Supplement to: Anesi GL, et al. Perceived hospital stress, SARS-CoV-2 activity, and care process temporal variance during the COVID-19 pandemic

Appendices

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Appendix A. Severe acute respiratory infection (SARI) patient definition

For the purposes of the parent SARI-PREP study and the hospital stress survey, SARI patients were defined as patients presenting for acute care and being admitted to the hospital due to symptoms of lower respiratory tract infection and with presumed or laboratory-confirmed SARS-CoV-2 or influenza A or B infection. Symptoms of lower respiratory tract infection were defined as fever and cough and either (i) radiographic infiltrates on chest imaging, (ii) oxygen saturation (SpO2) < 94% on room air, (iii) new or increased supplemental oxygen requirement including any non-invasive ventilation or invasive mechanical ventilation. Due to very low numbers of SARI patients without SARS-CoV-2 infection during the pandemic,[1,2] the SARI patients that are the origin of the perceived stress reported in the hospital stress survey results can be interpreted as almost exclusively those with COVID-19.

Appendix B. Stress survey administration and data handling

The hospital stress survey asked about: the presence of stress in the hospital overall due to SARI patients including threats to patient safety (ordinal: "Has your hospital experienced significant stress due to patients with severe acute respiratory infections?"); the presence of stress specifically in the ED and ICU due to SARI patients (binary: "Has the Emergency Department/Intensive Care Unit(s) at your hospital experienced significant stress due to patients with severe respiratory infections?"); the need to operate differently (binary: "Have you had to do anything differently within the past week as a result of patient with severe acute respiratory infections?"); the presence of general and specific deviations in care delivery including in staffing numbers and ratios, elective surgeries, inter-hospital transfers, surge spaces, ED boarding, and limitations on care (binary); and the presence and degree of specific staffing and equipment shortages (ordinal). Binary questions assessed the presence or absence of stress or a resource. Ordinal assessments included categories of no stress, compensated stress, and uncompensated stress or outright unavailability of a resource. See **Appendix C** for the complete hospital stress survey instrument.

SARI patients, as defined by the parent prospective cohort study (see **Appendix A**), could include both SARS-CoV-2 and influenza etiologies of lower respiratory tract infection, but due to very low numbers of SARI patients without SARS-CoV-2 infection during the pandemic,[1,2] the origin of the perceived stress reported in the hospital stress survey, can be interpreted as almost exclusively from COVID-19.

Surveys were sent out weekly on Tuesday mornings, for reflection on the prior week's hospital stress, with a 72-hour response window and an automated reminder at 24 hours. SARI-PREP site survey primary respondents were site investigators—including critical care medicine and emergency medicine physicians—and were given the instruction to enlist additional local assistance via other leaders and stakeholders at the ICU, ward, and ED levels, including from multiple ICUs if present, and research coordinators, for broad data acquisition and entry. Respondents were largely the same at each institution week-to-week but respondent and supporting stakeholders and staff were allowed to change based on local needs. Primary respondents were SARI-PREP Study Group investigators and co-authors. All survey data were collected and managed using REDCap electronic data capture.

Due to rolling study site entry (**eTable 1**) and therefore a greater number of surveys per week during later surges, we calculated mean (and standard deviation [SD]) hospital stress responses among all contributing hospitals by pandemic week. Because responses to ordinal survey questions that reported higher orders of hospital stress and resource scarcity (i.e., uncompensated stress with greater potential for patient harm) were rare, ordinal stress measures were dichotomized for some analyses to report the presence or absence of stress or shortage, with compensated care processes considered as a stress state.

Appendix C. Hospital stress survey instrument

SARI-PREP Weekly Hospital Stress Survey

Responses to this survey should reflect the conditions at your institution during the previous week (Tuesday-Monday). Responses to the survey will be linked back to [site_enroll] patients enrolled in the SARI-PREP study. To the extent possible, your responses should reflect stress at the hospital level, rather than at the level of an individual department or unit. Please complete this survey within 72 hours of receiving the link.

Has your hospital experienced significant stress due to patients with severe acute respiratory infections?

- ◯ No stress (nothing being done differently)
- ◯ Process and/or staffing altered, but fully compensating (no patient harm)
- ◯ Process and/or staffing altered, and/or resources not available, resulting in potentially avoidable patient harm

Has the Emergency Department at your hospital experienced significant stress due to patients with severe respiratory infections?

- ◯ Yes
- ◯ No

Has the Intensive Care Unit(s) at your hospital experienced significant stress due to patients with severe respiratory infections?

- ◯ Yes
- ◯ No

Have you had to do anything differently within the past week as a result of patient with severe acute respiratory infections?

- ◯ Yes
- ◯ No

Please indicate where/how you did things differently as a result of patients with severe respiratory infections.

- ☐ Denying transfers
- ☐ Boarding more hospital admissions than usual (including ICU admissions) in the Emergency Department
- ☐ Using alternative ICU space to deliver critical care services (PACU, operating rooms, other alternative spaces)
- ☐ Cancelling elective operating room cases
- ☐ Increasing staffing
- ☐ Change staff to patient ratios due to staffing shortages
- ☐ Not performing certain interventions that otherwise might be routinely done (e.g., ECMO)
- ☐ Adapting interventions which are unique to an emergency setting (e.g., multi-patient mechanical ventilation from a single device)
- ☐ Other

Please specify "Other" changes made due to patients with severe acute respiratory infections.

____

Comments. Please include a brief explanation of each response you checked.

____

Choose the option that best describes your availability of staff of each of the following types, over the past WEEK:

Attending physicians

- ○ Adequate with usual ICU-trained staff
- ○ Adequate with additional ICU-experienced staff reassigned to support the pandemic response
- ○ Adequate with staff that include non-ICU trained personnel
- ○ Inadequate
- ○ I don't know

Residents and/or Fellows

- ◯ Adequate with usual ICU-trained staff
- ◯ Adequate with additional ICU-experienced staff reassigned to support the pandemic response
- ◯ Adequate with staff that include non-ICU trained personnel
- ◯ Inadequate
- ◯ I don't know

Nurses

- ◯ Adequate with usual ICU-trained staff
- ◯ Adequate with additional ICU-experienced staff reassigned to support the pandemic response
- ◯ Adequate with staff that include non-ICU trained personnel
- ◯ Inadequate
- ◯ I don't know

Physician assistants and/or Nurse practitioners

- ◯ Adequate with usual ICU-trained staff
- ◯ Adequate with additional ICU-experienced staff reassigned to support the pandemic response
- ◯ Adequate with staff that include non-ICU trained personnel
- ◯ Inadequate
- ◯ I don't know

Respiratory therapists

- ◯ Adequate with usual ICU-trained staff
- ◯ Adequate with additional ICU-experienced staff reassigned to support the pandemic response
- ◯ Adequate with staff that include non-ICU trained personnel
- ◯ Inadequate
- ◯ I don't know

Environmental hygiene services

- ◯ Adequate with usual ICU-trained staff
- ◯ Adequate with additional ICU-experienced staff reassigned to support the pandemic response
- ◯ Adequate with staff that include non-ICU trained personnel
- ◯ Inadequate
- ◯ I don't know

Other - please specify

- ◯ Adequate with usual ICU-trained staff
- ◯ Adequate with additional ICU-experienced staff reassigned to support the pandemic response
- ◯ Adequate with staff that include non-ICU trained personnel
- ◯ Inadequate
- ◯ I don't know

Please specify "Other" staff ____________________

Please indicate the availability of any of the following medications/equipment at this hospital over the past WEEK:

Neuromuscular blocking agents

- ◯ Adequate Availability, no shortage
- ◯ Shortage, but no change to clinical protocols
- ◯ Shortage that has impacted clinical protocols
- ◯ Currently unavailable
- ◯ I don't know

Vasopressors

- ◯ Adequate Availability, no shortage
- ◯ Shortage, but no change to clinical protocols
- ◯ Shortage that has impacted clinical protocols
- ◯ Currently unavailable
- ◯ I don't know

Antibiotics

- Adequate Availability, no shortage
- Shortage, but no change to clinical protocols
- Shortage that has impacted clinical protocols
- Currently unavailable
- I don't know

Bronchodilators

- Adequate Availability, no shortage
- Shortage, but no change to clinical protocols
- Shortage that has impacted clinical protocols
- Currently unavailable
- I don't know

Crystalloid

- Adequate Availability, no shortage
- Shortage, but no change to clinical protocols
- Shortage that has impacted clinical protocols
- Currently unavailable
- I don't know

High flow oxygen/high flow nasal cannula

- Adequate Availability, no shortage
- Shortage, but no change to clinical protocols
- Shortage that has impacted clinical protocols
- Currently unavailable
- I don't know

Renal replacement therapies – machines or disposables

- Adequate Availability, no shortage
- Shortage, but no change to clinical protocols
- Shortage that has impacted clinical protocols
- Currently unavailable
- I don't know

ECMO

- ◯ Adequate Availability, no shortage
- ◯ Shortage, but no change to clinical protocols
- ◯ Shortage that has impacted clinical protocols
- ◯ Currently unavailable
- ◯ I don't know

Other

- ◯ Adequate Availability, no shortage
- ◯ Shortage, but no change to clinical protocols
- ◯ Shortage that has impacted clinical protocols
- ◯ Currently unavailable
- ◯ I don't know

Please specify "Other" medication/equipment. ________________________

Choose the option that best describes the availability of each type of Personal Protective Equipment (PPE) at this hospital over the last WEEK:

Surgical masks

- ◯ Adequate availability, no shortage
- ◯ Shortage, but no change to clinical protocols
- ◯ Shortage that has impacted clinical protocols
- ◯ Currently unavailable
- ◯ I don't know

Face shields/goggles

- ◯ Adequate availability, no shortage
- ◯ Shortage, but no change to clinical protocols
- ◯ Shortage that has impacted clinical protocols
- ◯ Currently unavailable
- ◯ I don't know

Respiratory protection (N95 respirators, CAPRs or PAPRs)

- ◯ Adequate availability, no shortage
- ◯ Shortage, but no change to clinical protocols
- ◯ Shortage that has impacted clinical protocols
- ◯ Currently unavailable
- ◯ I don't know

Gloves

- ◯ Adequate availability, no shortage
- ◯ Shortage, but no change to clinical protocols
- ◯ Shortage that has impacted clinical protocols
- ◯ Currently unavailable
- ◯ I don't know

Environmental hygiene supplies

- ◯ Adequate availability, no shortage
- ◯ Shortage, but no change to clinical protocols
- ◯ Shortage that has impacted clinical protocols
- ◯ Currently unavailable
- ◯ I don't know

Patient Transfers to and from Hospital

In the past week, has your facility been unable to transfer a patient to a referral facility?

