Letters

RESEARCH LETTER

Association of Stay-at-Home Orders With COVID-19 Hospitalizations in 4 States

In analyses of the effectiveness of response measures to the outbreak of coronavirus disease 2019 (COVID-19), most studies have used the number of confirmed cases or deaths. However, case count is a conservative estimate of the actual number of infected individuals in the absence of community-wide serologic testing. Death count is a lagging metric and insufficient for proactive hospital capacity planning. A more valuable metric for assessing the effects of public health interventions on the health care infrastructure is hospitalizations.[1] As of April 18, 2020, governors in 42 states had issued statewide executive "stay-at-home" orders to help mitigate the risk that COVID-19 hospitalizations would overwhelm their state's health care infrastructure. This study assessed the association between these orders and hospitalization trends.

Methods | In March 2020, we began collecting data on cumulative confirmed COVID-19 hospitalizations from each state's department of health website on a daily basis.[2] Among states issuing a statewide stay-at-home order, we identified states with at least 7 consecutive days of cumulative hospitalization data for COVID-19 (including patients currently hospitalized and those discharged) before the stay-at-home order date and at least 17 days following the order date. Because the median incubation period of COVID-19 was reported to be 4 to 5.1 days[3,4] and the median time from first symptom to hospitalization was found to be 7 days,[5] we hypothesized that any association between stay-at-home orders and hospitalization rates would become evident after 12 days (median effective date). States included in this sample were Colorado, Minnesota, Ohio, and Virginia. Among the 4 states meeting the inclusion criteria, the earliest date with data on hospitalizations was March 10. All states were observed through April 28. We fit the best exponential growth function to cumulative hospitalization data in each state for dates up to and including the median effective date of that state's stay-at-home order. We computed 95% prediction bands on the exponential fit line to determine if the observed number of hospitalizations fell within the interval. We then examined whether the observed cumulative hospitalizations for dates after the median effective date deviated from the projected exponential growth in cumulative hospitalizations. In an additional analysis, a linear growth function was fit to cumulative hospitalization data for dates up to and including the median effective date, and goodness of fit was assessed with an R^2 comparison. All analyses were performed using Microsoft Excel version 14.1.

Results | In all 4 states, cumulative hospitalizations up to and including the median effective date of a stay-at-home order closely fit and favored an exponential function over a linear fit (R^2 = 0.973 vs 0.695 in Colorado; 0.965 vs 0.865 in Minnesota; 0.98 vs 0.803 in Ohio; 0.994 vs 0.775 in Virginia) (**Table**). However, after the median effective date, observed hospitalization growth rates deviated from projected exponential growth rates with slower growth in all 4 states. Observed hospitalizations consistently fell outside of the 95% prediction bands of the projected exponential growth curve (**Figure**).

For example, Minnesota's residents were mandated to stay at home starting March 28. On April 13, 5 days after the median effective date, the cumulative projected hospitalizations were 988 and the actual hospitalizations were 361. In Virginia, projected hospitalizations 5 days after the median effective date were 2335 and actual hospitalizations were 1048.

Discussion | In 4 states with stay-at-home orders, cumulative hospitalizations for COVID-19 deviated from projected best-fit exponential growth rates after these orders became effective. The deviation started 2 to 4 days sooner than the median effective date of each state's order and may reflect the use of a median incubation period for symptom onset and time to

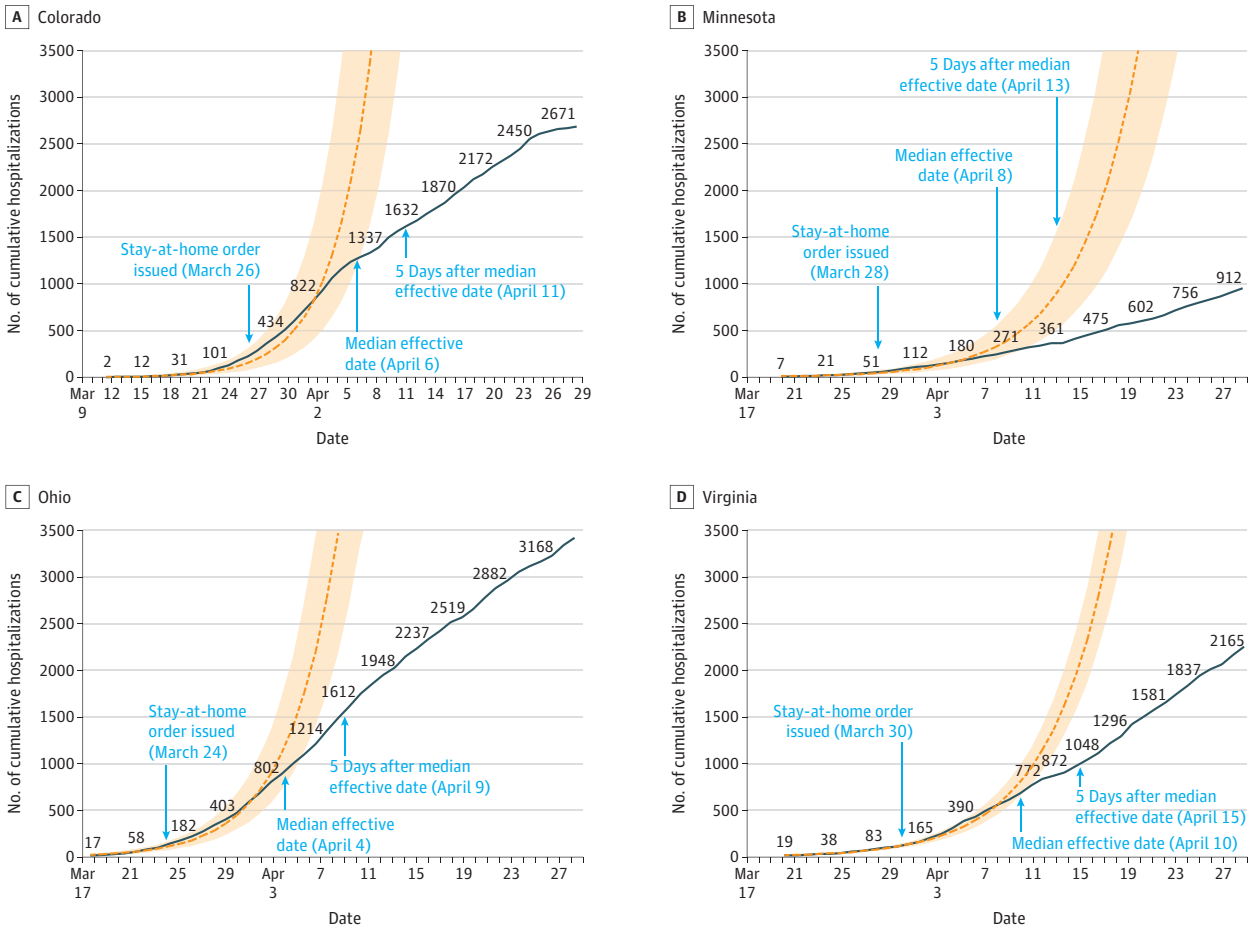
Table. Cumulative Hospitalizations Due to COVID-19 in Colorado, Minnesota, Ohio, and Virginia, March 10 Through April 28, 2020

