

The Current State of COVID-19 in Colorado

12/16/2020

Prepared by the Colorado COVID-19 Modeling Group

Colorado School of Public Health: Andrea Buchwald, Elizabeth Carlton, Debashis Ghosh, Irina Kasarskis, Jonathan Samet, Emily Wu; University of Colorado School of Medicine: Kathryn Colborn; University of Colorado-Boulder Department of Applied Mathematics: Sabina Altus, David Bortz; University of Colorado Denver: jimi adams; Colorado State University: Jude Bayham

For Contact: Jon.Samet@CUAnschutz.edu

Summary

- Transmission control continues to improve and is now at 82%, but December holidays are ahead.
- There is no evidence of a Thanksgiving bump, up to 18 days after the holiday.
- The effective reproductive number is below 1, but infection prevalence remains dangerously high.
- Infections are decreasing or flat in most LPHA regions across the state. The estimated effective reproductive number varies from 0.6 to 1.2. Infections are spreading most rapidly in the East Central region and continue to increase in the Northwest LPHA region. Infection prevalence remains high in most regions.
- On the current trajectory, hospital demand and cases will continue to decline, but it will be weeks before hospital demand and infection prevalence reach low levels, for example as low as during the summer. This declining trajectory could be reversed by holiday lapses. Potential peaks are lower than projected previously.

Snapshot of Current SARS-CoV-2 Transmission in Colorado Based on COVID-19 Hospitalization Data Through 12/14

Effective reproduction number: 0.73 (95% CI: 0.69, 0.78). *Infections are increasing.*

Estimated prevalence of infections: Approximately 1,700 (95% CI: 1,541, 1,718) of every 100,000 Coloradans or 1 in every 59 Coloradans are currently infectious. *The estimated infection prevalence is lower than last week.*

Estimated number of infections to date: An estimated 19.6% (95% CI: 19.5%, 19.7%) of the Colorado population has been infected to date.

Estimated current level of transmission control: 82% (95% CI: 80.7%, 83.2%) for the period of 11/21 to 12/01. *There is an approximate 82% reduction in total transmission-relevant contacts, including reductions due to mask-wearing, physical distancing, contact tracing, self-isolation, and all other policy and behavioral changes compared to uncontrolled transmission, as in the very early days of the pandemic.*

Snapshot of the Potential Future Trajectory of SARS-CoV-2 in Colorado

In the next two weeks: At the end of the next two weeks, there is a 50% chance that the count of patients hospitalized with COVID-19 will be at 1000, including 328 patients in the ICU, if we remain on the current trajectory at 82% transmission control.

Introduction

We used our age-structured SEIR (susceptible-exposed-infected-recovered) model and COVID-19 hospital census data to characterize the current status of the COVID-19 epidemic in Colorado and the collective impact of efforts to date to reduce the spread of the SARS-CoV-2 virus. We use these estimates of the current state of the epidemic to generate projections of the potential future course of SARS-CoV-2 in Colorado under different scenarios of transmission control measures. These include estimates of hospital needs over the next two weeks based on the current estimated trajectory, and long-term projections that consider the impact of changes in transmission control level due to policies and/or behaviors.

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. Further details and a link to model documentation are provided in the appendix at the bottom of this report. The estimates presented in this report are based on hospitalization data through **12/14**.

COVID-19 Hospitalizations

Figure 1 shows the daily number of people hospitalized with COVID-19 since March 2020, when the first case of SARS-CoV-2 was reported in Colorado. COVID-19 hospitalizations are a sensitive measure of SARS-CoV-2 transmission. While many SARS-CoV-2 infections are not captured by surveillance systems, we expect that almost all COVID-19 hospitalizations are identified.

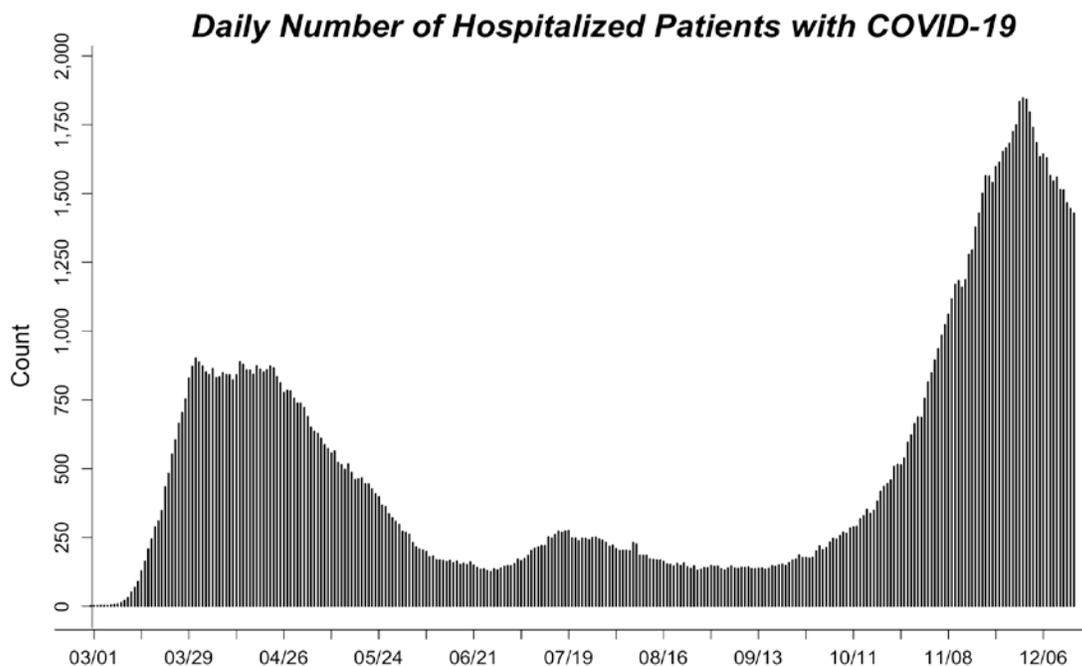


Figure 1 (above). Daily count of hospitalized COVID-19 cases through 12/14. The time series of COVID-19 hospitalizations in Colorado is based on hospitalization data provided by CDPHE through 4/07/2020 and the EMResource hospital census of COVID-19 hospitalizations starting 4/08/2020 (EMResource hospital census appeared to undercount COVID-19 hospitalizations before that date).

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. 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 (Figure 2).

Transmission control is estimated by fitting model output to hospitalization data using model fitting approaches.

Our current estimate of transmission control is 82% (95% CI: 80.7%, 83.2%). This estimate is for the period 11/21 to 12/01, given the timespan between infection and hospitalization.

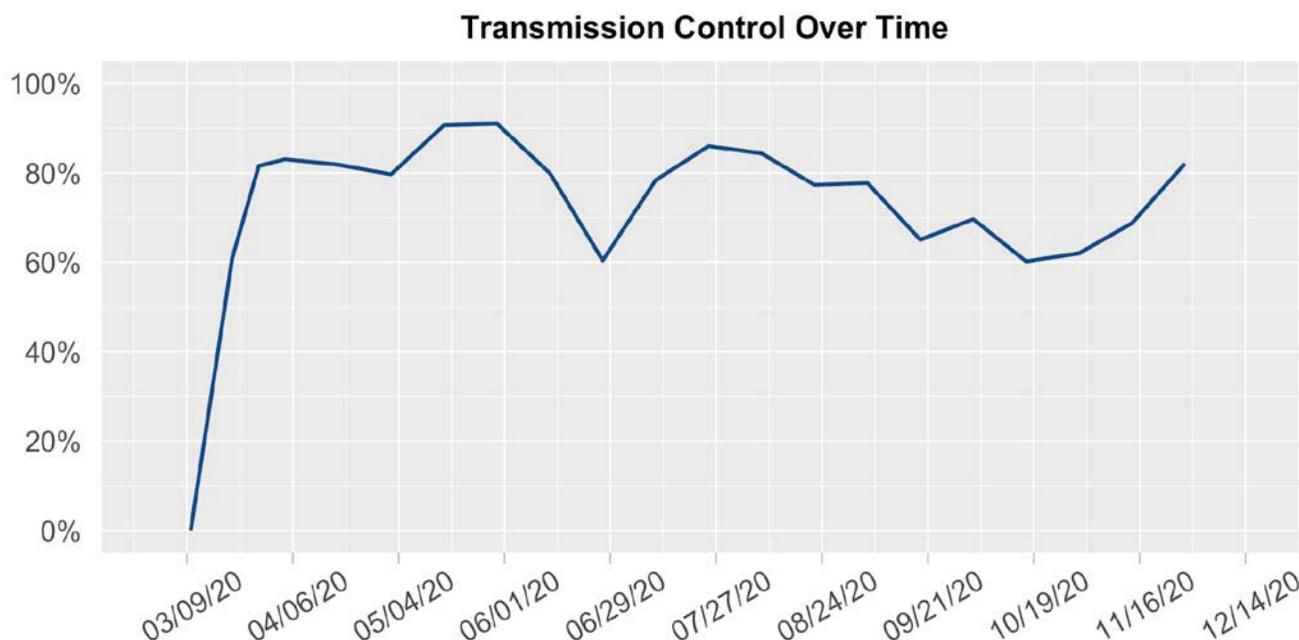


Figure 2 (above). The estimated transmission control value for each two-week period since the beginning of the epidemic. On the graph, the value is shown for the mid-point of each two-week period. Transmission control is estimated using model fitting approaches to align model output with COVID-19 hospitalizations.