- ◯ Yes
- ◯ No

Was the transfer not made because the referral facility's needs exceeded current, local capabilities due to severe acute respiratory infection patients?

- ◯ Yes
- ◯ No
- ◯ Unknown

In the past week, has your facility been unable to accept a patient with severe acute respiratory infection from another facility?

- ◯ Yes
- ◯ No

Was the transfer attempted because the patient's needs exceeded the referring facility’s capabilities?

- ◯ Yes
- ◯ No
- ◯ Unknown

Appendix D. Approach to missing data and related sensitivity analyses

There was rolling study site entry into the cohort study (**eTable 1**). After study site cohort entry, missingness (9% survey non-response, 9-11% missingness in individual core stress measures reflecting low missingness within returned surveys) might plausibly be the result of decreased attention to the stress survey due to high stress (e.g., competing demands for time and attention)[3] or low stress (e.g., less urgency felt towards stress survey participation and subject matter), it might be random, or due to some other unknown pattern. Given the high response rate and low missingness, primary analyses utilized a complete case analysis approach. In sensitivity analyses, we repeated our analyses using three approaches: imputing missing stress variables as last value carried forward including across rare multiple weeks of missingness (implying similar stress to recent), assuming stress present when missing (implying non-response due to high stress and competing demands), or assuming stress absent when missing (implying non-response due to reduced urgency of subject matter). Data were not imputed for study weeks prior to cohort entry for a given study site.

Appendix E. Hospital stress, care deviations, or resource scarcity differences between pandemic surge periods

The presence of hospital stress, care deviations, and resource scarcity were variably reported differently between pandemic surges and compared to between-surge periods (**Tables 1-2** and **eTables 4-8**). Multiple measures of hospital stress and care deviations—such as ICU and ED stress, operating differently overall, denying inter-hospital transfers, and cancelling elective surgeries—had peaks during the third Ancestral Wuhan strain and/or the Omicron BA.1 subvariant surges. This might represent, respectively, continued hospital learning (i.e., hospital adaptation) in an earlier part of the pandemic and the unique disruption of the Omicron BA.1 subvariant surge with massive SARS-CoV-2 case activity.[4,5] Stress decreased but did fully resolve during within-pandemic between-surge periods.

Staffing availability issues were most pronounced during the ancestral Wuhan strain surge, were not appreciably higher during the Omicron BA.1 subvariant surge as compared to other variant surges despite significantly higher case numbers, and likewise did not normalize during within-pandemic between-surge periods. This might reflect changes to organizational structures that have improved hospital adaptation and resiliency as well as increasing COVID-19 vaccination coverage and prior SARS-CoV-2 infections among the healthcare workforce, even with waning immunity.[6]

Medication and equipment availability issues, while rare in total, were reported more frequently during the more recent Omicron BA.1 and Omicron BA.2.12.1+ subvariant surges.

Shortages in respiratory protection equipment (e.g., N95 respirators and PAPRs), discussed at length early in the pandemic,[7,8] were largely limited to the ancestral Wuhan strain surge, when it was frequently reported (mean of 67% [SD 15%] of hospitals per week), and rare thereafter (at most a mean of 5% of hospitals per week from Spring 2021 onward). This likely reflects a combination of an improved supply chain and changes in bedside practices.[9]

Periods in which 100% of participating study sites reported weekly overall hospital stress occurred during the ancestral Wuhan strain (third U.S. national surge, nine consecutive weeks during December 2020 – February 2021, n = 7 hospitals) and the Omicron BA.1 subvariant surge (four consecutive weeks during December 2021 – January 2022, n = 13 hospitals). Among the 39 hospital-weeks in which sites reported unavailability of some hospital resources resulting in potentially avoidable patient harm, 31 (80%) hospital-weeks occurred during the Delta variant and Omicron BA.1 subvariant surges.

Supplemental Tables

eTable 1. Study sites and program entry dates

Study Site	Cohort entry week
New York University	
Bellevue Hospital (New York, NY)	11/17/2020
NYU Langone Health (New York, NY)	12/1/2020
University of Washington	
Harborview Medical Center (Seattle, WA)	11/17/2020
UW Medical Center - Montlake (Seattle, WA)	11/17/2020
UW Medical Center - Northwest (Seattle, WA)	1/5/2021
University of Southern California	
Los Angeles County+USC Medical Center (Los Angeles, CA)	1/19/2021
Keck Hospital of USC (Los Angeles, CA)	1/26/2021
USC Verdugo Hills Hospital (Glendale, CA)	2/23/2021
Denver Health	
Denver Health Medical Center (Denver, CO)	7/6/2021
Emory Healthcare	
Emory University Hospital (Atlanta, GA)	9/7/2021
Emory Decatur Hospital (North Decatur, GA)	9/7/2021
University of California, Irvine	
UCI Medical Center (Orange, CA)	10/19/2021
University of Arizona	
University of Arizona Medical Center (Tucson, AZ)	1/4/2022

eTable 2. Pandemic surge periods and dominant variants

Dominant variant/subvariant	Time interval
Ancestral Wuhan strain (third U.S. national surge)	11/17/2020 (study start) – 3/5/2021 (Winter 2020-2021)
Alpha	3/26/2021 – 4/23/2021 (Spring 2021)
Delta	7/27/2021 – 11/6/2021 (Summer-Fall 2021)
Omicron BA.1	11/7/2021 – 3/1/2022 (Winter 2021-2022)
Omicron BA.2.12.1 + early BA.4/BA.5	5/2/2022 – 6/30/2022 (study end) (Spring-Summer 2022)

eTable 3. SARS-CoV-2 case data sources

Study Site	State	State SARS-CoV-2 case data sources	County	County SARS-CoV-2 case data sources
Bellevue Hospital	NY	Johns Hopkins Coronavirus Resource Center (https://coronavirus.jhu.edu/region/us/new-york)	New York	NYC Department of Health and Mental Hygiene (https://github.com/nychealth/coronavirus-
NYU Langone Health	NY		New York	
Harborview Medical Center	WA	Washington State Department of Health (https://doh.wa.gov/emergencies/covid-19/data-dashboard#downloads)	King	Washington State Department of Health (https://doh.wa.gov/emergencies/covid-19/data-dashboard)
UW Medical Center - Montlake	WA		King	
UW Medical Center - Northwest	WA		Snohomish	
Keck Hospital of USC	CA	California Department of Public Health (https://public.tableau.com/app/profile/ca.open.data/viz/COVID-19CasesDashboardv2_0/CaseStatistics)	Los Angeles	California Department of Public Health (https://public.tableau.com/app/profile/ca.open.data/viz/COVID-19CasesDashboardv2_0/CaseStatistics)
Los Angeles County+USC Medical Center	CA		Los Angeles	
USC Verdugo Hills Hospital	CA		Los Angeles	
UCI Medical Center	CA		Orange	
Denver Health Medical Center	CO	Colorado Department of Public Health and Environment (https://public.tableau.com/views/Colorado_COVID19_Data/CO_Case_Summary?%3Alanguage=en&%3Adisplay_count=y&%3Aorigin=viz_share_link%3AshowVizHome)	Denver	Denver Public Health and Environment (https://denvergov.org/Government/COVID-19-Information/COVID-19-in-Denver/COVID-19-Case-Dashboards/COVID-19-Epi-Curve-Dashboards)
Emory University Hospital	GA	Georgia Department of Public Health https://dph.georgia.gov/covid-19-status-report)	DeKalb	Georgia Department of Public Health https://dph.georgia.gov/covid-19-status-report)
Emory Decatur Hospital	GA		DeKalb	
University of Arizona Medical Center	AZ	Johns Hopkins Coronavirus Resource Center (https://coronavirus.jhu.edu/region/us/arizona)	Pima	Covid Act Now (https://covidactnow.org/us/arizona-az/county/pima_county/?s=36582423)

eTable 4. Perceived hospital stress and care deviations by hospital weeks and pandemic periods

