adults vaccinated (Scenario 2)	70% of teens (age 12-17) vaccinated (Scenario 3)	80% of adults and 70% of teens vaccinated (Scenario 4)
Current trajectory	0	839	165	939
TC_{pb} reduced by 5%	0	1,392	303	1,547
TC_{pb} reduced by 10%	0	2,113	435	2,377
TC_{pb} reduced by 5% and increased mixing in children/teens	0	2,192	570	2,627
TC_{pb} reduced by 10% and increased mixing in children/teens	0	3,345	965	3,989

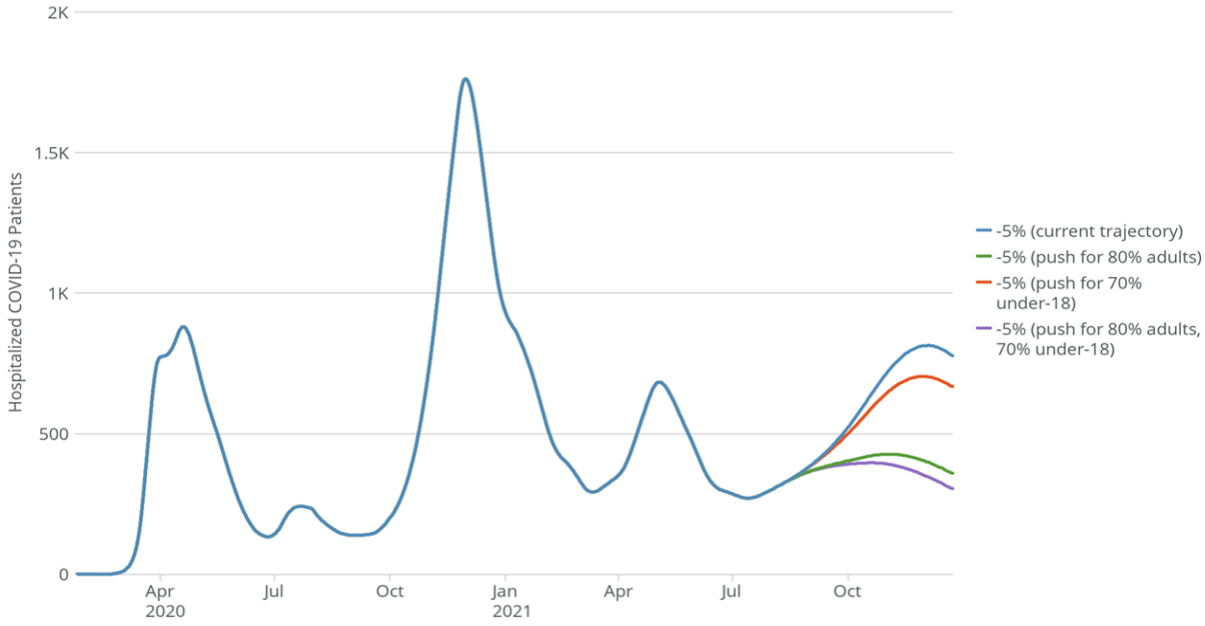
Prevented COVID-19 hospitalizations are estimated as the difference between the projected number of hospitalizations under the current trajectory scenario for a given transmission control level and the projected number of hospitalizations for a vaccination scenario at the same level of transmission control.

Hospital demand is projected to be below the December 2020 peak in all scenarios modeled. However, hospitalizations could approach the pastt December peak if vaccination uptake is low, transmission control declines by 10% and contact rates increase in children and teens (Figure 3).