Model Fit

We assess model fit by comparing the model-estimated number of hospitalizations to actual hospitalizations. Figure 3 shows 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. For reference, a line showing the estimated trajectory one-week prior is also shown.

A figure showing model fit since the beginning of the pandemic is provided in the appendix.

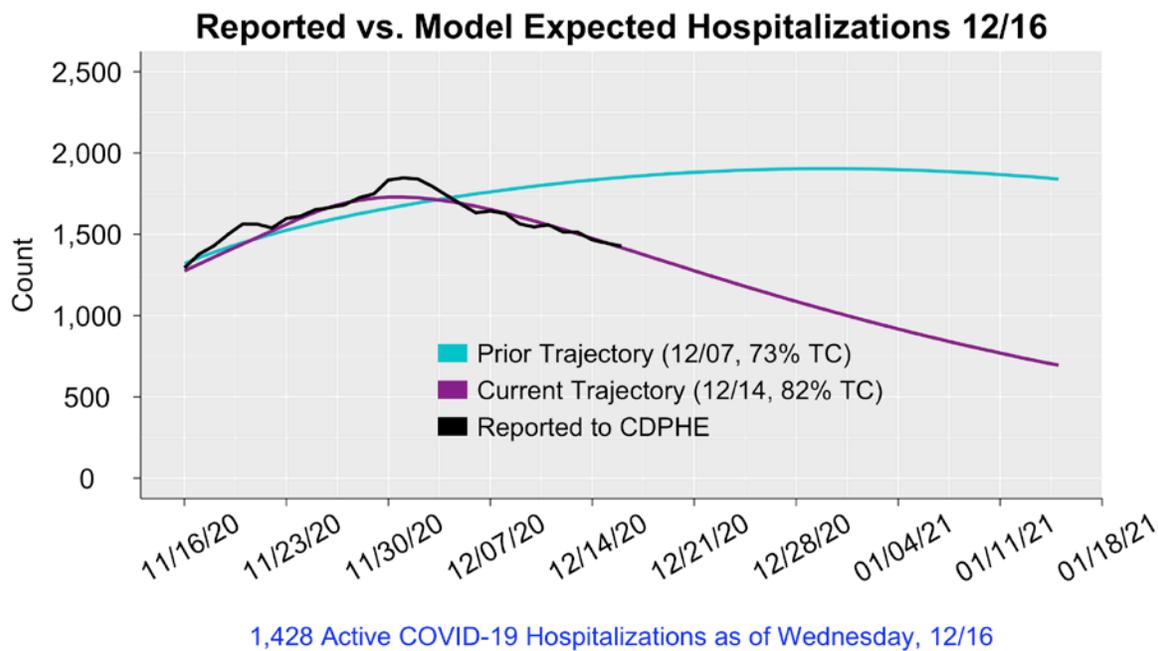


Figure 3 (above). The projected course of COVID-19 hospitalizations if Colorado were to remain on the current estimated trajectory (purple line) or on the trajectory estimated one week prior (turquoise line). Each trajectory is generated assuming transmission control remains at the current or one-week prior estimate.

The Effective Reproduction Number

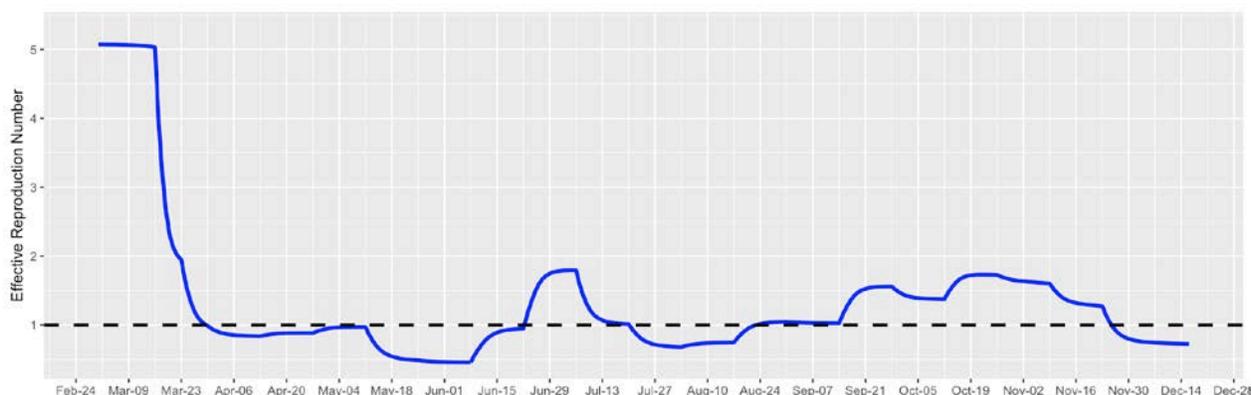
The effective reproduction number (R_e) is a measure of how rapidly infections are spreading or declining. When the effective reproduction number is below 1, infections are decreasing. When the effective reproduction number is above 1, infections are increasing. The effective reproduction number is estimated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

Our current estimate of R_e is 0.73. Due to the lag between infections and hospitalizations, this estimate of R_e reflects the spread of infections occurring on approximately 12/01. The estimated values of the reproduction number since March are shown in Figure 4 and the most recent three estimates are presented in Table 1.

Table 1 (below). Estimates of the effective reproduction number (R_e) in Colorado over the last three weeks based on the SEIR model. We also include estimates from RT-Live, an external source that calculates the reproductive number using reported SARS-CoV-2 cases and testing data.

	Current Estimate (12/14)	Estimate One Week Prior (12/07)	Estimate Two Weeks Prior (11/30)
Estimate of R_e , approach 1, TC model*	0.73 (0.69, 0.78)	1.05 (1.03, 1.08)	1.17 (1.12, 1.21)
Estimate of R_e , approach 2, TC model*	0.75	1.38	1.25
Estimate from RT-Live	1.03 (0.81, 1.24)	1.01 (0.76, 1.16)	1.04 (0.8, 1.21)

*Our estimates are based on hospitalization data through the date listed. Estimates from the external sites are extracted on the date listed. Due to the lag between infection and hospitalization, our estimates reflect transmission approximately 13 days prior to the date listed. Approach 1 uses model output to estimate the average number of new cases generated by existing cases, accounting for the latent period and duration of infectiousness. The second method uses the model structure to estimate the dominant eigenvalue for a matrix describing population flows across the model compartments.



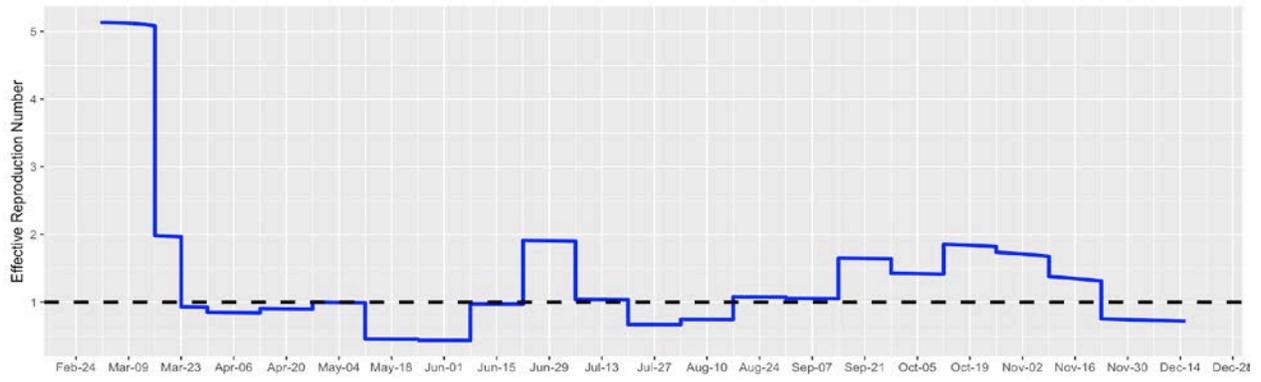


Figure 4 (above). Estimates of the effective reproduction number over time, using approach 1 (top) and approach 2 (bottom) based on the TC model.

Infection Prevalence

Infection prevalence provides an estimate of the proportion of the population that is currently (as of 12/14) 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 detected and not detected by the Colorado Electronic Disease Reporting System (CEDRS).

Infection prevalence is estimated using our age-structured SEIR model fit to hospitalization data. These estimates are generated by assuming the most recent transmission control parameter (estimated for the period 11/21 to 12/01) remains at the estimated value through 12/14. 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 over time; we assume that all variables vary by age category.

We estimate that there are approximately 98,200 (95% CI: 90,000, 993, 100,000) infectious individuals in Colorado at present (12/14): approximately 1,700 (95% CI: 1,540, 1,720) of every 100,000 Coloradans or 1 in every 59 people (95% CI: 58, 65).

Figure 5 illustrates the estimated infection prevalence over time in comparison to the number of hospitalized COVID-19 patients. Because, on average, COVID-19 patients are spending less time in the hospital now than at the start of the pandemic, more infections are estimated per hospitalized COVID-19 patient now compared to March when stays were substantially longer.