Hospital stress metric	Total study period	Between-surge periods	Ancestral Wuhan strain	Alpha variant	Delta variant	Omicron BA.1 subvariant	Omicron BA.2.12.1 subvariant
	Hospital-weeks, n (%)						
Hospital-weeks	839 (100.0)	214 (25.5)	86 (10.3)	40 (4.8)	156 (18.6)	213 (25.4)	130 (15.5)
Overall hospital stress							
Unavailability of some hospital resources resulting in potentially avoidable patient harm	39 (5.2)	3 (1.4)	4 (4.9)	1 (2.7)	13 (8.6)	18 (9.1)	0 (0.0)
Alterations in care processes and/or staffing which were fully compensated for	260 (34.3)	21 (10.8)	68 (84.0)	14 (37.8)	73 (48.3)	84 (42.2)	0 (0.0)
No stress	459 (60.6)	171 (87.7)	9 (11.1)	22 (59.5)	65 (43.1)	97 (48.7)	95 (100.0)
Intensive care unit stress	231 (30.5)	13 (6.7)	55 (67.9)	10 (27.0)	66 (44.0)	87 (43.7)	0 (0.0)
Emergency department stress	115 (15.2)	1 (0.5)	13 (16.1)	1 (2.7)	25 (16.6)	75 (37.7)	0 (0.0)
Care deviations	244 (32.8)	18 (9.7)	63 (78.8)	12 (33.3)	63 (42.3)	88 (44.4)	0 (0.0)
Increasing hospital staffing	112 (14.6)	15 (7.5)	46 (56.8)	9 (24.3)	15 (9.9)	27 (13.5)	0 (0.0)
Denying inter-hospital transfers	125 (16.3)	4 (2.0)	10 (12.4)	2 (5.4)	49 (32.5)	60 (30.0)	0 (0.0)
Cancelling elective surgeries	85 (11.1)	0 (0.0)	32 (39.5)	0 (0.0)	25 (16.6)	28 (14.0)	0 (0.0)
Increased ED boarding	82 (10.7)	1 (0.5)	3 (3.7)	0 (0.0)	22 (14.6)	56 (28.0)	0 (0.0)
Using surge ICU spaces	30 (3.9)	3 (1.5)	9 (11.1)	2 (5.4)	0 (0.0)	16 (8.0)	0 (0.0)
Changing staff-to-patient ratios	30 (3.9)	1 (0.5)	6 (7.4)	0 (0.0)	3 (2.0)	20 (10.0)	0 (0.0)
Limiting certain interventions	15 (2)	1 (0.5)	2 (2.5)	0 (0.0)	0 (0.0)	12 (6.0)	0 (0.0)
Crisis standards of care	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.5)	0 (0.0)
Inter-hospital transfers							
Unable to transfer a patient elsewhere	70 (9.3)	11 (5.5)	4 (6.1)	0 (0.0)	13 (8.6)	33 (16.5)	9 (9.3)
Unable to accept a requested transfer	226 (30.1)	20 (10.1)	12 (18.2)	6 (16.2)	69 (45.7)	108 (54.0)	11 (11.3)

Notes: Analyses performed by hospital-week. Primary results and percentages are reported as complete case analyses. See sensitivity analysis results for alternative handling of rare missing data. ED, emergency department; ICU, intensive care unit.

eTable 5. Perceived ICU staffing status by hospital weeks and pandemic periods

Staff role	Adequate with usual ICU-trained staff	Adequate with additional ICU-experienced staff reassigned for pandemic response	Adequate with staff that include non-ICU trained personnel	Inadequate
	Hospital-weeks, n (%)			
Attending physicians				
Total study period	641 (83.9)	107 (14.0)	9 (1.2)	7 (0.9)
Between-surge periods	178 (89.5)	21 (10.6)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	38 (46.9)	40 (49.4)	3 (3.7)	0 (0.0)
Alpha variant	28 (75.7)	9 (24.3)	0 (0.0)	0 (0.0)
Delta variant	135 (89.4)	12 (8.0)	3 (2.0)	1 (0.7)
Omicron BA.1 subvariant	166 (83.4)	24 (12.1)	3 (1.5)	6 (3.0)
Omicron BA.2.12.1 subvariant	96 (99.0)	1 (1.0)	0 (0.0)	0 (0.0)
Residents or Fellows				
Total study period	582 (83.9)	85 (12.3)	22 (3.2)	5 (0.7)
Between-surge periods	166 (91.2)	12 (6.6)	4 (2.2)	0 (0.0)
Ancestral Wuhan strain	25 (34.7)	36 (50.0)	11 (15.3)	0 (0.0)
Alpha variant	25 (75.8)	5 (15.2)	3 (9.1)	0 (0.0)
Delta variant	120 (88.9)	12 (8.9)	2 (1.5)	1 (0.7)
Omicron BA.1 subvariant	156 (85.7)	20 (11.0)	2 (1.1)	4 (2.2)
Omicron BA.2.12.1 subvariant	90 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Bedside registered nurses				
Total study period	625 (82.2)	113 (14.9)	3 (0.4)	19 (2.5)
Between-surge periods	185 (93.4)	9 (4.6)	4 (2.0)	0 (0.0)
Ancestral Wuhan strain	40 (49.4)	37 (45.7)	2 (2.5)	2 (2.5)
Alpha variant	31 (83.8)	6 (16.2)	0 (0.0)	0 (0.0)
Delta variant	120 (80.5)	25 (16.8)	1 (0.7)	3 (2.0)
Omicron BA.1 subvariant	161 (81.3)	31 (15.7)	0 (0.0)	6 (3.0)
Omicron BA.2.12.1 subvariant	88 (90.7)	5 (5.2)	0 (0.0)	4 (4.1)
Physician assistants or nurse practitioners				
Total study period	541 (84.5)	77 (12.0)	12 (1.9)	10 (1.6)
Between-surge periods	153 (91.6)	14 (8.4)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	34 (50.0)	30 (44.1)	4 (5.9)	0 (0.0)
Alpha variant	23 (82.1)	3 (10.7)	2 (7.1)	0 (0.0)
Delta variant	105 (84.0)	14 (11.2)	2 (1.6)	4 (3.2)
Omicron BA.1 subvariant	141 (84.9)	15 (9.0)	4 (2.4)	6 (3.6)
Omicron BA.2.12.1 subvariant	85 (98.8)	1 (1.2)	0 (0.0)	0 (0.0)
Respiratory therapists				
Total study period	620 (81.2)	100 (13.1)	8 (1.1)	36 (4.7)
Between-surge periods	185 (93.0)	14 (7.0)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	53 (66.3)	24 (30.0)	1 (1.3)	2 (2.5)
Alpha variant	32 (86.5)	5 (13.5)	0 (0.0)	0 (0.0)
Delta variant	99 (65.6)	18 (11.9)	5 (3.3)	29 (19.2)
Omicron BA.1 subvariant	158 (79.0)	35 (17.5)	3 (1.0)	5 (2.5)
Omicron BA.2.12.1 subvariant	93 (95.9)	4 (4.1)	0 (0.0)	0 (0.0)
Environmental services				
Total study period	662 (91.6)	17 (2.4)	8 (1.1)	36 (5.0)
Between-surge periods	185 (96.4)	0 (0.0)	0 (0.0)	7 (3.7)
Ancestral Wuhan strain	62 (93.9)	3 (4.5)	0 (0.0)	1 (1.5)
Alpha variant	32 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	130 (90.3)	5 (3.5)	6 (4.2)	3 (2.1)
Omicron BA.1 subvariant	168 (86.6)	9 (4.6)	1 (0.5)	16 (8.3)
Omicron BA.2.12.1 subvariant	85 (89.5)	0 (0.0)	1 (1.1)	9 (9.5)

Notes: Analyses performed by hospital-week. Primary results and percentages are reported as complete case analyses. ICU, intensive care unit.

eTable 6. Perceived medication availability issues by hospital weeks and pandemic periods

Resource	Adequate availability, no shortage	Shortage, but no change to clinical protocols	Shortage that has impacted clinical protocols	Currently unavailable
	Hospital-weeks, n (%)			
Antibiotics				
Total study period	707 (92.8)	25 (3.3)	28 (3.7)	2 (0.3)
Between-surge periods	191 (96.5)	1 (0.5)	6 (3.0)	0 (0.0)
Ancestral Wuhan strain	80 (98.8)	1 (1.2)	0 (0.0)	0 (0.0)
Alpha variant	37 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	148 (98.0)	3 (2.0)	0 (0.0)	0 (0.0)
Omicron BA.1 subvariant	167 (83.9)	15 (7.5)	15 (7.5)	2 (1.0)
Omicron BA.2.12.1 subvariant	84 (87.5)	8 (8.3)	4 (4.2)	0 (0.0)
Crystalloid fluids				
Total study period	722 (94.6)	29 (3.8)	11 (1.4)	1 (0.1)
Between-surge periods	191 (96.5)	5 (2.5)	2 (1.0)	0 (0.0)
Ancestral Wuhan strain	81 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Alpha variant	37 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	148 (98.0)	2 (1.30	1 (0.7)	0 (0.0)
Omicron BA.1 subvariant	180 (90.5)	12 (6.0)	6 (3.0)	1 (0.5)
Omicron BA.2.12.1 subvariant	85 (87.6)	10 (10.3)	2 (2.1)	0 (0.0)
Bronchodilators				
Total study period	752 (98.4)	9 (1.2)	3 (0.4)	0 (0.0)
Between-surge periods	198 (99.5)	1 (0.5)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	81 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Alpha variant	37 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	149 (98.7)	0 (0.0)	0 (0.0)	0 (0.0)
Omicron BA.1 subvariant	198 (99.5)	1 (0.5)	0 (0.0)	0 (0.0)
Omicron BA.2.12.1 subvariant	89 (91.8)	7 (7.2)	1 (1.0)	0 (0.0)
Vasopressors				
Total study period	738 (96.5)	26 (3.4)	1 (0.1)	0 (0.0)
Between-surge periods	192 (96.5)	7 (3.5)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	81 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Alpha variant	37 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	145 (96.0)	6 (4.0)	0 (0.0)	0 (0.0)
Omicron BA.1 subvariant	196 (98.0)	3 (1.5)	1 (0.5)	0 (0.0)
Omicron BA.2.12.1 subvariant	87 (86.7)	10 (10.3)	0 (0.0)	0 (0.0)
Neuromuscular blockade agents				
Total study period	737 (96.5)	27 (3.5)	0 (0.0)	0 (0.0)
Between-surge periods	190 (95.5)	9 (4.5)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	80 (98.8)	1 (1.2)	0 (0.0)	0 (0.0)
Alpha variant	37 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	150 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Omicron BA.1 subvariant	194 (97.0)	6 (3.0)	0 (0.0)	0 (0.0)
Omicron BA.2.12.1 subvariant	86 (88.7)	11 (11.3)	0 (0.0)	0 (0.0)