Transmission control remains on current trajectory



Transmission control declines by 5% by Labor Day to 75%



Transmission control declines by 10% by Labor Day

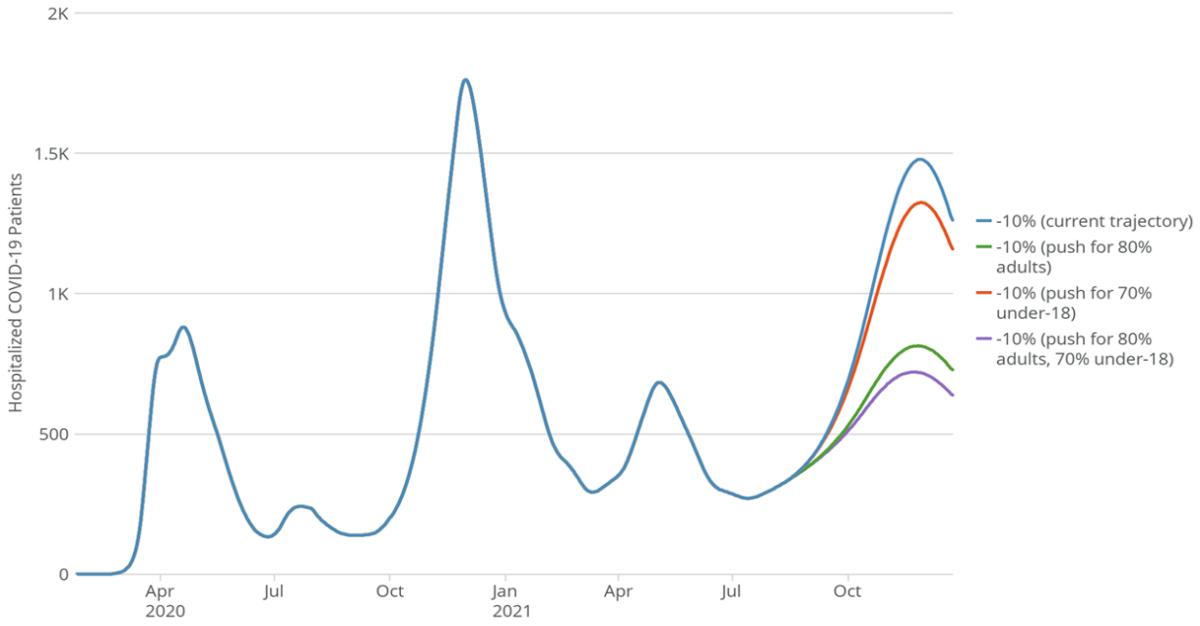


Figure 3. Actual and projected COVID-19 hospital demand for different vaccine scenarios and different levels of transmission control from March 2020 through December, 2021.

Number of vaccinations needed to prevent a single COVID hospitalization in the next three months. Vaccinating 80% of Colorado adults by Labor Day will prevent more COVID hospitalizations than vaccinating 70% of Colorado teens. However, the scenario of vaccinating adults will also require far more vaccinations than that for teens. To allow a comparison that accounts for both the number of first doses and the hospitalizations prevented, we generated estimates of the number of vaccinations needed to prevent a single COVID hospitalization in the next three months under each scenario (Table 4). We note that the long-term impact of vaccinations will be much higher than shown here, leading to prevented hospitalizations for months to come.

As transmission control declines, each vaccine dose in adults or teens has a greater impact on preventing COVID-19 hospitalizations. If transmission control declines 5% by Labor Day, approximately 54 vaccinations in adults will be required to prevent one COVID hospitalization, compared to 72 vaccinations in teens (12-17 year olds). If contact rates increase among young populations in the fall, the impact of vaccinating a teenager is similar to the impact of vaccinating an adult.

Table 4. The estimated number of vaccinations required to prevent a single COVID-19 hospitalization under each scenario.

Transmission Control Scenario	80% of adults vaccinated (Scenario 2)	70% of teens (age 12-17) vaccinated (Scenario 3)
No shift	87	130
TC reduced by 5%	54	72
TC reduced by 5% and increased mixing in children/teens	36	52
TC reduced by 10%	35	40
TC reduced by 10% and increased mixing in children/teens	23	23

The number of vaccinations required to prevent a hospitalization is calculated based on the projected number of COVID-19 hospitalizations from present (July 28, 2021) to November 1, 2021 and the additional vaccinations required.

Impact on infection prevalence in the unvaccinated. Our projections also include estimates of the prevalence of infection in unvaccinated individuals. This measure is a proxy for the risk of infection among unvaccinated individuals. The prevalence among unvaccinated individuals highlights the potential for disruption of activities (e.g., the need to miss work or school in order to isolate) and for the spread of disease to others, including spread to other unvaccinated individuals as well as spread leading to breakthrough cases among the vaccinated. We caution that our projections are state-wide estimates. In reality, prevalence will vary **substantially** by region.

Increased vaccination in adults and/or teens will decrease the prevalence of infection in unvaccinated populations (Table 5). Vaccinating adults will have a greater impact in reducing infection prevalence among the unvaccinated compared to vaccinating teens.