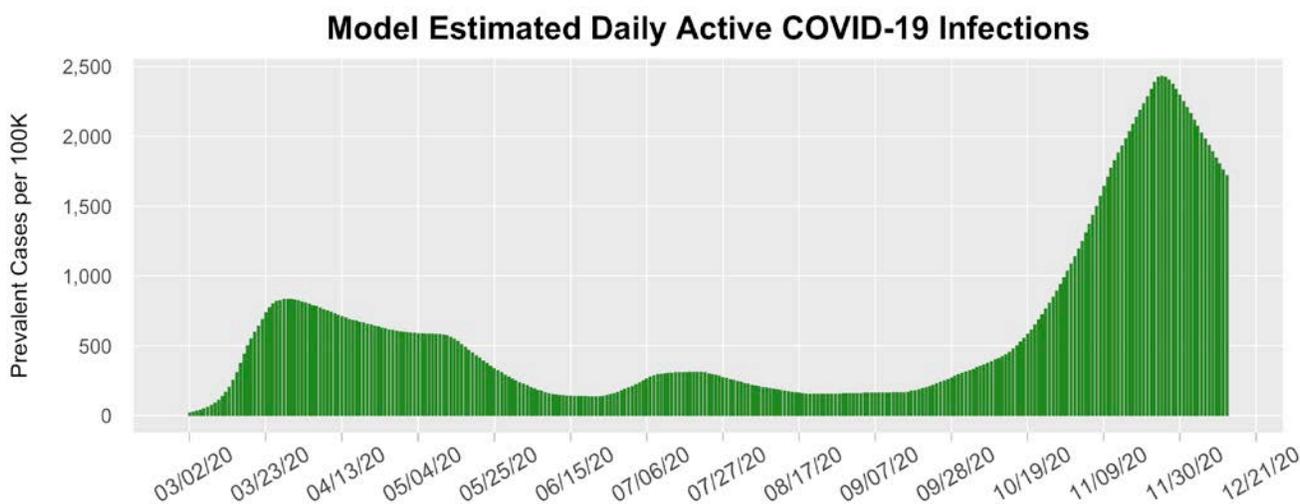


Figure 5 (above). Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and based on hospitalizations.

Case Detection

Comparing observed to model-estimated infections, **we estimate that approximately 27% of infections were detected by state surveillance systems, including both asymptomatic and symptomatic infections in the two week period from 11/21 to 12/04 (Figure 6).**

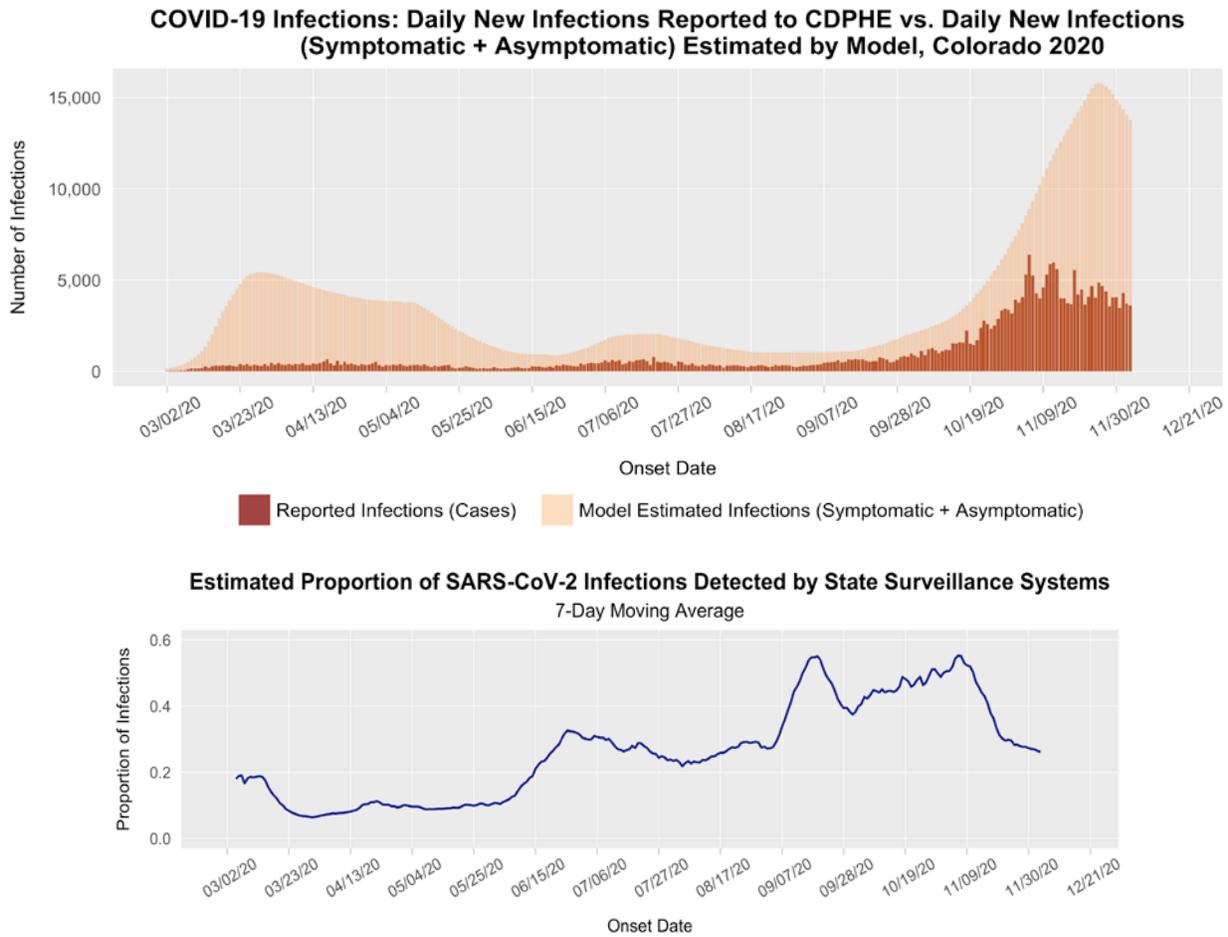


Figure 6 (above). Estimated daily number of new (incident) SARS-CoV-2 infections based on the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown in the top panel. Lower panel shows the 7-day moving average of the estimated proportion of SARS-COV2 infections that are being captured by Colorado state surveillance systems, over time. The proportion detected is estimated by dividing the total number of new cases captured by state surveillance systems by the model-estimated number of new infections each day. The number of cases captured by the state surveillance systems is the number of cases reported by CDPHE, using the onset date of symptoms (if onset date is not available, onset date is imputed by CDPHE using a proxy distribution of recent onset dates). Data are shown through 12/04 to account for typical lags between symptom onset and case report.

Cumulative Infections

As more people develop immunity, due to vaccination or prior infection, the spread of infections slows because infectious individuals are less likely to encounter individuals who are still susceptible to infection. The estimated cumulative number of infections provides an estimate of the percent of the population that may be immune, although we still do not know how long immunity lasts after an infection. As a vaccine becomes available and our understanding of SARS-CoV-2 immunity changes, these estimates will be updated.

The cumulative number of infections is estimated using our age-structured SEIR model fit to hospitalization data. As with our prevalence estimates, these estimates are generated by assuming the most recent transmission control parameter estimate remains at the estimated value through 12/14. These estimates are sensitive to model assumptions, including assumptions about the probability an infected individual will be symptomatic and require hospital care, as well as assumptions about length of hospital stay, which varies over time; all of the above are variables that we assume vary by age.

We estimate that 1,140,000 (95% CI: 1,140,000, 1,150,000) people in Colorado, or 19.6% (95% CI: 19.5%, 19.7%) of the population, have been infected to date (12/14).

Reported Infections and Hospitalizations by Age and Race/Ethnicity

Like many infectious diseases, COVID-19 is not equally distributed across the population. Some groups may face higher exposures and/or more severe health effects. We use reported case and hospitalization data provided by CDPHE to examine the distribution of infections and hospitalizations by age group, as well as by race and ethnicity. Age groups are defined to align with the four age groups used in the model.

Reported SARS-CoV-2 Cases by Age Group. Figure 7 shows the 7-day moving average of reported new SARS-CoV-2 infections by age group.

People under age 40 account for 52% of reported SARS-CoV-2 cases in the last two weeks (11/23 to 12/07).