Notes: Analyses performed by hospital-week. Primary results and percentages are reported as complete case analyses.

eTable 7. Perceived organ support equipment availability by hospital weeks and pandemic periods

Resource	Adequate availability, no shortage	Shortage, but no change to clinical protocols	Shortage that has impacted clinical protocols	Currently unavailable
	Hospital-weeks, n (%)			
High flow oxygen				
Total study period	761 (99.7)	2 (0.3)	0 (0.0)	0 (0.0)
Between-surge periods	198 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	81 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Alpha variant	37 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	148 (98.7)	2 (1.3)	0 (0.0)	0 (0.0)
Omicron BA.1 subvariant	200 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Omicron BA.2.12.1 subvariant	97 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Renal replacement therapy				
Total study period	686 (95.3)	16 (2.2)	18 (2.5)	0 (0.0)
Between-surge periods	176 (94.1)	5 (2.7)	6 (3.2)	0 (0.0)
Ancestral Wuhan strain	71 (88.8)	6 (7.5)	3 (3.8)	0 (0.0)
Alpha variant	35 (94.6)	2 (5.4)	0 (0.0)	0 (0.0)
Delta variant	139 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Omicron BA.1 subvariant	177 (94.7)	2 (1.1)	8 (4.3)	0 (0.0)
Omicron BA.2.12.1 subvariant	88 (97.8)	1 (1.1)	1 (1.1)	0 (0.0)
Extracorporeal membrane oxygenation (ECMO)				
Total study period	604 (90.2)	24 (3.6)	10 (1.5)	32 (4.8)
Between-surge periods	165 (95.4)	2 (1.2)	1 (0.6)	5 (2.9)
Ancestral Wuhan strain	61 (82.4)	13 (17.6)	0 (0.0)	0 (0.0)
Alpha variant	30 (100.0	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	114 (89.1)	3 (2.3)	2 (1.6)	9 (7.0)
Omicron BA.1 subvariant	161 (85.3)	5 (2.8)	7 (4.0)	14 (7.9)
Omicron BA.2.12.1 subvariant	83 (94.3)	1 (1.1)	0 (0.0)	4 (4.6)

Notes: Analyses performed by hospital-week. Primary results and percentages are reported as complete case analyses.

eTable 8. Perceived personal protective equipment availability by hospital weeks and pandemic periods

Resource	Adequate availability, no shortage	Shortage, but no change to clinical protocols	Shortage that has impacted clinical protocols	Currently unavailable
	Hospital-weeks, n (%)			
Surgical masks				
Total study period	755 (99.0)	5 (0.7)	3 (0.4)	0 (0.0)
Between-surge periods	199 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	77 (96.3)	3 (3.8)	0 (0.0)	0 (0.0)
Alpha variant	37 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	160 (99.3)	1 (0.7)	0 (0.0)	0 (0.0)
Omicron BA.1 subvariant	197 (99.0)	2 (1.0)	0 (0.0)	0 (0.0)
Omicron BA.2.12.1 subvariant	95 (97.9)	2 (2.1)	0 (0.0)	0 (0.0)
Eye protection (face shields, goggles)				
Total study period	756 (99.3)	1 (0.1)	4 (0.5)	0 (0.0)
Between-surge periods	198 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	77 (96.3)	3 (3.8)	0 (0.0)	0 (0.0)
Alpha variant	37 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	149 (98.7)	1 (0.7)	1 (0.7)	0 (0.0)
Omicron BA.1 subvariant	198 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Omicron BA.2.12.1 subvariant	97 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Respiratory protection (N95 respirators, PAPRs)				
Total study period	689 (90.5)	17 (2.2)	55 (7.2)	0 (0.0)
Between-surge periods	186 (93.5)	4 (2.0)	9 (4.5)	0 (0.0)
Ancestral Wuhan strain	29 (36.3)	8 (10.0)	43 (53.8)	0 (0.0)
Alpha variant	35 (94.6)	0 (0.0)	2 (5.4)	0 (0.0)
Delta variant	148 (99.3)	1 (0.7)	0 (0.0)	0 (0.0)
Omicron BA.1 subvariant	194 (97.5)	4 (2.0)	1 (0.5)	0 (0.0)
Omicron BA.2.12.1 subvariant	97 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Examination gloves				
Total study period	739 (96.9)	24 (3.2)	0 (0.0)	0 (0.0)
Between-surge periods	195 (98.0)	4 (2.0)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	78 (7.5)	2 (2.5)	0 (0.0)	0 (0.0)
Alpha variant	37 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	150 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Omicron BA.1 subvariant	189 (94.5)	11 (5.5)	0 (0.0)	0 (0.0)
Omicron BA.2.12.1 subvariant	90 (92.8)	7 (7.2)	0 (0.0)	0 (0.0)
Environmental hygiene supplies				
Total study period	692 (95.3)	18 (2.5)	15 (2.1)	1 (0.1)
Between-surge periods	187 (98.4)	3 (1.6)	0 (0.0)	0 (0.0)
Ancestral Wuhan strain	64 (95.5)	3 (4.5)	0 (0.0)	0 (0.0)
Alpha variant	30 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)
Delta variant	139 (93.3)	2 (1.3)	8 (5.4)	0 (0.0)
Omicron BA.1 subvariant	181 (93.3)	5 (2.6)	7 (3.6)	1 (0.5)
Omicron BA.2.12.1 subvariant	91 (94.8)	5 (5.2)	0 (0.0)	0 (0.0)

Notes: Analyses performed by hospital-week. Primary results and percentages are reported as complete case analyses. PAPR, powered air purifying respirator.

eTable 9. Hospital stress measure correlation

Stress measure	Overall hospital stress	ICU stress	ED stress	Operating differently
	Spearman correlation, rho (p-value)[a]			
	Primary complete case analysis			
Overall hospital stress	1			
ICU stress	0.82 (<0.0001)	1		
ED stress	0.52 (<0.0001)	0.53 (<0.0001)	1	
Operating differently	0.83 (<0.0001)	0.77 (<0.0001)	0.46 (<0.0001)	1
	Imputation by carrying forward prior result after cohort entry			
Overall hospital stress	1			
ICU stress	0.83 (<0.0001)	1		
ED stress	0.52 (<0.0001)	0.53 (<0.0001)	1	
Operating differently	0.83 (<0.0001)	0.77 (<0.0001)	0.46 (<0.0001)	1
	Imputation by assuming stress present when missing			
Overall hospital stress	1			
ICU stress	0.85 (<0.0001)	1		
ED stress	0.61 (<0.0001)	0.64 (<0.0001)	1	
Operating differently	0.81 (<0.0001)	0.77 (<0.0001)	0.55 (<0.0001)	1
	Imputation by assuming stress absent when missing			
Overall hospital stress	1			
ICU stress	0.83 (<0.0001)	1		
ED stress	0.54 (<0.0001)	0.55 (<0.0001)	1	
Operating differently	0.84 (<0.0001)	0.77 (<0.0001)	0.48 (<0.0001)	1

Notes: Analyses performed by hospital-week. [a] rho = +1 and –1 are interpreted as perfect positive and negative correlation, respectively, and rho = 0 is interpreted as no correlation. ED, emergency department; ICU, intensive care unit.

eTable 10. Association of county SARS-CoV-2 cases and hospital stress

Stress measure	OR per change in 10 SARS-CoV-2 cases per 100,000 residents (95% CI, p-value)
	Primary complete case analysis
Overall hospital stress	1.087 (1.051-1.125, p = 0.001)
ICU stress	1.065 (1.034-1.096, p < 0.001)
ED stress	1.038 (1.015-1.061, p = 0.001)
	Imputation by carrying forward prior result after cohort entry
Overall hospital stress	1.074 (1.042-1.106, p < 0.001)
ICU stress	1.061 (1.033-1.089, p < 0.001)
ED stress	1.024 (1.009-1.040, p = 0.002)
	Imputation by assuming stress present when missing
Overall hospital stress	1.074 (1.043-1.105, p < 0.001)
ICU stress	1.053 (1.027-1.080, p < 0.001)
ED stress	1.024 (1.005-1.044, p = 0.012)
	Imputation by assuming stress absent when missing
Overall hospital stress	1.040 (1.017-1.064, p = 0.001)
ICU stress	1.035 (1.013-1.057, p = 0.002)
ED stress	1.024 (1.009-1.039, p = 0.002)
	Delta variant surge
Overall hospital stress	1.302 (0.957-1.773, p = 0.09)
ICU stress	1.341 (0.972-1.849, p = 0.07)
ED stress	2.928 (1.368-6.263, p = 0.006)
	Omicron BA.1 subvariant surge
Overall hospital stress	1.087 (1.046-1.130, p < 0.001)
ICU stress	1.052 (1.021-1.084, p = 0.001)
ED stress	1.050 (1.021-1.080, p = 0.001)