Table 5. The estimated prevalence of infection among unvaccinated Coloradans on October 1, 2021 for different vaccination and transmission control scenarios. Prevalence is estimated as the number of infected individuals per 100,000 people.

	Current trajectory (Reference)	80% of adults vaccinated (Scenario 2)	70% of teens (age 12-17) vaccinated (Scenario 3)	80% of adults and 70% of teens vaccinated (Scenario 4)
Unvaccinated prevalence per 100,000				
No shift	1,000	896	966	881
TC reduced by 5%	1,451	1,277	1,391	1,256
TC reduced by 5% and increased mixing in children/teens	2,830	2,649	2,678	2,514
TC reduced by 10%	2,037	1,788	1,960	1,748
TC reduced by 10% and increased mixing in children/teens	4,059	3,721	3,779	3,521
Percent reduction in unvaccinated prevalence*				
No shift		10.40%	3.40%	11.90%
TC reduced by 5%		11.99%	4.14%	13.44%
TC reduced by 5% and increased mixing in children/teens		6.40%	5.37%	11.17%
TC reduced by 10%		12.22%	3.78%	14.19%
TC reduced by 10% and increased mixing in children/teens		8.33%	6.90%	13.25%

*Percent reduction compared to the vaccine slow down (reference) scenario at a given level of transmission control.

Conclusions/key findings

1. Vaccinating 80% of Colorado adults and 70% of Colorado teens by Labor Day will allow Colorado to continue its return to normal activities.
2. Vaccinating 80% of Colorado adults by Labor Day will prevent more COVID hospitalizations. Achieving this goal would prevent 1000s of hospitalizations if transmission control declines in the weeks ahead.
3. On a per vaccination basis, vaccinating an adult prevents more hospitalizations than vaccinating a teen. The differential gains from vaccinating adults are reduced if mixing increases among children and teens.
4. Increasing vaccinations can reduce the prevalence of infection in the unvaccinated.

5. If vaccination uptake is low among adults in August and transmission control decreases substantially, Colorado could see a peak in COVD-19 hospitalizations this fall that approaches the December 2020 peak.

Appendix 1. Current estimated state of SARS-CoV-2 in Colorado

Model Fit

We assess model fit by comparing the model-estimated number of hospitalizations to actual hospitalizations. We show the current estimated trajectory of hospitalizations, based on the most recent model-fit, compared to the daily reported number of people hospitalized with COVID-19 (Figure A1). For reference, a line showing the estimated trajectory one-week prior is also shown. A figure showing hospitalizations and model fit since the beginning of the pandemic is provided in the appendix.

