

# THE LANCET Infectious Diseases

## Supplementary webappendix

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## Appendix: Projecting the demand for ventilators at the peak of COVID-19 outbreaks in the United States

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### Methods

For the number of ICU beds that will be occupied by COVID-19 patients at the time of peak hospitalization in the US (denoted  $N_I$ ), we used estimates from a mathematical model simulating a COVID-19 outbreak in the US<sup>1</sup>. For the proportion of COVID-19 ICU patients requiring ventilation, we used clinical data from seven studies on the use of noninvasive and invasive ventilation for ICU patients<sup>2-8</sup>. We used  $p_V = 1 - (1 - p_N)(1 - p_I)$  to calculate the likelihood of a single COVID-19 ICU patient requiring ventilation at some point during their stay, where  $p_N$  is the proportion needing noninvasive ventilation and  $p_I$  is the fraction requiring invasive ventilation. We evaluate the fraction of ICU patients requiring both using  $p_B = p_N + p_I - p_V$ .

We use an average recovery time of 13.25 days in the ICU and 7 days from ICU admission to death<sup>1</sup> in our calculation, with 23.5% mortality for hospitalized COVID-19 patients.<sup>1</sup> Given the median time from hospital admission to acute respiratory distress syndrome of two days,<sup>9</sup> we assumed that patients who require both invasive and noninvasive ventilation spend two days in the ICU using noninvasive ventilation. Thus, the proportion of ICU patients needing invasive ventilation at any given time is  $q_I = (1 - 0.235)(11.25/13.25)p_B + (0.235)(5/7)p_B + p_I(1 - p_N)$ . The proportion of ICU patients needing noninvasive ventilation at any given time is expressed as  $q_N = p_V - q_I$ . Therefore, the number of COVID-19 ICU patients needing invasive ventilation would be  $N_I q_I$  and the number of COVID-19 ICU patients needing noninvasive ventilation is given by  $N_I q_N$ . For estimating the proportion of COVID-19 ICU patients needing invasive and noninvasive ventilation, we combined data from seven independent studies (Table A1).

Projections are reported as the average and interquartile range over 100 independent realizations performed in the previous study for the scenario where there is no community intervention (i.e. COVID-19 cases exhibiting mild symptoms do not self-isolate)<sup>1</sup>. Specifically, the average number of COVID-19 ICU patients at the outbreak peak is 293,520 (IQR: 257,800- 336,320).

In the US, 29.0% of the existing 97,776 ICU beds are routinely occupied by patients requiring invasive mechanical ventilation,<sup>10,11</sup> indicating 28,355 ventilators would be in use by non-COVID-19 patients. Thus, 33,833 (~54.40%) of the 62,188 routinely used invasive ventilators would be

available (Table A2). Accounting for additional units in storage that are likely to be deployed during this outbreak (Table A2), 69,660 invasive ventilators could be available for COVID-19 patients. Assuming all noninvasive ventilators are accessible for routine use prior to the COVID-19 outbreak, we used the same rate (54.4%) to approximate the availability of noninvasive ventilators.

**Table A1.** The number of ICU patients, ICU patients who needed noninvasive ventilation, and those who required invasive ventilation, as reported in previous studies. The likelihood that an ICU patient requires any type of ventilation, requires both types of ventilation, or requires a specific type of ventilation at any given moment during ICU treatment is then derived for each report.

| Study                      | ICU patients | Invasive                | Noninvasive              | Likelihood of ventilation | Requires invasive and noninvasive § | Invasive use at any given moment * | Noninvasive use at any given moment* |
|----------------------------|--------------|-------------------------|--------------------------|---------------------------|-------------------------------------|------------------------------------|--------------------------------------|
| Wang et al. <sup>2</sup>   | 36           | 17 (47.22%)             | 15 (41.67%)              | 69.21%                    | 19.68%                              | 43.63%                             | 25.58%                               |
| Guan et al. <sup>3</sup>   | 67           | 25 (37.31%)             | 29 (43.28%)              | 64.44%                    | 16.15%                              | 34.36%                             | 30.08%                               |
| Zhou et al. <sup>4**</sup> | 50           | 32 (64.00%)             | 26 (52.00%)              | 82.72%                    | 33.28%                              | 57.92%                             | 24.80%                               |
| Cao et al. <sup>5</sup>    | 18           | 7 (38.89%)              | 2 (11.11%)               | 45.68%                    | 4.32%                               | 38.10%                             | 7.58%                                |
| Chen et al. <sup>6**</sup> | 23           | 4 (17.39%)              | 13 (56.52%)              | 64.08%                    | 9.83%                               | 15.60%                             | 48.48%                               |
| Yang et al. <sup>7</sup>   | 52           | 22 (42.31%)             | 29 (55.77%)              | 74.48%                    | 23.60%                              | 38.00%                             | 36.48%                               |
| Huang et al. <sup>8</sup>  | 13           | 4 <sup>†</sup> (30.77%) | 8 <sup>††</sup> (61.54%) | 73.37%                    | 18.94%                              | 27.32%                             | 46.05%                               |
| Total                      | 259          | 111 (42.86%)            | 122 (47.10%)             | 69.77%                    | 20.19%                              | 39.18%                             | 30.59%                               |