Notes: Full study period logistic regression models performed on the level of the hospital-week and adjusted for hospital and pandemic variant/surge period in order to take into account both SARS-CoV-2 variant characteristics and longitudinal time. CI, confidence interval; ED, emergency department; ICU, intensive care unit; OR, odds ratio; SARS-CoV-2, Severe Acute Respiratory Syndrome Coronavirus 2.

eTable 11. Timing differences among hospital stress measures' starts and ends during pandemic surges

Stress measure	z (p-value) compared to overall hospital stress start	z (p-value) compared to overall hospital stress end
	Delta variant surge	
ICU stress start/end week	2.038 (0.0416)*	0.536 (0.5918)
ED stress start/end week	2.044 (0.0410)*	2.973 (0.0029)*
	Omicron BA.1 subvariant surge	
ICU stress start/end week	1.638 (0.1015)	1.503 (0.1330)
ED stress start/end week	1.598 (0.1101)	2.088 (0.0368)*

*Notes: * p < 0.05 for Wilcoxon rank-sum tests. ED, emergency department; ICU, intensive care unit.*

eTable 12. Comparisons between county SARS-CoV-2 cases at hospital stress measures' starts and ends during pandemic surges

Stress measure	z (p-value) compared to cases at overall hospital stress start	z (p-value) compared to cases at overall hospital stress end
	Delta variant surge	
Cases at ICU stress start/end	0.314 (0.7538)	-1.180 (0.2381)
Cases at ED stress start/end	0.839 (0.4013)	-1.635 (0.1020)
	Omicron BA.1 subvariant surge	
Cases at ICU stress start/end	-1.457 (0.1450)	-0.848 (0.3964)
Cases at ED stress start/end	-1.599 (0.1098)	-1.430 (0.1526)

*Notes: * p < 0.05 for Wilcoxon rank-sum tests. ED, emergency department; ICU, intensive care unit.*

eTable 13. Hospital stress measure duration during pandemic surges

Stress measure	z (p-value) compared to overall hospital stress duration
	Delta variant surge
ICU stress duration	1.441 (0.1494)
ED stress duration	3.038 (0.0024)*
	Omicron BA.1 subvariant surge
ICU stress duration	1.240 (0.2151)
ED stress duration	2.027 (0.0426)*

*Notes: * p < 0.05 for Wilcoxon rank-sum tests. ED, emergency department; ICU, intensive care unit.*

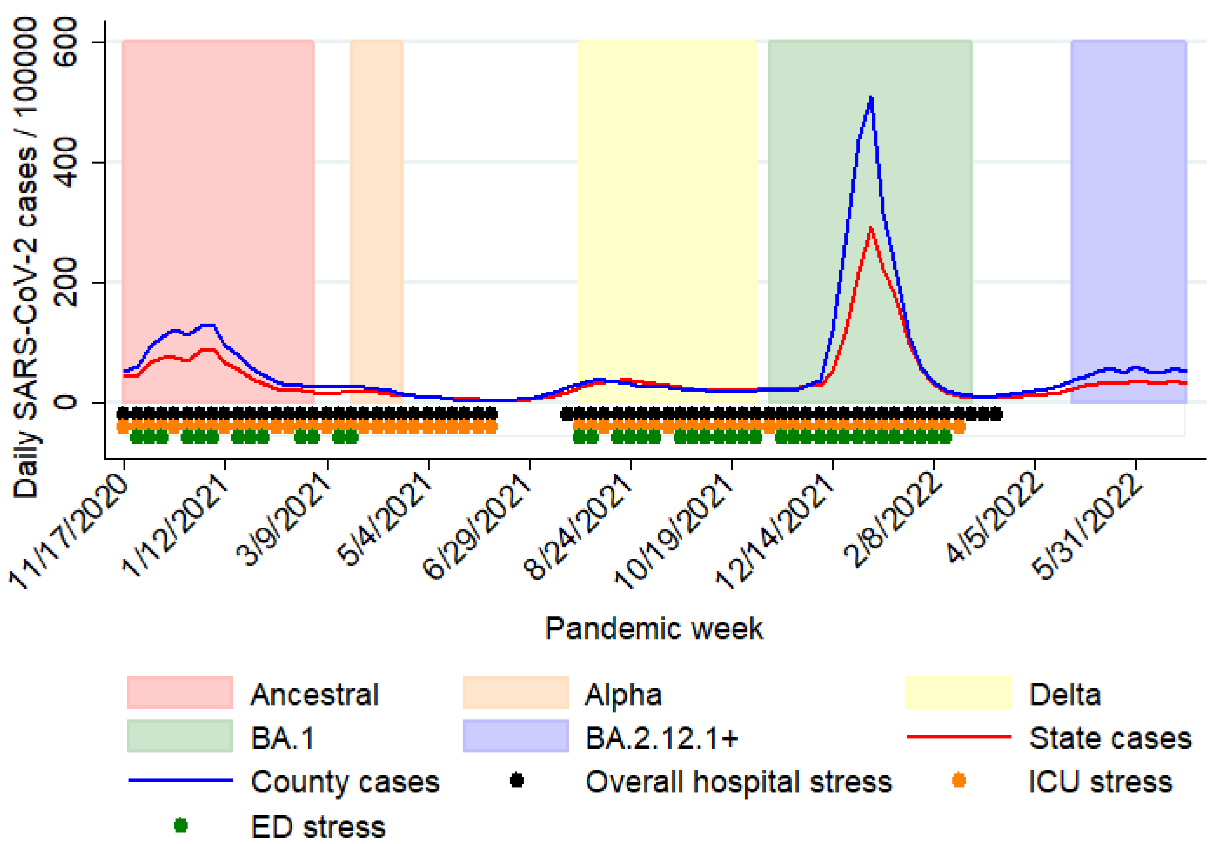
Supplemental Figures

Figure Legend

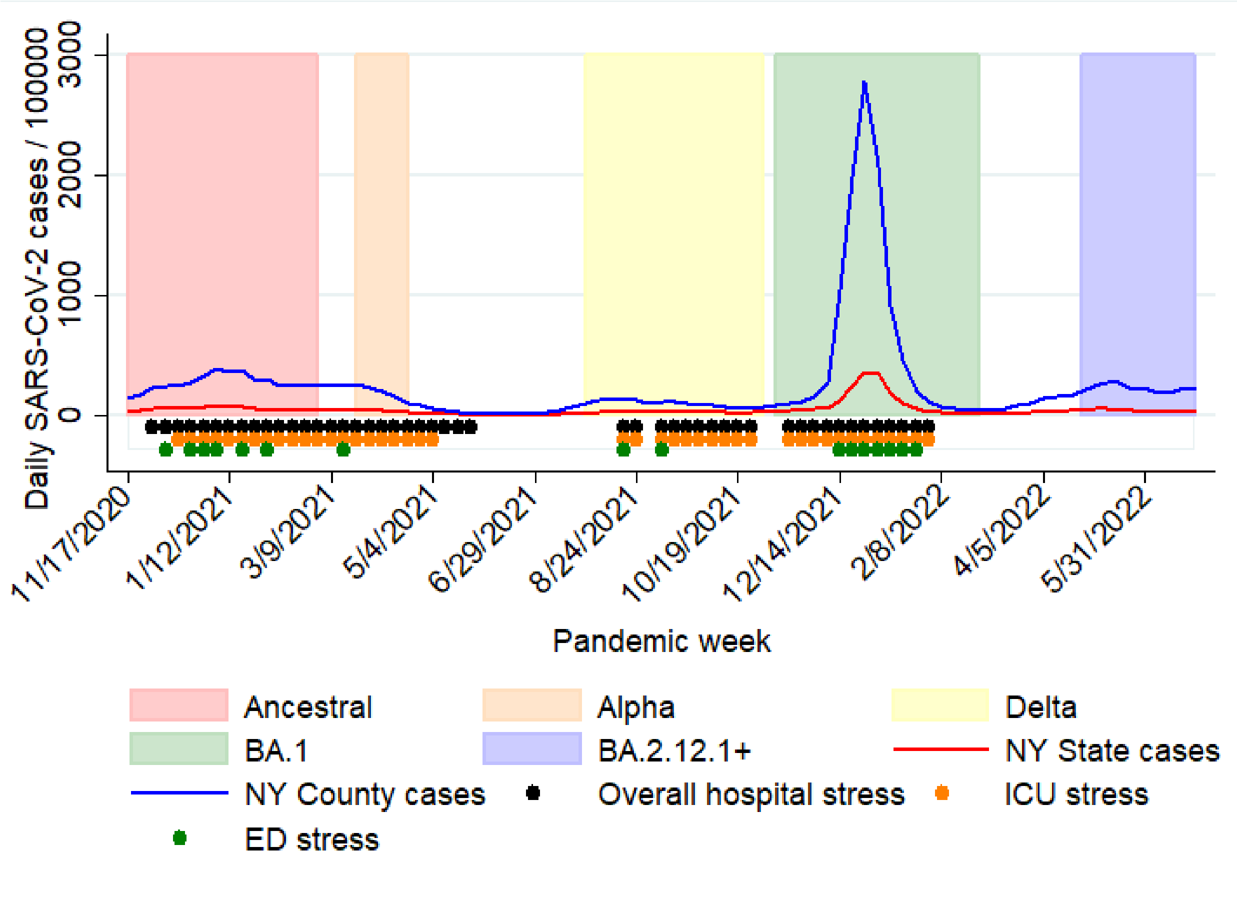
eFigure 1. Hospital stress and SARS-CoV-2 cases by pandemic week
State (red) and county (blue) daily SARS-CoV-2 cases per 100,000 residents, calculated over weekly means and covering all study site states and counties, are plotted by study week. The presence of overall hospital stress (black), ICU stress (orange), and ED stress (green) at any reporting study site in a given study week are noted below by study week. The SARS-CoV-2 variant and subvariant–dominated surges are noted in shaded colors. Overall hospital stress and ICU stress appear more commonly reported and to persist longer than ED stress. ED, emergency department; ICU, intensive care unit; SARS-CoV-2, Severe Acute Respiratory Syndrome Coronavirus 2.