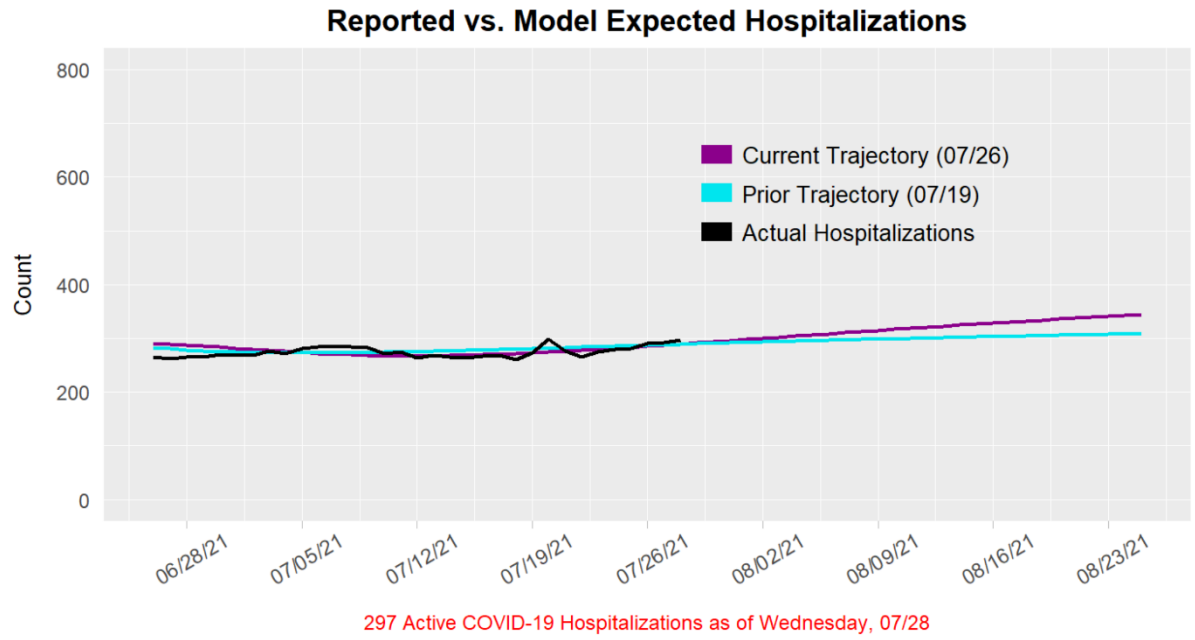


Figure A1. The projected course of COVID-19 hospitalizations if Colorado were to remain on the current estimated trajectory (purple line) or on the trajectory estimated one week prior (turquoise line). Each trajectory is generated assuming Colorado rolls out vaccines on schedule, as described in the long-term projections.

The Effective Reproduction Number

The effective reproduction number (Re) is a measure of how rapidly infections are spreading or declining. When the effective reproduction number is below 1, infections are decreasing. When the effective reproduction number is above 1, infections are increasing. The effective reproduction number is estimated using our age-structured SEIR model fit to hospitalization data.

Our current estimate of Re is 1.1. Due to the lag between infections and hospitalizations, this estimate of Re reflects the spread of infections occurring on approximately 07/13.

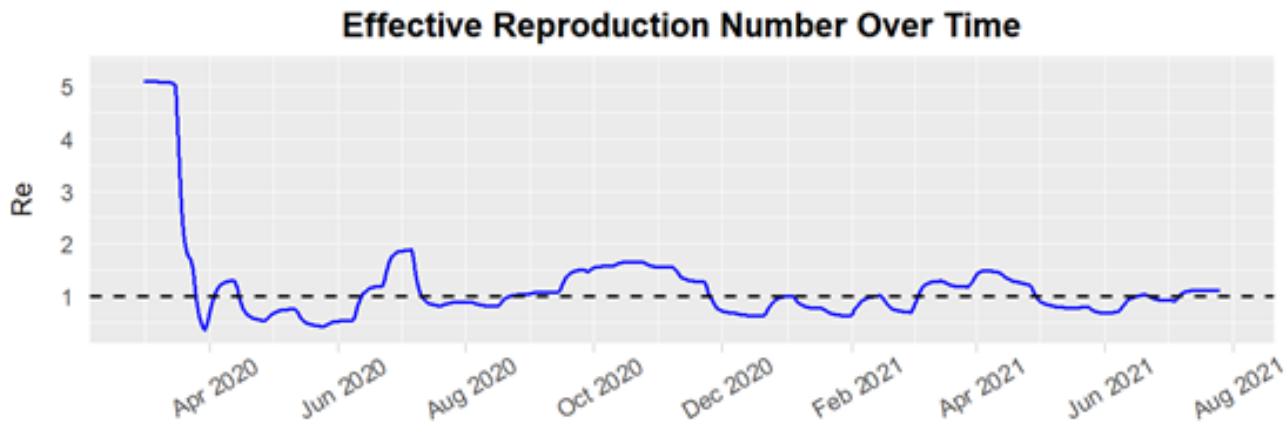


Figure A2. Estimates of the effective reproduction number over time.

Infection Prevalence

Infection prevalence provides an estimate of the proportion of the population that is currently infected with SARS-CoV-2 and capable of spreading infections. At higher levels of infection prevalence, susceptible individuals are more likely to encounter infectious individuals among their contacts. Because many people experience no symptoms or mild symptoms of COVID-19, many infections are not identified by surveillance systems. The estimates we present here are intended to provide an approximation of all infections, including those not detected by the Colorado Electronic Disease Reporting System (CEDRS).

These estimates are generated using the model by assuming the most recent transmission control parameter (estimated for the period 07/03 to 07/13) remains at the estimated value through 07/26. These estimates are sensitive to the model assumptions, including assumptions about the probability an infected individual will be symptomatic and require hospital care, and assumptions about length of hospital stay, which vary by age.

We estimate that approximately 401 of every 100,000 Coloradoans or 1 in every 249 people are infectious in Colorado as of 07/26.