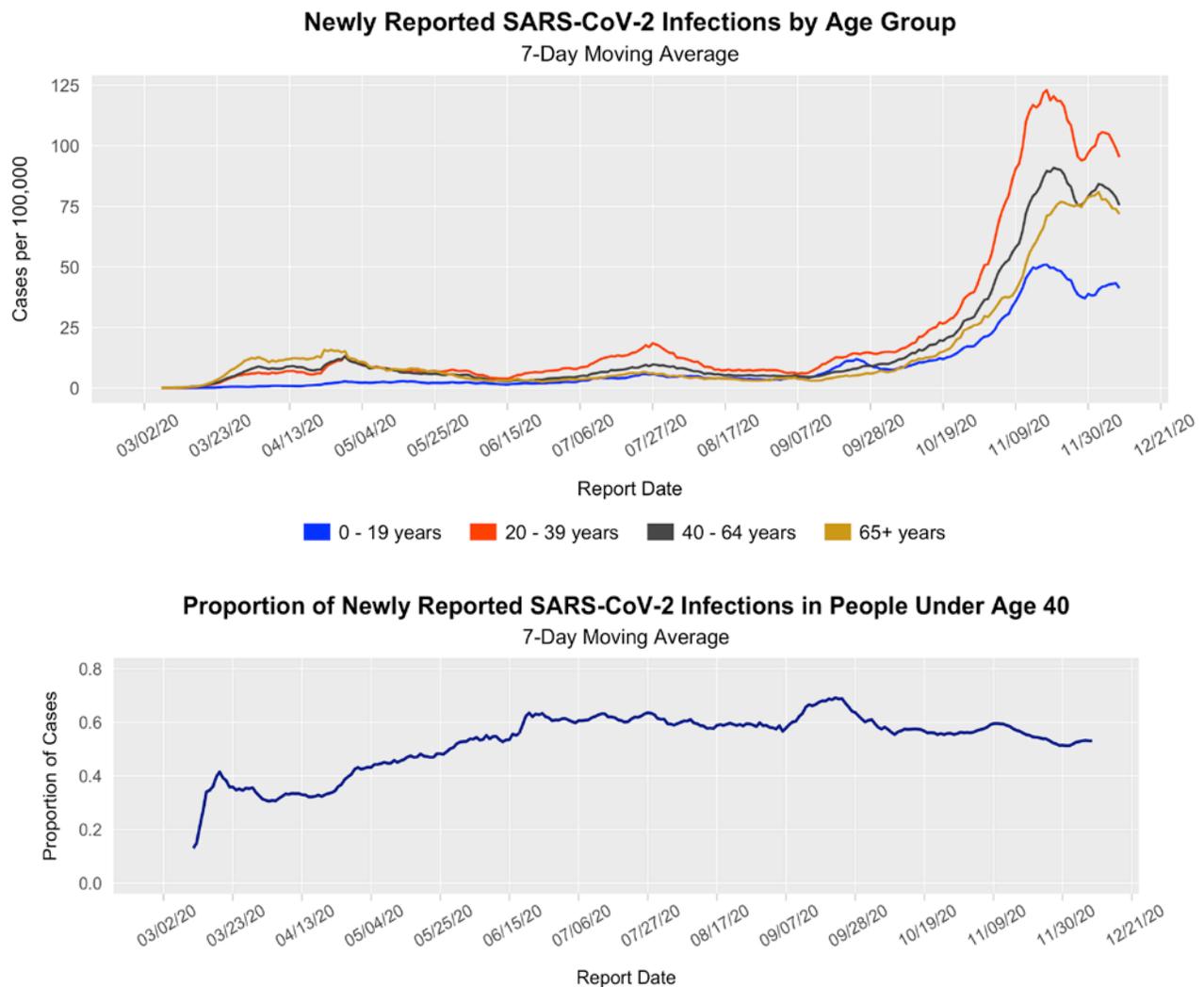


Figure 7 (above). Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by age group (top) and the proportion of all cases among individuals under 40 (bottom). Reported cases are based on CDPHE data and shown by report date. Incident cases per 100,000 were obtained by standardizing weekly reported age-specific case and hospitalization counts to the Colorado population distribution by age, gathered from the Colorado Census 2020 estimates. Data are shown through 12/07, to account for typical lags in collection of age data for reported cases.

COVID-19 Hospitalizations by Age Group. Figure 8 shows the daily count of individuals hospitalized with COVID-19 by age group from March through the present, based on COVID Patient Hospitalization Surveillance (COPHS) provided by CDPHE. Due to lags in reporting, COPHS data include hospitalizations through 12/09.

People under age 40 account for **10%** of COVID-19 hospital use over the last two weeks (11/26 to 12/09).

People age 40 to 64 account for **35%** of COVID-19 hospital use over the last two weeks.

People age 65+ account for **55%** of COVID-19 hospital use over the last two weeks.

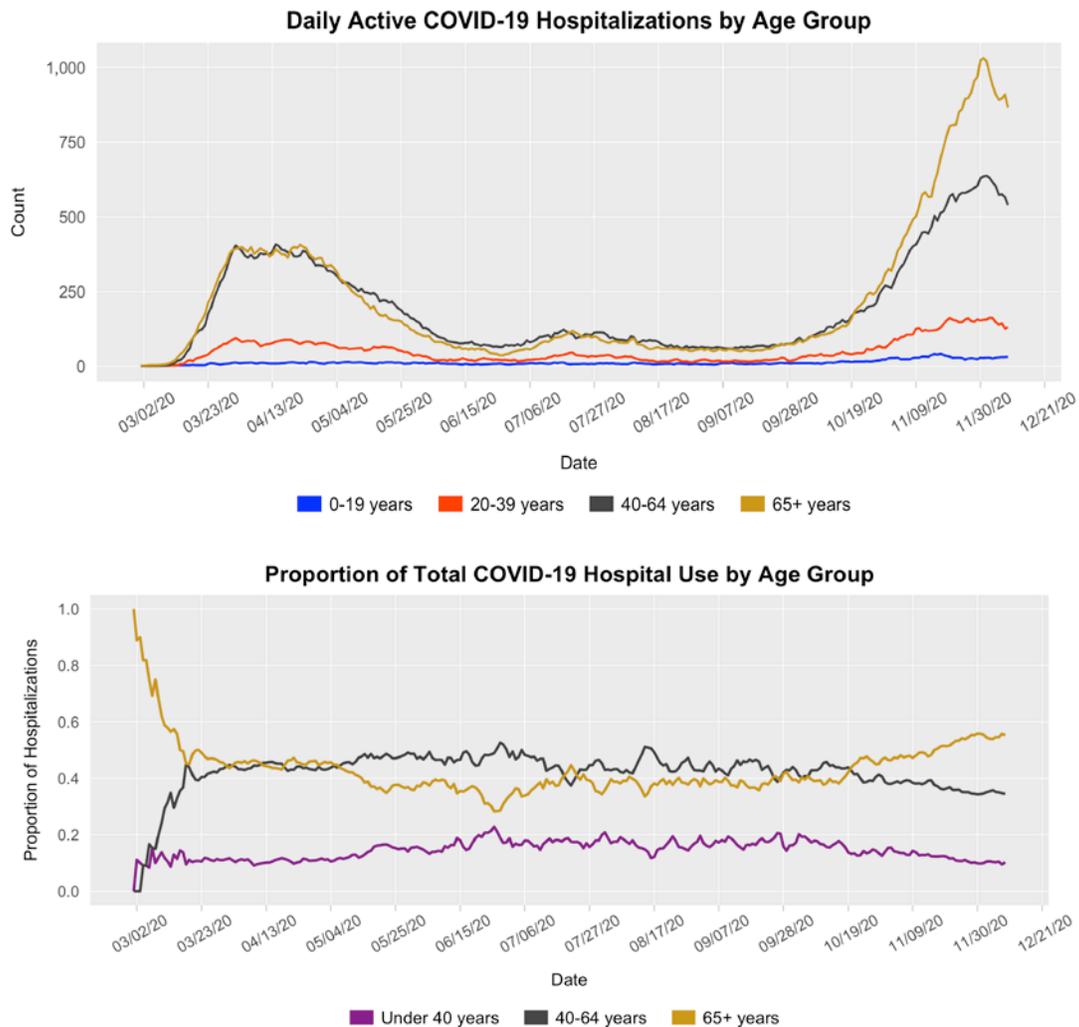


Figure 8 (above). The number of individuals hospitalized with COVID-19 by age group from March through the present (top) and the proportion of COVID-19 hospital beds occupied by individuals under 40 years, 40-64 years, and 65+ years (bottom). Data based on COVID Patient Hospitalization Surveillance (COPHS) through 12/09.

COVID-19 Reported Cases by Race/Ethnicity. Figure 9 shows the number of reported cases by race/ethnicity from March through the present.

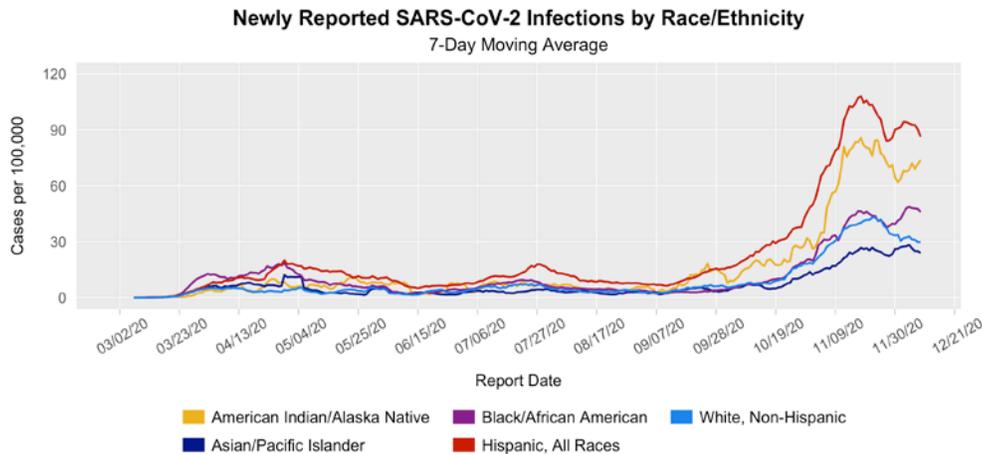


Figure 9 (above). Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by race and ethnicity in Colorado. Reported cases are based on CDPHE data and shown by report date. Cases per 100,000 were obtained by standardizing weekly reported race-specific case counts to the race/ethnicity distribution of the state of Colorado gathered from the CDPHE COVID-19 Case Summary Dashboard. These standardized estimates combine Asian and Native Hawaiian/Pacific Islander races and exclude Other/Unknown races (which account for **33%** of observations over the last two weeks). Data is shown through 12/07 to account for lags in collection of race/ethnicity data for reported cases.