eFigures 2-9. Hospital stress and SARS-CoV-2 cases by pandemic week.
State (red) and county (blue) daily SARS-CoV-2 cases per 100,000 residents, calculated over weekly means and covering the study sites' state and county, are plotted by study week beginning with the first study site cohort entry for that county. The presence of overall hospital stress (black), ICU stress (orange), and ED stress (green) at the study site(s) in that county are noted below by study week. The SARS-CoV-2 variant and subvariant–dominated surges, beginning at study site cohort entry, are noted in shaded colors. Overall hospital stress and ICU stress often appear more commonly reported and to persist longer than ED stress. ED, emergency department; ICU, intensive care unit; SARS-CoV-2, Severe Acute Respiratory Syndrome Coronavirus 2.

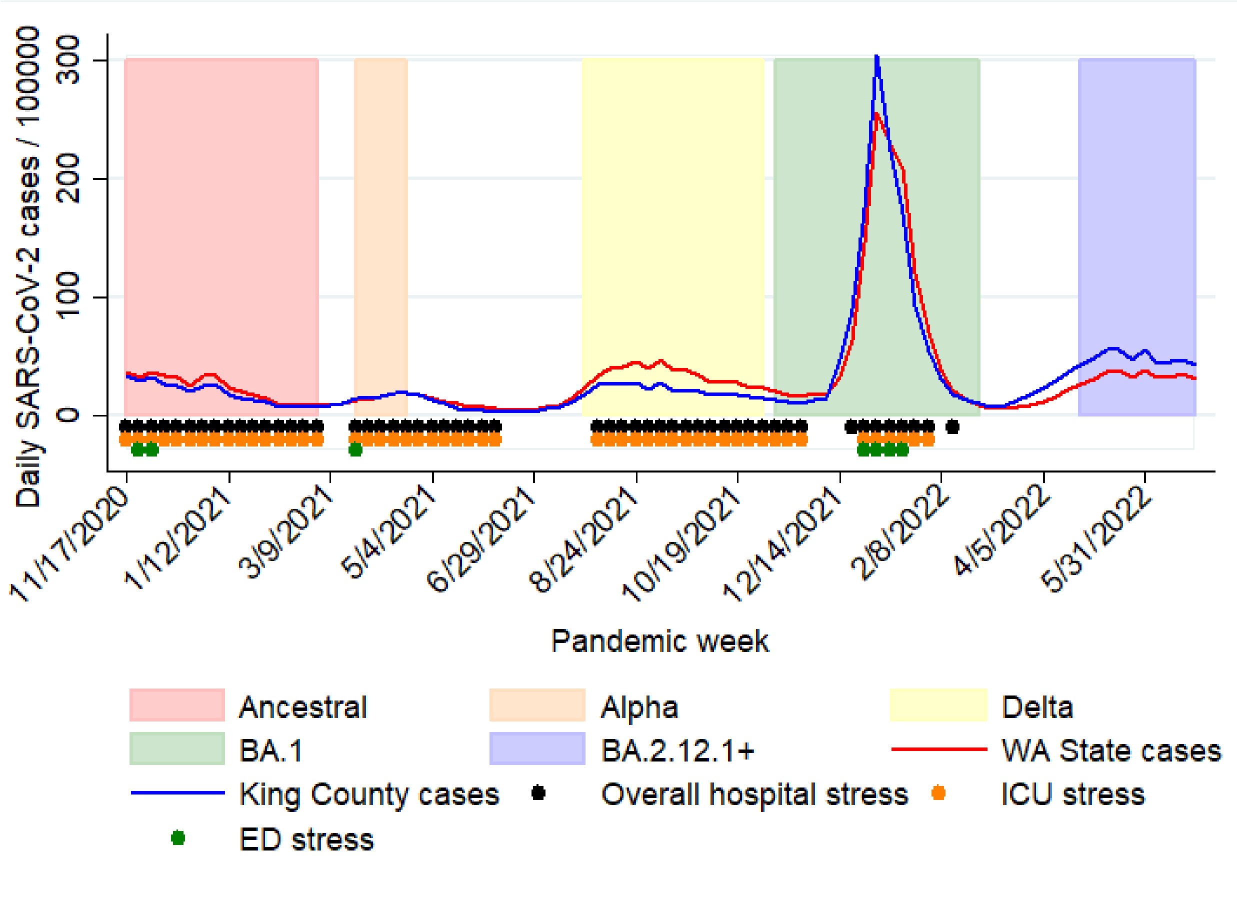
eFigure 1. Hospital stress and SARS-CoV-2 cases by pandemic week: All study sites



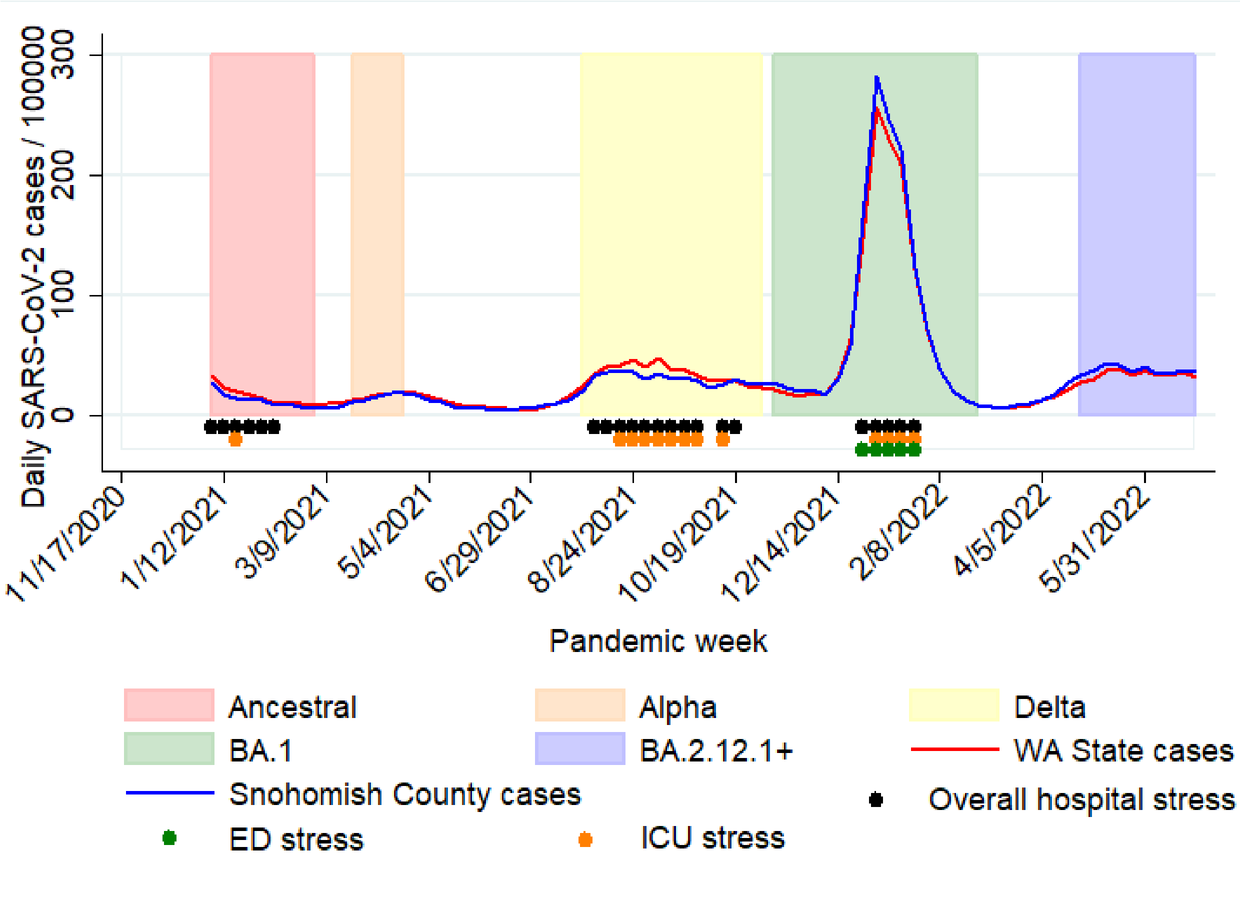
eFigure 2. Hospital stress and SARS-CoV-2 cases by pandemic week: New York State and New York County