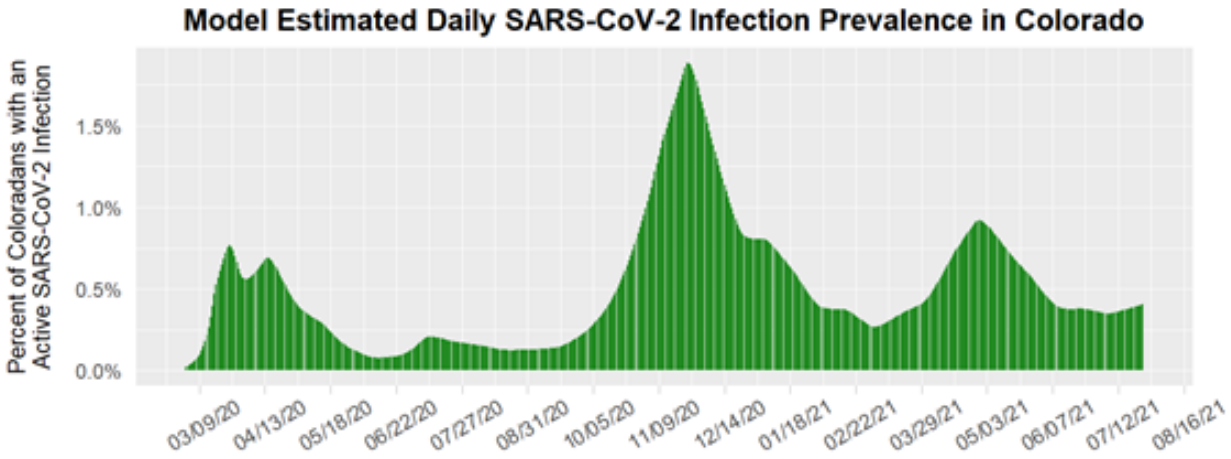


Figure A3. Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and based on hospitalizations.

Transmission Control

Transmission control is an estimate of the collective impact of behaviors and policies such as mask wearing, physical distancing, case isolation, contact tracing, and moving activities outside on slowing the spread of infections from infected to susceptible individuals. When transmission control is 0%, spread of infections is uncontrolled, as in the very early days of the pandemic. When transmission control is close to 100%, the spread of the virus from an infected person to others is rare. We estimate transmission control for each two-week period since March 2020. Transmission control is estimated by aligning model output to hospitalization data using model fitting approaches. The most recent model update allows us to estimate two values of transmission control. We can estimate the level of transmission control due to policies and behaviors (TCpb). This is the level of transmission were there no variants of concern in Colorado. We estimate TCpb as 80%. We can also estimate transmission control that accounts for policies, behaviors, and variants (TC); TC corresponds to the estimates made previously. This value accounts for the proportion of total infections presumed to be caused by B.1.1.7 and B.1.427/429 variants. The difference between TCpb and TC represents the consequences of the more transmissible variants versus the previously circulating strains.

Our current estimate of effective transmission control due to policy, behaviors, and variants is 44%. This estimate is for the period 07/03 to 07/13, given the lag between infection and hospitalization.