§ We assumed independence for the need of invasive and noninvasive ventilation

\* We assumed patients who require both invasive and noninvasive ventilation are on noninvasive ventilation for two days during their stay in the ICU

\*\* We assumed ventilation occurs only for ICU patients

† Accounts for the two patients on invasive mechanical ventilation and extracorporeal membrane oxygenation;

†† Noninvasive ventilation or high-flow nasal cannula

**Table A2.** The number of invasive, noninvasive ventilators and limited-featured ventilators

| <b>Ventilator</b>                          | <b>Number</b> | <b>Reference</b> |
|--|---------------|------------------|
| Total: Invasive Ventilator                 | 98,015        |                  |
| <i>Routinely used invasive ventilators</i> | 62,188        | 12               |
| <i>SNS invasive stockpile</i>              | 12,700        | 13               |
| <i>Portable mechanical gas</i>             | 9,745         | 12               |
| <i>Standby</i>                             | 3,894         | 12               |
| <i>Portable mechanical pneumatic</i>       | 9,488         | 12               |
| Total: Noninvasive                         | 22,976        | 12               |
| Total: Limited-featured ventilators        | 52,635        |                  |
| <i>High frequency</i>                      | 3,531         | 12               |
| <i>Neonatal pediatric</i>                  | 5,833         | 12               |
| <i>CPAP</i>                                | 8,567         | 12               |
| <i>Automatic resuscitator</i>              | 32,668        | 12               |
| <i>Basic EMS transport</i>                 | 2,036         | 12               |

## Appendix References

- 1 Moghadas SM, Shoukat A, Fitzpatrick MC, *et al.* Projecting hospital utilization during the COVID-19 outbreaks in the United States. *Proc Natl Acad Sci U S A*.
- 2 Wang D, Hu B, Hu C, *et al.* Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China. *JAMA*. 2020; **323**: 1061.
- 3 Guan W-J, Ni Z-Y, Hu Y, *et al.* Clinical Characteristics of Coronavirus Disease 2019 in China. *N Engl J Med* 2020; published online Feb 28. DOI:10.1056/NEJMoa2002032.
- 4 Zhou F, Yu T, Du R, *et al.* Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. *The Lancet*. 2020. DOI:10.1016/s0140-6736(20)30566-3.
- 5 Cao J, Hu X, Cheng W, Yu L, Tu W-J, Liu Q. Clinical features and short-term outcomes of 18 patients with corona virus disease 2019 in intensive care unit. *Intensive Care Med* 2020; published online March 2. DOI:10.1007/s00134-020-05987-7.
- 6 Chen N, Zhou M, Dong X, *et al.* Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. *The Lancet*. 2020; **395**: 507–13.
- 7 Yang X, Yu Y, Xu J, *et al.* Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study. *The Lancet Respiratory Medicine*. 2020. DOI:10.1016/s2213-2600(20)30079-5.
- 8 Huang C, Wang Y, Li X, *et al.* Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet* 2020; **395**: 497–506.
- 9 Wu C, Chen X, Cai Y, *et al.* Risk Factors Associated With Acute Respiratory Distress Syndrome and Death in Patients With Coronavirus Disease 2019 Pneumonia in Wuhan, China. *JAMA Intern Med* 2020; published online March 13. DOI:10.1001/jamainternmed.2020.0994.
- 10 Wunsch H, Wagner J, Herlim M, Chong DH, Kramer AA, Halpern SD. ICU occupancy and mechanical ventilator use in the United States. *Crit Care Med* 2013; **41**: 2712–9.
- 11 Fast Facts on U.S. Hospitals, 2020 | AHA. American Hospital Association. <https://www.aha.org/statistics/fast-facts-us-hospitals> (accessed March 13, 2020).
- 12 Rubinson L, Vaughn F, Nelson S, *et al.* Mechanical ventilators in US acute care hospitals. *Disaster Med Public Health Prep* 2010; **4**: 199–206.
- 13 SCCM | United States Resource Availability for COVID-19. Society of Critical Care Medicine (SCCM). <https://sccm.org/Blog/March-2020/United-States-Resource-Availability-for-COVID-19> (accessed March 23, 2020).