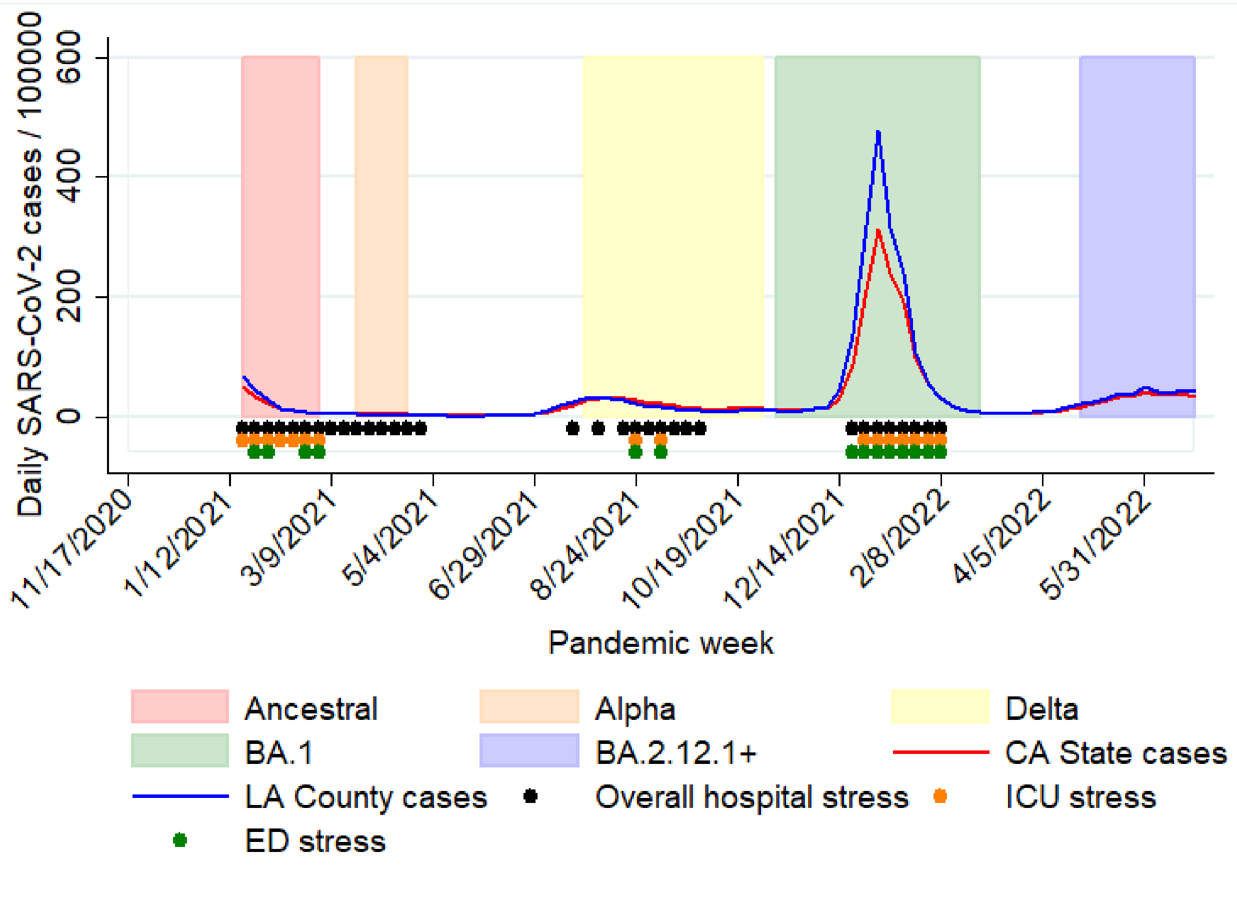
eFigure 3. Hospital stress and SARS-CoV-2 cases by pandemic week: Washington State and King County



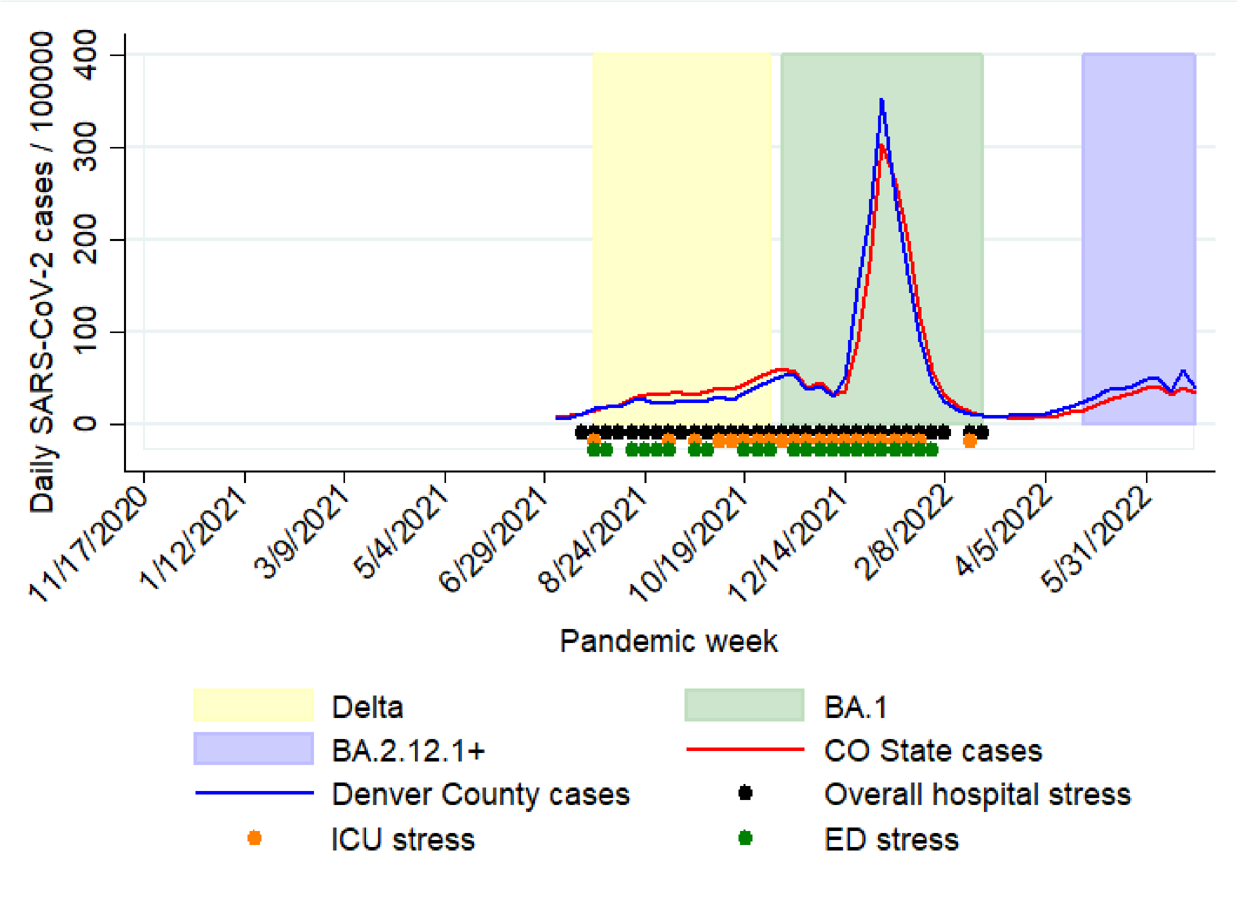
eFigure 4. Hospital stress and SARS-CoV-2 cases by pandemic week: Washington State and Snohomish County



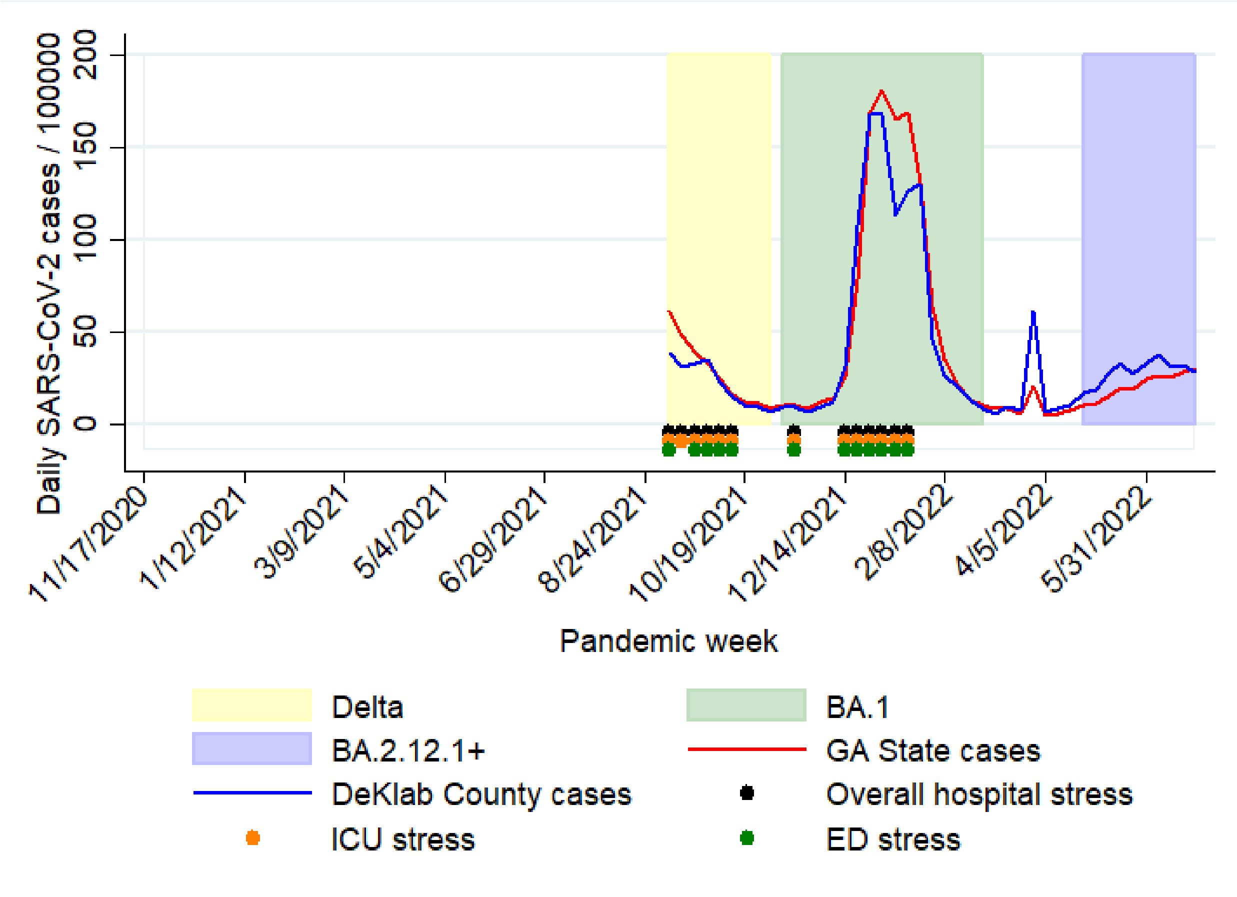
eFigure 5. Hospital stress and SARS-CoV-2 cases by pandemic week: California State and Los Angeles County



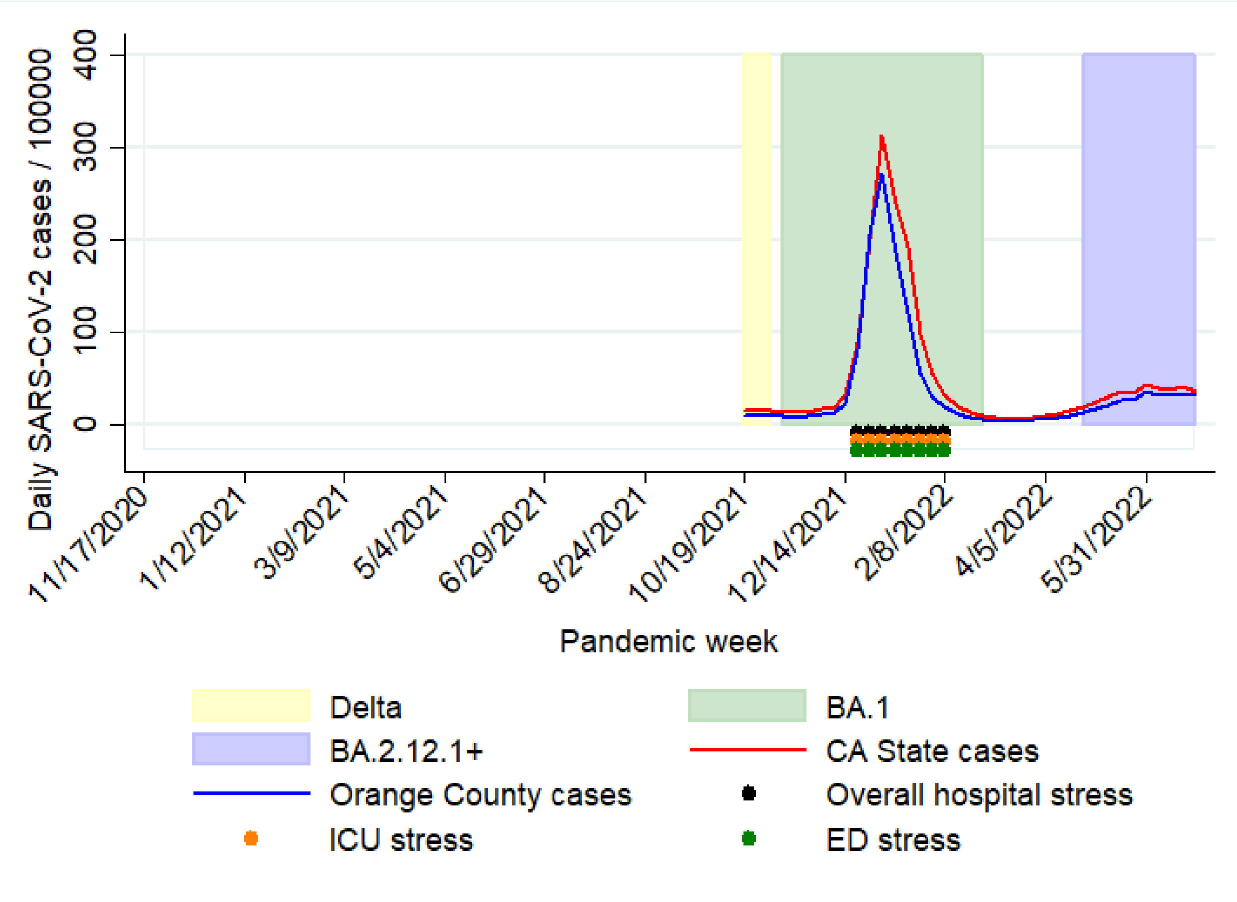
eFigure 6. Hospital stress and SARS-CoV-2 cases by pandemic week: Colorado State and Denver County



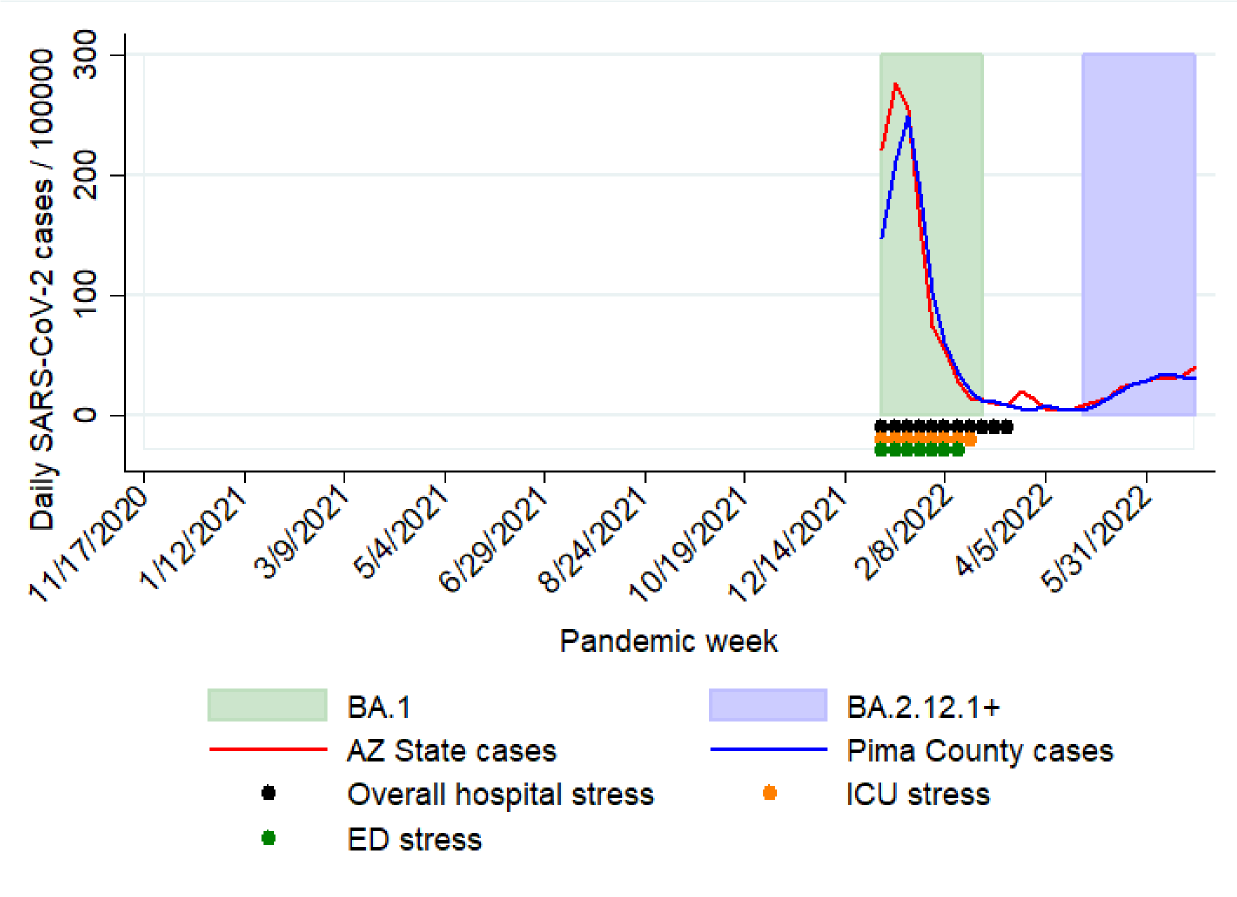
eFigure 7. Hospital stress and SARS-CoV-2 cases by pandemic week: Georgia State and DeKalb County



eFigure 8. Hospital stress and SARS-CoV-2 cases by pandemic week: California State and Orange County



eFigure 9. Hospital stress and SARS-CoV-2 cases by pandemic week: Arizona State and Pima County



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