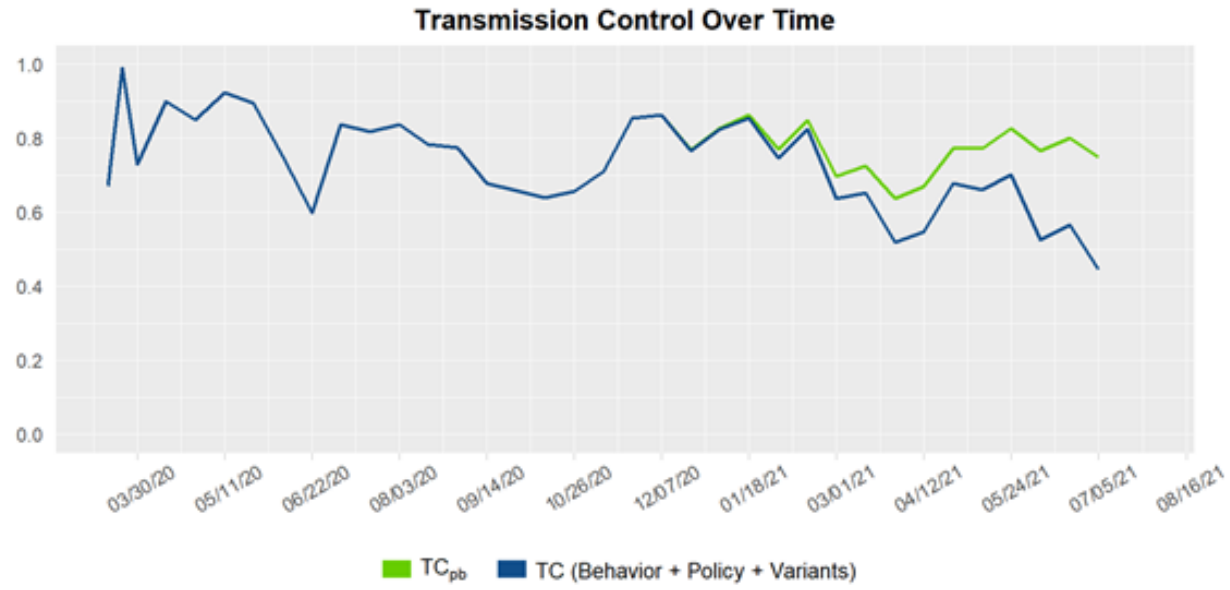


Figure A4. The estimated transmission control value for each two-week period since the beginning of the epidemic due to behavior and policy only (green line) and the estimated transmission control accounting for behavior, policy, and variants (blue line). On the graph, the value is shown for the mid-point of each two-week period. Transmission control is estimated using model fitting approaches to align model output with COVID-19 hospitalizations.

Population Immunity

People can develop immunity to SARS-CoV-2 by vaccination and by prior infection. The proportion of the population immune is an important measure because as more people develop immunity, the spread of infections slows. When many people are immune, infectious individuals are less likely to encounter individuals who are still susceptible to infection (not immune).

We estimate the proportion of the population immune using our age-structured SEIR model and data on vaccinations in Colorado provided by CDPHE. This estimate of population immunity has two components. It accounts for the proportion of people estimated to be immune due to vaccination (yellow line), and the proportion of people estimated to be immune due to either vaccination or prior infection (blue line). In the model, the two-dose vaccines are assumed be 80% effective at preventing infections 14 days after the first dose, and 90% effective one week after the second dose. Vaccination data by age are provided by CDPHE and we assume all individuals who receive first doses also received second doses on schedule. This estimate also accounts for the number of people estimated to have immunity due to prior infection. In our model, immunity from infection is assumed to act like a vaccine, whereby the vast majority of people develop immunity that wanes slowly over time and a few people do not become immune, based on

recent scientific evidence. We assume symptomatic infection confers immunity in 92.5% of people and the percent immune wanes at a rate such that 80% remain immune one year after infection. We assume asymptomatic infection confers immunity to 85% of people and immunity decays at the same rate as acquired immunity from symptomatic infection. Our estimates account for overlap between the vaccinated population and those with immunity due to prior infection. We note that recent studies suggest vaccinations boost immunity in those previously infected.

We estimate that approximately 3,640,000 people in Colorado, or 63% of the Colorado population, are currently immune to SARS-CoV-2 as of 07/26.