Estimating Transmission Control Behaviors by Age

Due to the variation in behavior by age and the increase in cases seen among younger age groups, we estimate how transmission control varies by age group. We use CEDRS case data presented in Figure 7 to fit age-group specific levels of transmission control. We make the following assumptions about detection rate: We take the probability of detection from the overall model (calculated by comparing daily model estimated infections to reported infections (Figure 10) as a time series (daily time-step) and fit observed CEDRS case data to age-specific estimated infections over time. To account for age-specific differences in detection rate, we fit parameters for age-differences in detection rate to hospitalization data and then refit the TC parameters to case data.

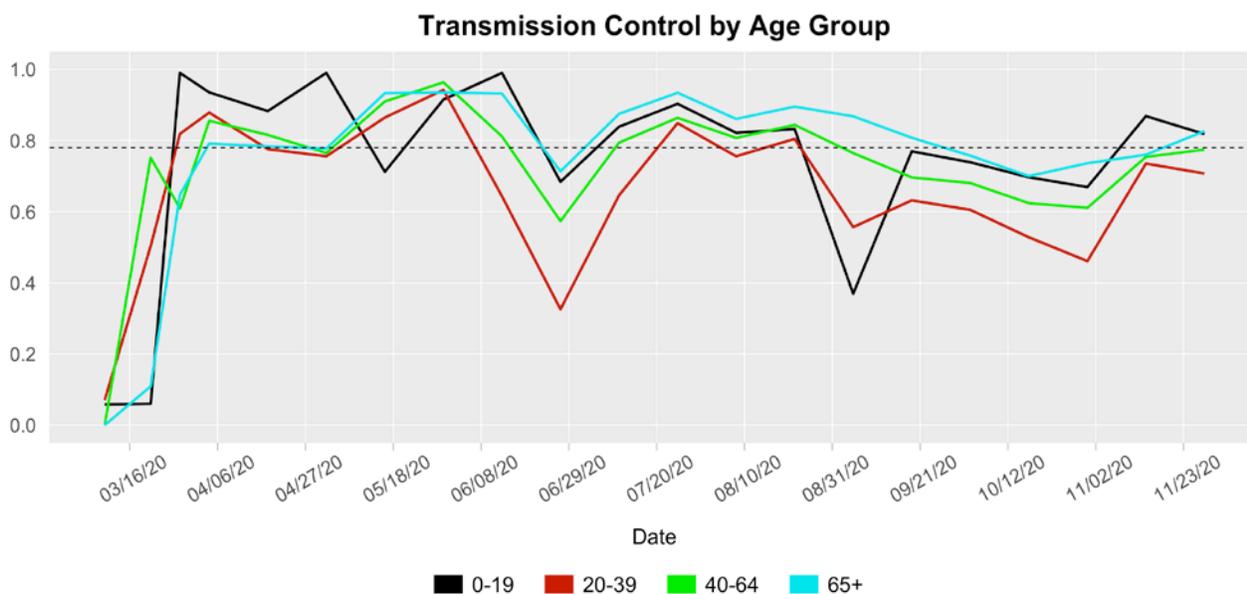


Figure 10 (above). Estimates of transmission control by age plotted over time. Transmission control values are plotted at the midpoint of the corresponding time period. As the last period for which transmission control is estimated is 11/21-12/01, the point on the graph is plotted at 11/26. Grey dashed line indicates threshold value of transmission control = 78%.

Near-Term Forecast

We generated estimated hospital and ICU demand over the next two weeks assuming Colorado remains on the current trajectory and accounting for uncertainty in our current estimated trajectory (Figure 11). **In two weeks on December 29, there is a 50% chance that at least 1,000 patients will be hospitalized with COVID-19, including 328 patients in the ICU, if we remain on the current trajectory.**

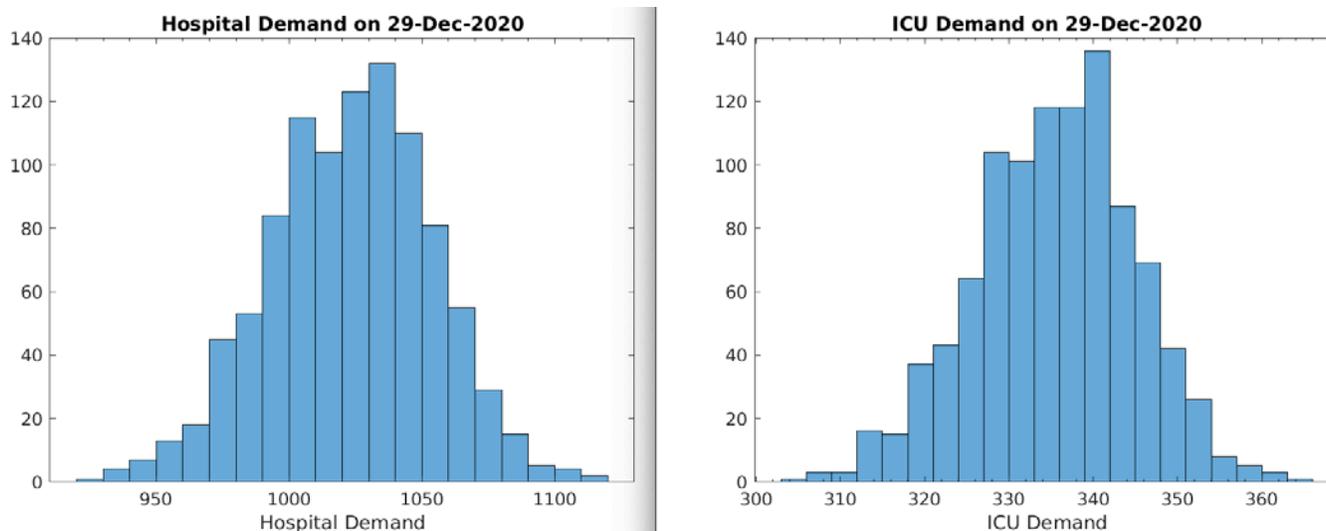


Figure 11 (above). Estimated number of hospitalized COVID-19 patients (left) and COVID-19 patients requiring ICU care (right) in two weeks if we remain on the current trajectory. These estimates are based on 10,000 simulated runs of the model, with 1,000 of those runs randomly selected for visualization.

Long-Term Projections

We generate projections of future hospital and ICU demand under the following scenarios:

- **Scenario 1.** Colorado remains on the current trajectory (82% TC) as shown in Figures 12 and 13.
- **Scenario 2.** Colorado shifts to 70% and 60% transmission control (TC) on Friday, 12/18 and remains at those levels indefinitely as shown in Figure 14.
- **Scenario 3.** Colorado remains on the current trajectory (82% TC), but there are increases in contacts over the holidays as shown in Figure 15. Because we do not yet know how much contacts may change over the holidays, we run simulations for a range of changes – from a 10% to a 30% absolute increase in contacts during the holidays. In these scenarios, transmission control decreases to 72%, 62% or 52% between 12/24/2020 and 01/02/2021.

In each of these scenarios, we first evaluate the potential hospital demand in the weeks ahead. We then examine the estimated changes in infection prevalence.

A note about uncertainty. This section includes projections based on the scenarios outlined above, not predictions. There is considerable uncertainty about how policies and behaviors over the last few weeks will influence the course of the epidemic in the weeks ahead. In addition, incomplete understanding of the virus creates uncertainty. For example, if immunity wanes in the months after infection, the magnitude of the peaks may be higher than shown in these scenarios – particularly in the 70% and 60% scenarios where the timing of the peak depends on reaching herd immunity. It is possible that care demand peaks sooner, or later and with greater magnitude, depending on policy, behaviors, and immunity. While the projections are shown through 2021, the course in 2021 is highly uncertain at present.

Hospital Demand on the Current Trajectory (Scenario 1)

Figure 12 and Table 2 show estimated hospital demand if Colorado remains on the current trajectory without an increase in contacts over the holidays. Figure 13 shows the range of estimated hospital demand in four weeks, on 1/12/2021, for this scenario. These projections show a decrease in hospital and ICU demand in the weeks ahead.

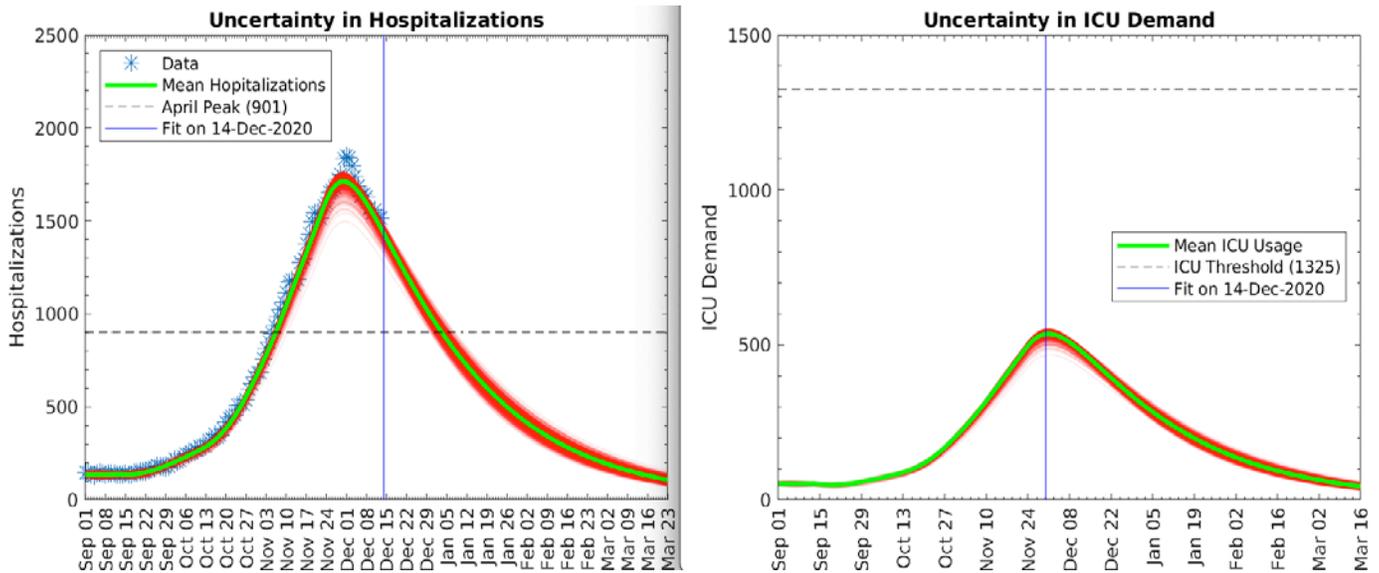


Figure 12 (above). Estimated number of hospitalized COVID-19 patients (left) and COVID-19 patients requiring ICU care (right) if Colorado remains on the current trajectory. Additional lines show the range of uncertainty in the projection. These estimates are based on 10,000 simulated runs of the model, with 1,000 of those runs randomly selected for visualization. The red band around the mean provides an indication of uncertainty.

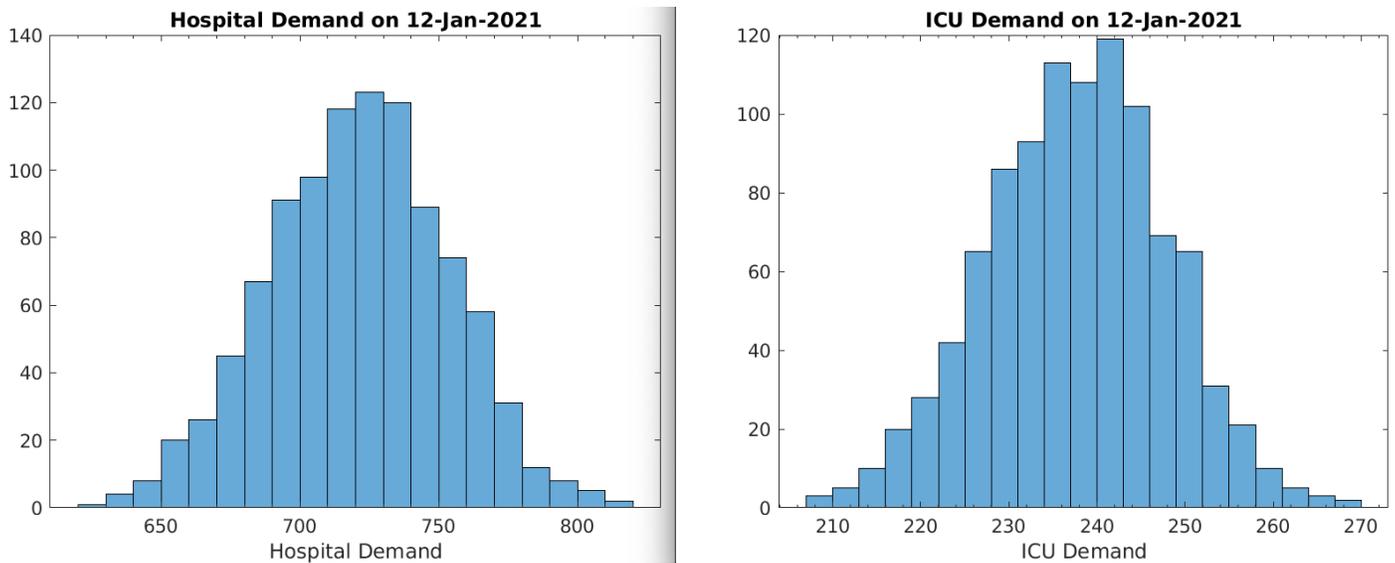


Figure 13 (above). Probability distribution of the number of hospitalized COVID-19 patients (left) and COVID-19 patients requiring ICU care (right) in four weeks if Colorado remains on the current trajectory. These estimates assume contacts do not increase over the holidays. These estimates are based on 10,000 simulated runs of the model, with 1,000 of those runs randomly selected for visualization.

Hospital Demand if Transmission Control Decreases to 70% or 60% (Scenario 2)

Figure 14 and Table 2 show estimated hospital demand if transmission control decreases to 70% or 60% on Friday, 12/18, compared to remaining on the current trajectory. If transmission control drops to 70% or 60%, hospital demand is projected to increase. If transmission control decreases to 60%, the state is projected to come close to ICU capacity and exceed the recent peak in demand.

Long Term Projections with Immediate Changes to Transmission Control

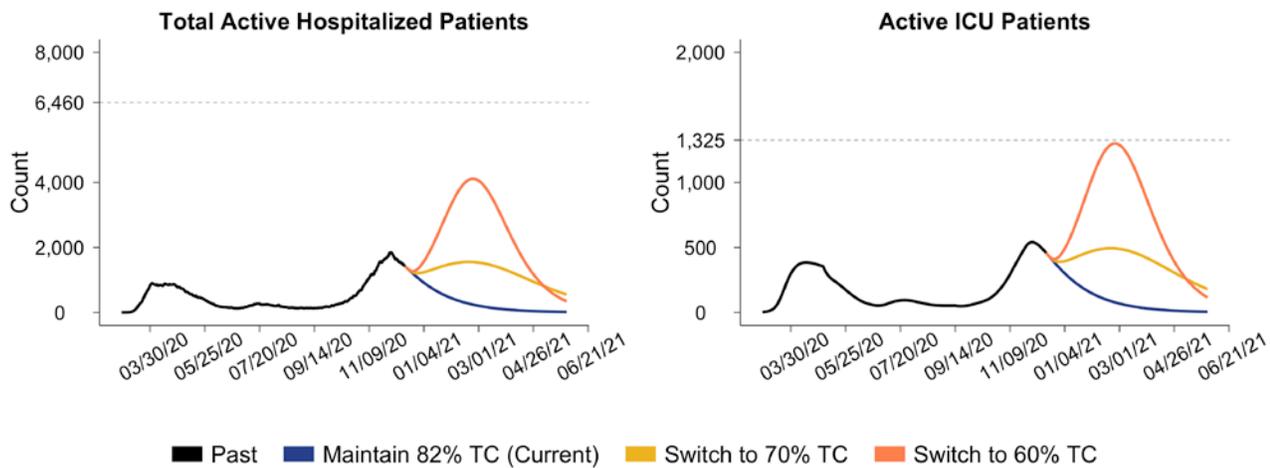


Figure 14 (above). Projected daily total number of patients actively hospitalized for COVID-19 (left) and active COVID-19 ICU patients (right), assuming transmission control remains at current levels (82%) indefinitely as indicated by the blue line. This scenario also features a transition to 70% TC (yellow line) and 60% TC (orange line) indefinitely beginning Friday, 12/18. Horizontal dashed lines indicate capacity limits for all hospitalizations (6,460 med/surg beds available for COVID-19 patients) and critical care (1,325 ICU beds available for COVID-19 patients). Figures on hospital capacity limits are provided by CDPHE.

Hospital Demand if Transmission Control Decreases Over the Holidays (Scenario 3)

Figure 15 and Table 2 show estimated hospital demand if transmission control decreases by 10, 20 or 30% (to 72%, 62% or 52% TC) over the winter holidays, from 12/24/2020 to 01/02/2021 and then returns to current levels of transmission control after the holidays. Under these scenarios, hospital demand is projected to increase under the 20% and 30% lapse scenarios.