State	Fitting period[a]	Stay-at-home issue date	Median effective date	Cumulative hospitalizations		Best exponential fit: ln(y) = ln(a) + bt			Linear fit: y = ct	
				On first day of reporting	On April 28	ln(a) (95% CI)	b (95% CI)	R^2	c (95% CI)	R^2
Colorado	March 10-April 6	March 26	April 6	2	2671	1.28 (1.02-1.54)	0.24 (0.22-0.25)	0.973	30.89 (25.28-36.5)	0.695
Minnesota	March 19-April 8	March 28	April 8	7	912	2.02 (1.8-2.24)	0.19 (0.17-0.21)	0.965	9.993 (8.86-11.12)	0.865
Ohio	March 17-April 4	March 24	April 4	17	3340	2.94 (2.75-3.13)	0.23 (0.21-0.24)	0.98	38.23 (32.78-43.67)	0.803
Virginia	March 19-April 10	March 30	April 10	19	2165	2.77 (2.69-2.85)	0.178 (0.172-0.184)	0.994	23.31 (19.74-26.9)	0.775

Abbreviation: COVID-19, coronavirus disease 2019.

[a] Fitting period consists of observed data from the first day of reporting up to and including the median effective date of the state's stay-at-home order.

Figure. Projected vs Observed COVID-19 Hospitalizations Before and After Stay-at-Home Orders, March 10 Through April 28, 2020



Blue lines indicate observed cumulative hospitalizations (including those currently hospitalized and those discharged) up to each day; select values are displayed for clarity. Dashed red lines begin on the first day of available reporting by each state and are the best-fit exponential curves for cumulative hospitalizations for the fitting period: first day of reporting up to and including the median effective date (panel A: $y = 3.5829 \exp(0.23599t)$, $R^2 = 0.9734$; B: $y = 7.521 \exp(0.1876t)$, $R^2 = 0.96445$; C: $y = 18.8482 \exp(0.2268t)$, $R^2 = 0.9798$; D: $y = 15.932 \exp(0.1397t)$, $R^2 = 0.99444$). Shaded regions indicate the 95% prediction bands of the exponential growth curves. Because the median incubation period of coronavirus disease 2019 (COVID-19) was reported to be 4 to 5.1 days[3,4] and the median time from first symptom to hospitalization was found to be 7 days,[5] it was hypothesized that any association between stay-at-home orders and hospitalization rates would become evident after 12 days (median effective date).

hospitalization to establish this date. Other factors that potentially decreased the rate of virus spread and subsequent hospitalizations include school closures, social distancing guidelines, and general pandemic awareness. In addition, economic insecurity and loss of health insurance during the pandemic may have also decreased hospital utilization. Limitations of the study include that these other factors could not be modeled in the analysis and that data on only 4 states were available.

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Accepted for Publication: May 13, 2020.

Published Online: May 27, 2020. doi:10.1001/jama.2020.9176

Author Contributions: Drs Sen and Karaca-Mandic had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: All authors.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: All authors.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: All authors.
Obtained funding: Sen, Karaca-Mandic.
Administrative, technical, or material support: Georgiou.

Conflict of Interest Disclosures: Dr Karaca-Mandic reported receiving personal fees from Tactile Medical, Precision Health Economics, and Sempre Health and grants from the Agency for Healthcare Research and Quality, the American Cancer Society, the National Institute for Health Care Management, the National Institute on Drug Abuse, and the National Institutes of Health. Dr Georgiou

reported receiving personal fees from HealthGrades. Dr Sen reported no disclosures.

Funding/Support: This research uses publicly available data from the University of Minnesota COVID-19 Hospitalization Project, which is partially funded by the University of Minnesota Office of Academic Clinical Affairs and United Health Foundation.

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Additional Contributions: Yi Zhu, MA, University of Minnesota Carlson School of Management, contributed to this project by launching the University of Minnesota COVID-19 Hospitalization Project website. Mr Zhu received no compensation for his contributions.

Additional Information: A preliminary plot of Minnesota's current hospitalization numbers (not cumulative hospitalizations) with data prior to April 15 was shared by the authors on Twitter and LinkedIn.

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