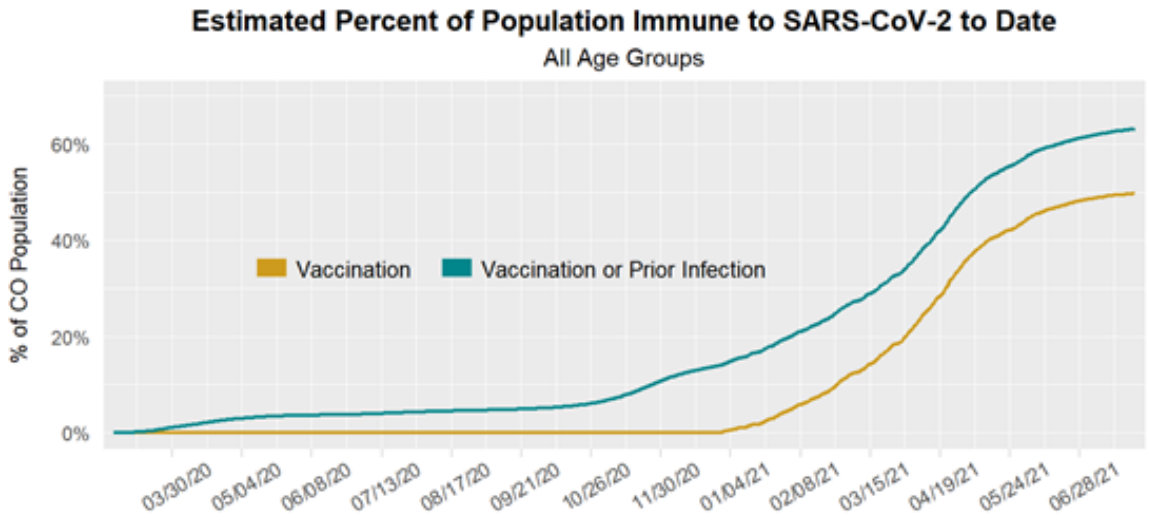


Figure A5. Estimated percent of the population in Colorado assumed to be immune to SARS-CoV-2 due to infection and/or vaccination through 07/26.

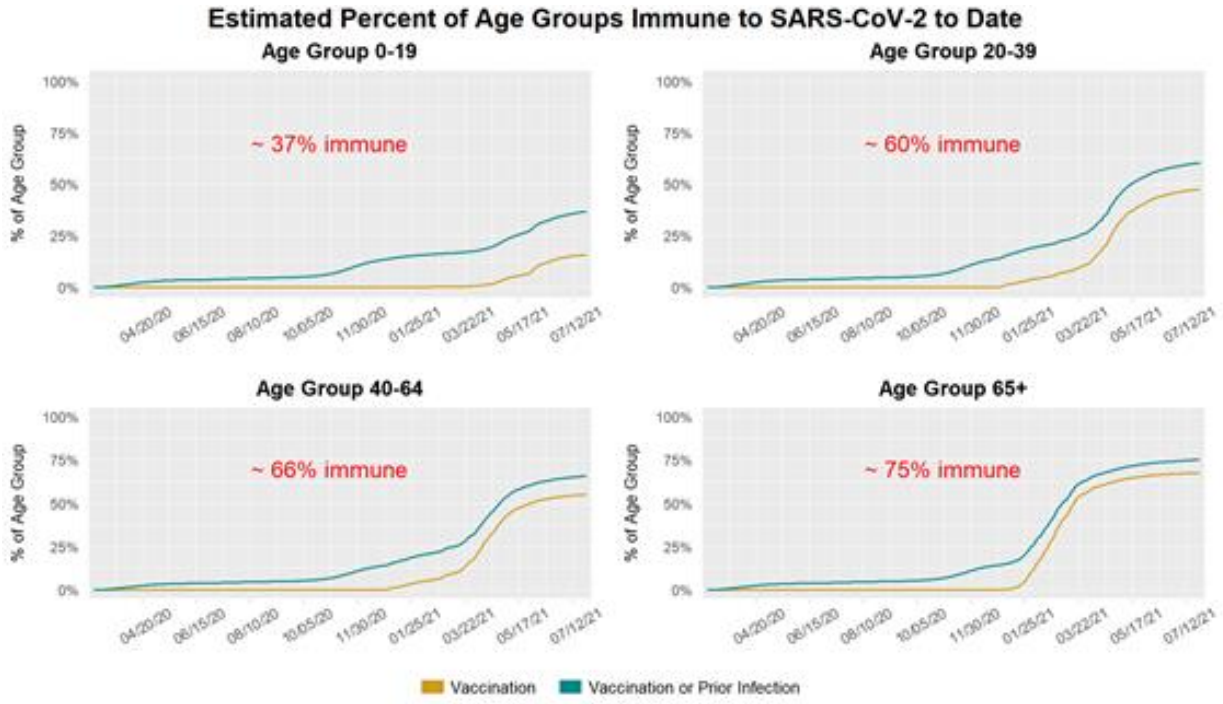


Figure A6. Estimated percent of each age group in Colorado assumed to be immune to SARS-CoV-2 due to infection and/or vaccination through 07/26.

Appendix 2. Code, documentation and model fit

Code, Documentation, and Prior Reports
Code for our model is available on GitHub: https://github.com/agb85/covid-19

Documentation for the model can be found at: https://agb85.github.io/covid-19/SEIR%20Documentation.pdf

Prior modeling reports and documentation can be found at: https://agb85.github.io/covid-19/

Regional modeling results can be found at: https://www.colorado-data.org/regional-epidemic-models