Long Term Projections with Lapse in TC Over the Winter Holidays

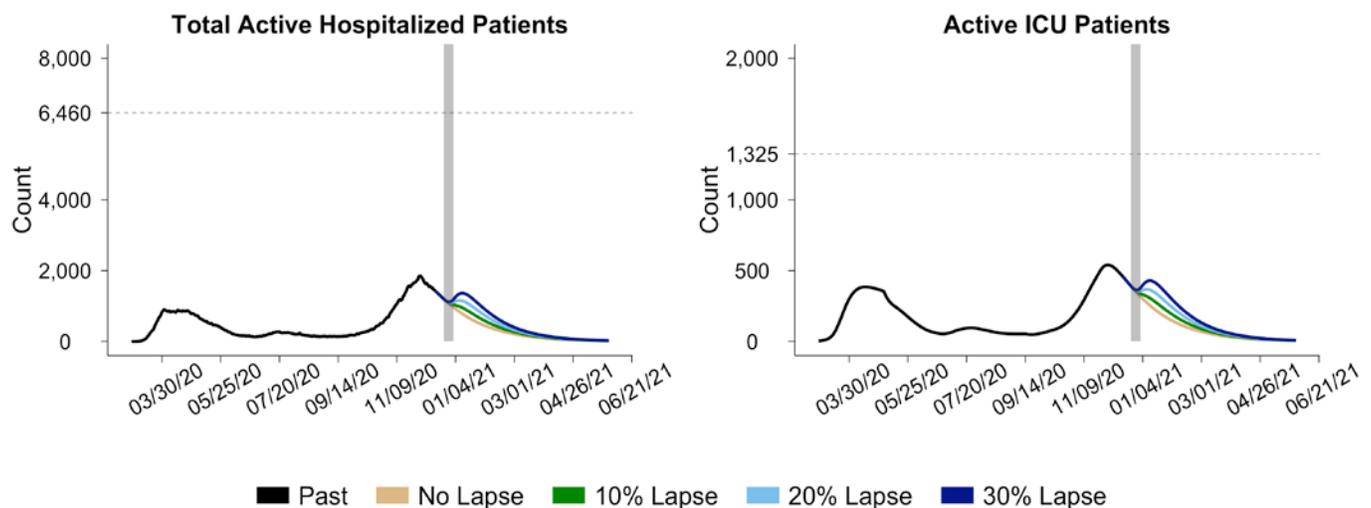


Figure 15 (above). Projected daily total number of patients actively hospitalized for COVID-19 (left) and active COVID-19 ICU patients (right), assuming transmission control remains at the current level (82%) as indicated by the beige line. This scenario also explores a brief 10% lapse in TC from 82% to 72% as indicated by the green line, a brief 20% lapse in TC from 82% to 62% as indicated by the light blue line, and a brief 30% lapse in TC from 82% to 52% as indicated by the dark blue line over the Christmas holiday period (12/24 to 1/2/2021). This time period is

represented by the grey shaded region on the graph. At the end of a lapse period, TC is assumed to return to the level of TC held previously before the lapse began, i.e., 82%. Horizontal dashed lines indicate capacity limits for all hospitalizations (6,460 med/surg beds available for COVID-19 patients) and critical care (1,325 ICU beds available for COVID-19 patients). Figures on hospital capacity limits are provided by CDPHE.

Table 2 (below). Comparison of the projected date that ICU surge capacity is reached, the date that ICU demand peaks, the estimated number of ICU beds needed at the peak, and the cumulative COVID-19 deaths at different levels of transmission control.

	Date ICU Capacity Reached*	Date of ICU Peak	ICU Need at Peak	Cumulative Cases Through 12/31/2020**	Cumulative Deaths Through 12/31/2020**
Maintain 82% TC (Current)	N/A	12/2/20	past	1,370,000	4,750
Switch to 70% TC on Fri 12/18	N/A	12/2/20	past	1,440,000	4,790
Switch to 60% TC on Fri 12/18	N/A	2/24/21	1,300	1,510,000	4,840
Current + No Holiday Lapse	N/A	12/2/20	past	1,370,000	4,750
Current + 10% Holiday Lapse	N/A	12/2/20	past	1,390,000	4,750
Current + 20% Holiday Lapse	N/A	12/2/20	past	1,420,000	4,760
Current + 30% Holiday Lapse	N/A	12/2/20	past	1,450,000	4,770

*ICU bed capacity for COVID-19 patients is estimated to be 1,325 in Colorado, a figure provided by CDPHE.

**Estimates are rounded to three or two significant figures.

When Will Infection Prevalence Return to Prior Levels?

In order to facilitate decision-making around policy changes such as the reopening of businesses to full occupancy, we estimated the projected prevalence of active COVID-19 infections through May 2021, assuming we remain on the current trajectory (Scenario 1). Figure 16 shows that if we remain on the current trajectory, infection prevalence will decline rapidly. However, since infection prevalence is currently so high, contacts will remain risky in the weeks ahead. On the current trajectory, infection prevalence will fall below the spring peak (836 per 100,000) on approximately 1/11/2021 and will reach the summer low point (138 per 100,000) on approximately 3/18/2021. If transmission control drops in the weeks ahead, prevalence will decline more slowly.

Prevalence of Active COVID-19 Infections in Colorado

Full Timeline Projection

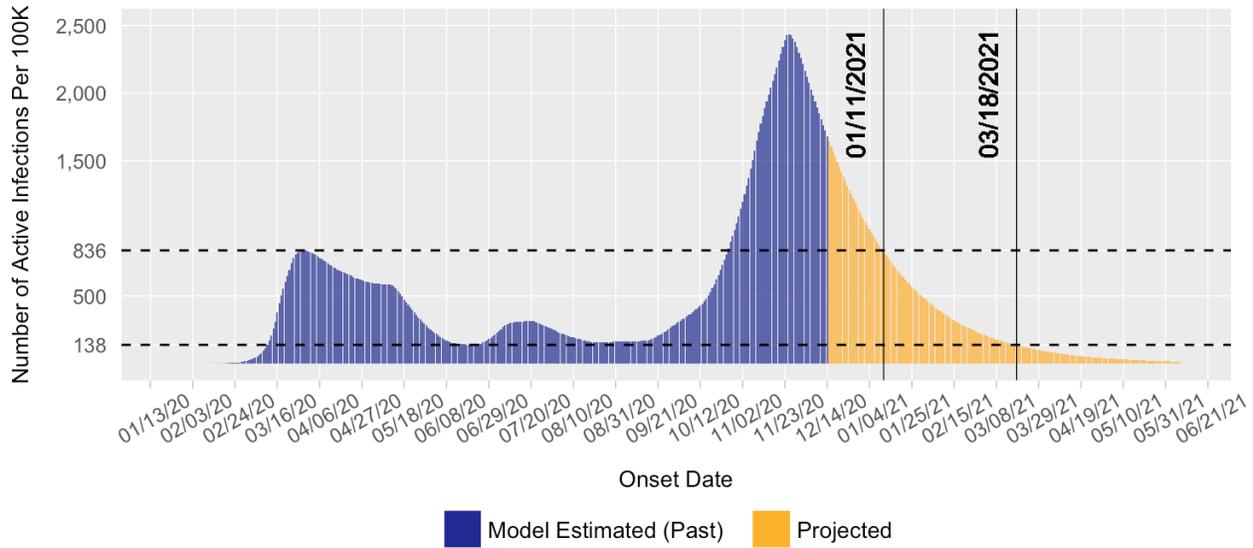


Figure 14 (above). Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and estimates based on hospitalizations. Horizontal dashed lines indicate the spring peak (836 per 100K) and summer low point (138 per 100K). Vertical solid lines indicate the approximate dates when projected infection prevalence will drop below these levels, assuming transmission control remains at the current value of 82%.

Table 3 (below). Estimated dates at which prevalence will dip below the spring peak (top row) and summer low point (bottom row) under assumptions of varying lapses in transmission control over the winter holiday period (12/24/2020 to 01/02/2021). The current trajectory (82%) is used as a reference trajectory and assumes no holiday lapse.

	Current Trajectory (No Holiday Bump)	10% Holiday Bump	20% Holiday Bump	30% Holiday Bump
Date prevalence declines to 836 per 100K (peak prevalence estimated for the first wave)	1/11/21	1/21/21	1/30/21	2/6/21
Date prevalence declines to 138 per 100K (low prevalence estimated for summer 2020)	3/18/21	3/26/21	4/1/21	4/5/21

Appendix

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/>

Model Fit

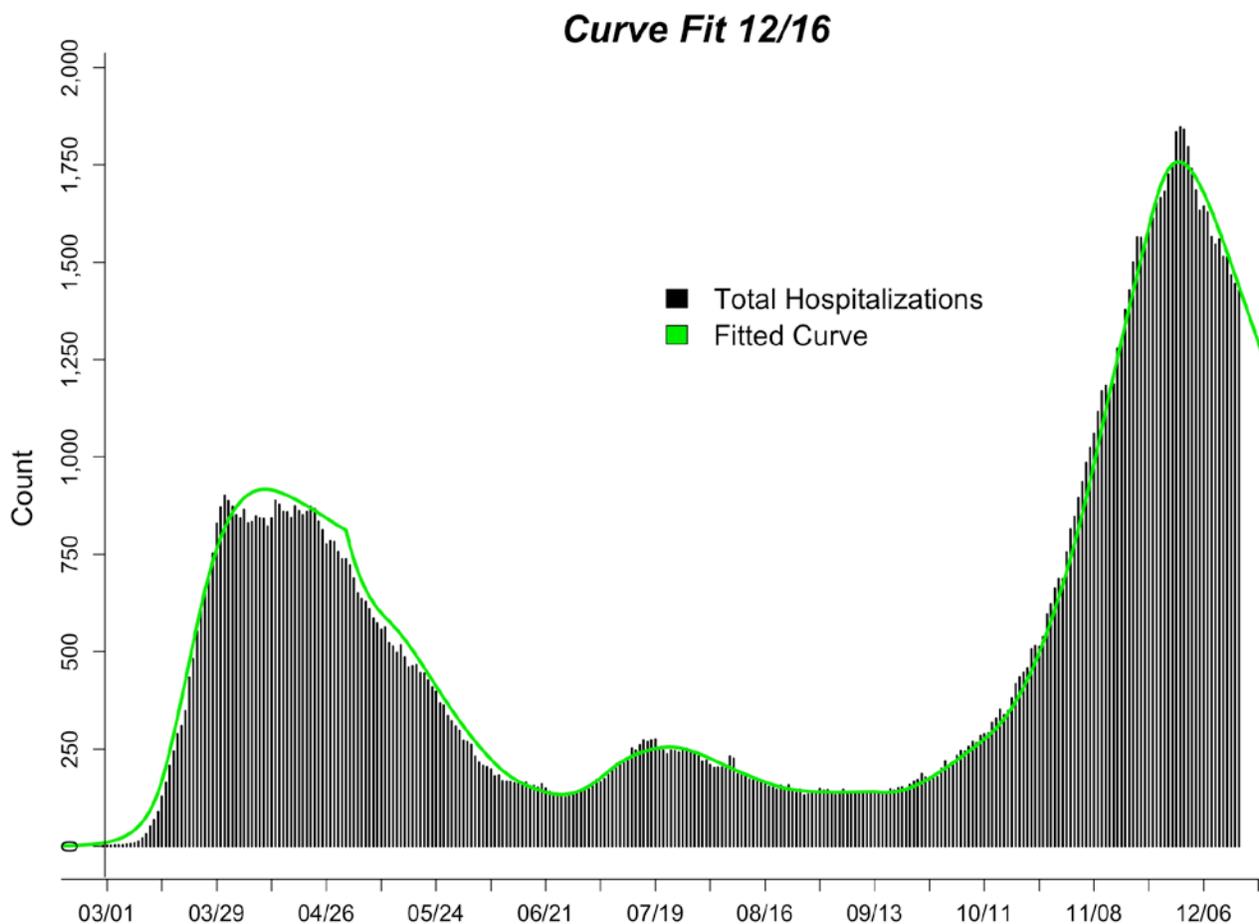


Figure A1 (above). Current model fit (green line) to the count of hospitalized COVID-19 cases (black lines) through 12/14 using the age-structured SEIR model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

Appendix Table A1 (below). Estimated model parameters based on fitting our model output of total hospitalizations to reported hospitalizations in Colorado. The new “TC” model includes a single transmission control parameter that accounts for all reduction in effective contacts as a result of all policy and behavior changes to reduce transmission.

	Range of Possible Values	Fitted Value from TC Model	Fit Using Data Through
Estimated current TC level for the period 11/21 to 12/01	0-99%	82% (95% CI: 80.7%, 83.2%)	12/14/20
Estimated TC level one week prior for the period 11/08 to 11/23	0-99%	73% (95% CI: 72.5%, 74.1%)	12/7/20
Estimated TC level two weeks prior for the period 11/01 to 11/21	0-99%	71% (95% CI: 69.7%, 72.1%)	11/30/20
The rate of infection (beta)	0.2 - 0.6**	0.48	6/24/20
Ratio of infectiousness for symptomatic vs. asymptomatic individuals (lambda)	1.0 - 4.0**	1.39	6/24/20

*Two-week transmission control parameters are estimated weekly and averaged over time period of interest.

The range of potential parameter values for the rate of infectiousness for symptomatic vs. asymptomatic individuals [1, 2] are based on the literature, and for the rate of infection, were obtained from the MIDAS Online COVID-19 compilation of parameter estimates [3].**

A Note on Immunity

There is currently considerable uncertainty about the duration of functional immunity in response to SARS-CoV-2 infection. Some longitudinal studies have documented high titers of functional antibodies in individuals recovered from infection as far out as six months post-infection [4-6], while other studies have documented high rates of seroreversion as early as 60 days [7, 8]. Despite growing evidence of incomplete or temporary immunity in some recovered COVID-19 patients, most transmission models currently assume complete and long-lasting immunity to SARS-CoV-2 reinfection. Here we demonstrate the impacts of varying assumptions about immunity in estimates of near-term COVID-19 hospital demand. Using our current SEIR model of SARS-CoV-2 transmission in Colorado, and given the current state of the pandemic, we show the impact of assuming temporary immunity on hospital demand in the coming weeks. For demonstration, we assume immunity lasts for an average of 360 days among individuals with symptomatic infection, and only 180 days among individuals with asymptomatic infections, who have been shown to produce less of an immune response [8-12]. We see, that under this assumption, the curve continues past the peak in the lifetime immunity assumption, peaking at 2,110 hospitalizations on January 5th compared to 2,010 on December 27th under a trajectory where TC = 73% starting 11/08. Thus, when we assume 6-month immunity for individuals with asymptomatic infection the projected peak is 5% higher than model estimates assuming durable immunity following all infections. If the duration of immunity is shorter, either among symptomatic or asymptomatic infections, the projected peak would be higher.

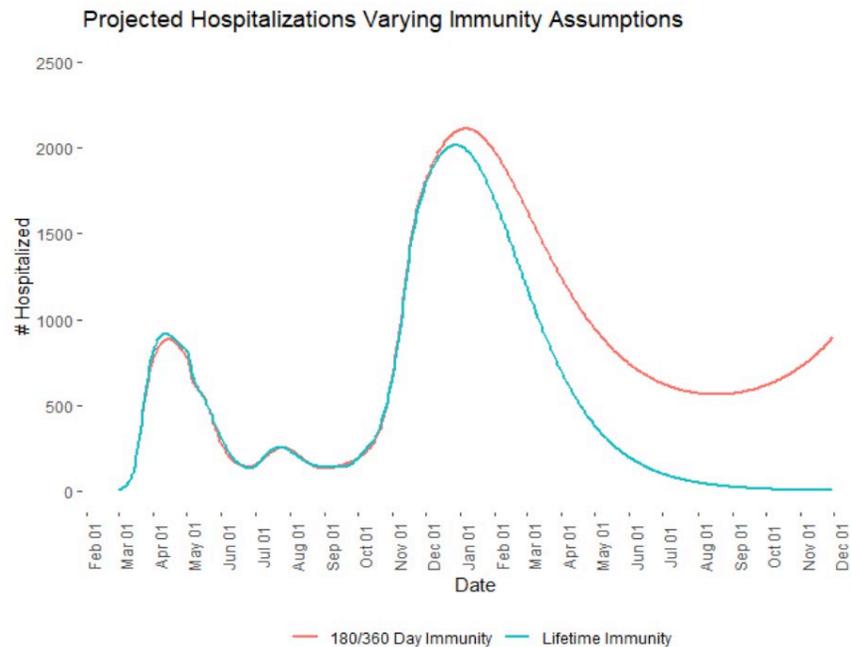


Figure A2 (above). Model projections of hospital demand comparing projections under the assumption that all people infected develop lifetime immunity (blue line) compared to the assumption that symptomatic individuals develop immunity for 360 days, and asymptomatic individuals develop immunity for 180 days.

References

1. Li R, Pei S, Chen B, Song Y, Zhang T, Yang W, et al. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV-2). *Science*. 2020;368(6490):489-93. Epub 2020/03/18. doi: 10.1126/science.abb3221. PubMed PMID: 32179701; PubMed Central PMCID: PMC7164387.
2. Zou L, Ruan F, Huang M, Liang L, Huang H, Hong Z, et al. SARS-CoV-2 Viral Load in Upper Respiratory Specimens of Infected Patients. *The New England journal of medicine*. 2020;382(12):1177-9. Epub 2020/02/20. doi: 10.1056/NEJMc2001737. PubMed PMID: 32074444; PubMed Central PMCID: PMC7121626.
3. MIDAS. MIDAS Online COVID-19 Portal 2020. Available from: https://github.com/midas-network/COVID-19/tree/master/parameter_estimates/2019_novel_coronavirus.
4. Wu J, Liang B, Chen C, Wang H, Fang Y, Shen S, et al. SARS-CoV-2 infection induces sustained humoral immune responses in convalescent patients following symptomatic COVID-19. *MedRxiv*. 2020.
5. Wajnberg A, Amanat F, Firpo A, Altman DR, Bailey MJ, Mansour M, et al. Robust neutralizing antibodies to SARS-CoV-2 infection persist for months. *Science*. 2020.
6. Dan JM, Mateus J, Kato Y, Hastie KM, Faliti C, Ramirez SI, et al. Immunological memory to SARS-CoV-2 assessed for greater than six months after infection. *bioRxiv*. 2020.
7. Seow J, Graham C, Merrick B, Acors S, Pickering S, Steel KJ, et al. Longitudinal observation and decline of neutralizing antibody responses in the three months following SARS-CoV-2 infection in humans. *Nature Microbiology*. 2020:1-10.
8. Self WH. Decline in SARS-CoV-2 Antibodies After Mild Infection Among Frontline Health Care Personnel in a Multistate Hospital Network—12 States, April–August 2020. *MMWR Morbidity and Mortality Weekly Report*. 2020;69.
9. Ibarondo FJ, Fulcher JA, Goodman-Meza D, Elliott J, Hofmann C, Hausner MA, et al. Rapid decay of anti-SARS-CoV-2 antibodies in persons with mild Covid-19. *New England Journal of Medicine*. 2020;383(11):1085-7.
10. Poland GA, Ovsyannikova IG, Kennedy RB. SARS-CoV-2 immunity: review and applications to phase 3 vaccine candidates. *The Lancet*. 2020.
11. Huang AT, Garcia-Carreras B, Hitchings MDT, Yang B, Katzelnick L, Rattigan SM, et al. A systematic review of antibody mediated immunity to coronaviruses: antibody kinetics, correlates of protection, and association of antibody responses with severity of disease. *medRxiv*. 2020:2020.04.14.20065771. doi: 10.1101/2020.04.14.20065771.