Model Fit

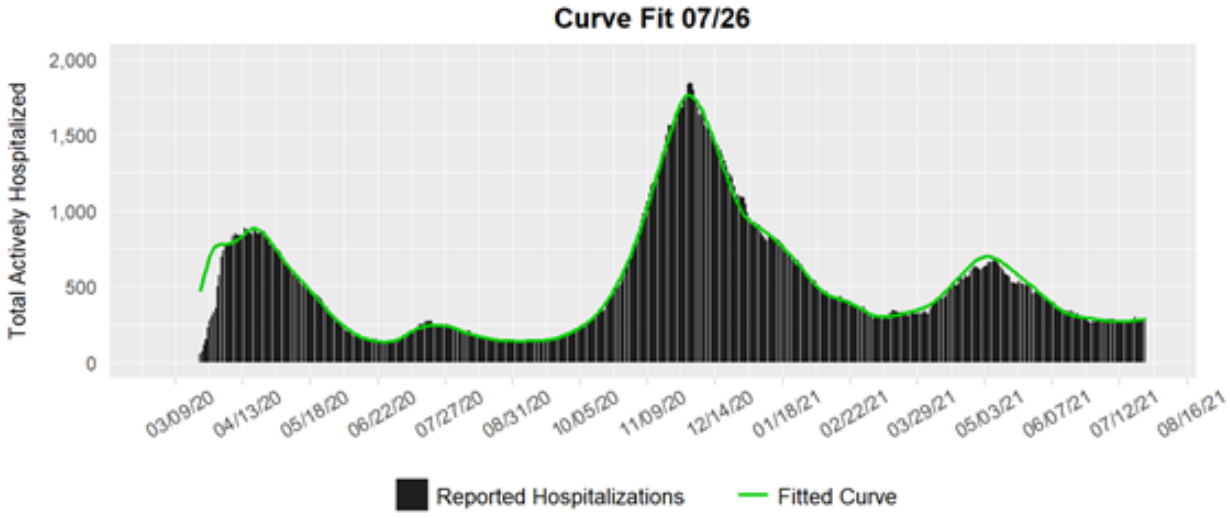


Figure A7. Current model fit (green line) to the count of hospitalized COVID-19 cases (black lines) through 07/26 using the age-structured SEIR model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

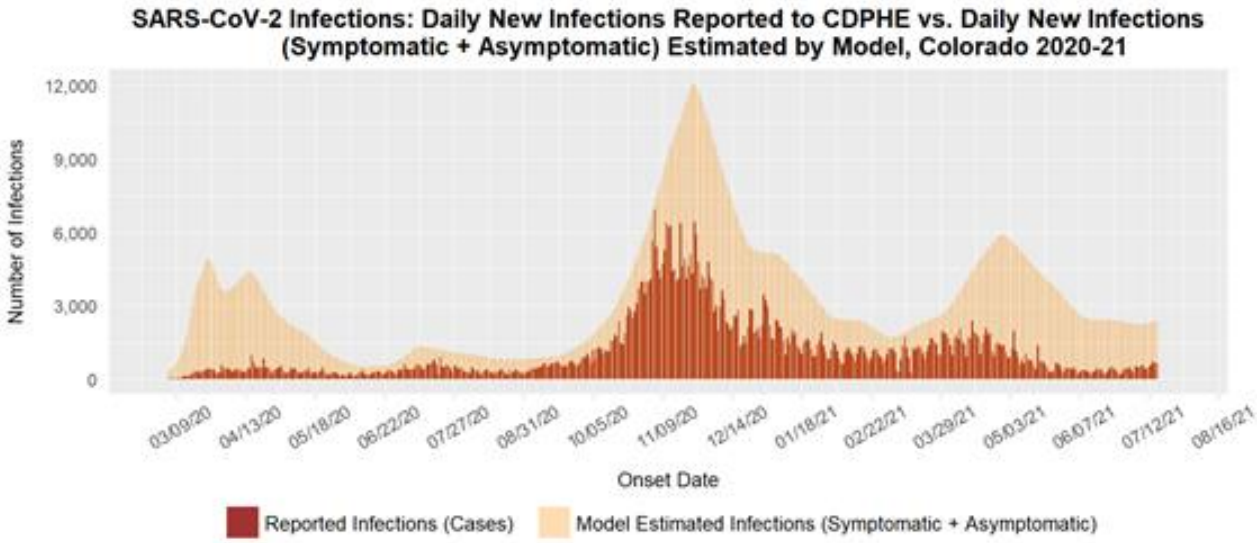


Figure A8. Estimated daily number of new (incident) SARS-CoV-2 infections based on the total estimated by the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown.