

# ORIGINAL RESEARCH

## Mechanical Ventilators in US Acute Care Hospitals

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### ABSTRACT

**Objective:** The supply and distribution of mechanical ventilation capacity is of profound importance for planning for severe public health emergencies. However, the capability of US health systems to provide mechanical ventilation for children and adults remains poorly quantified. The objective of this study was to determine the quantity of adult and pediatric mechanical ventilators at US acute care hospitals.

**Methods:** A total of 5752 US acute care hospitals included in the 2007 American Hospital Association database were surveyed. We measured the quantities of mechanical ventilators and their features.

**Results:** Responding to the survey were 4305 (74.8%) hospitals, which accounted for 83.8% of US intensive care unit beds. Of the 52 118 full-feature mechanical ventilators owned by respondent hospitals, 24 204 (46.4%) are pediatric/neonatal capable. Accounting for nonrespondents, we estimate that there are 62 188 full-feature mechanical ventilators owned by US acute care hospitals. The median number of full-feature mechanical ventilators per 100 000 population for individual states is 19.7 (interquartile ratio 17.2–23.1), ranging from 11.9 to 77.6. The median number of pediatric-capable device full-feature mechanical ventilators per 100 000 population younger than 14 years old is 52.3 (interquartile ratio 43.1–63.9) and the range across states is 22.1 to 206.2. In addition, respondent hospitals reported owning 82 755 ventilators other than full-feature mechanical ventilators; we estimate that there are 98 738 devices other than full-feature ventilators at all of the US acute care hospitals.

**Conclusions:** The number of mechanical ventilators per US population exceeds those reported by other developed countries, but there is wide variation across states in the population-adjusted supply. There are considerably more pediatric-capable ventilators than there are for adults only on a population-adjusted basis.

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**Key Words:** surge mechanical ventilation, disaster respiratory care, mass respiratory failure, surge capacity

Severe public health emergencies may lead to mass respiratory failure,<sup>1,3</sup> and survival of patients with severe acute respiratory failure (ARF) depends on timely access to life-sustaining care, including mechanical ventilation. The profound need for respiratory support during these events highlights the importance of ensuring an adequate supply and distribution of medical equipment for mechanical ventilation. Planning for mass respiratory public health emergencies has been hampered by not knowing how many ventilators there are in US hospitals, how they are distributed across the country, and whether, taken together, the numbers and types of ventilators in hospitals will provide sufficient surge capacity to meet anticipated needs.

There was significant consternation during the 2009 influenza pandemic about whether there would be sufficient ventilators in the United States to handle various projections of surges in ARF,<sup>4,5</sup> but existing knowledge of device number and distribution severely limited analyses. Estimates of the number of full-feature ventilators, which are the first-line ventilators used in US hospitals for the vast majority of ARF, range from 54 000 to 105 000, but the full number has never been enumerated.<sup>6,7</sup> Uncertainty regarding

US hospital ventilator capacity is further compounded when considering high-risk subpopulations such as children. One-quarter of the US population is children; not all full-feature ventilators can be used for small children or neonates. The number of full-feature ventilators in the United States that are capable of ventilating small children remains unknown. These uncertainties came to the forefront as the 2009 influenza pandemic unfolded, and there was a compelling need to enhance the accuracy and precision of the estimate of full-feature ventilators in US hospitals for adults and children, because these quantities reflect national ventilation capacity for ARF using usual, standard devices.

Public health emergencies may exceed full-feature ventilator capacity. For these scenarios, surge capacity strategies to repurpose additional positive pressure ventilation (PPV) equipment (eg, portable ventilators), which are owned by hospitals or maintained in public health

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stockpiles, have been proposed.<sup>1,8,9</sup> Fortunately, hospitals use a number of different ventilators in addition to full-feature devices for daily delivery of care. These additional PPV devices normally have a limited scope of use as compared with full-feature ventilators. They are used for specific subpopulations of patients (obstructive sleep apnea and continuous positive airway pressure [CPAP]-only device users) or limited durations (transport ventilators). It is unfortunate that the number of these additional devices is just as uncertain as full-feature ventilators. Determination of the total number of additional PPV devices, however, is not sufficient for quantifying ventilator surge capacity. Not all PPV categories and devices are equivalent. Some devices are capable of providing ventilatory support across a wide range of respiratory derangements and severity, whereas others are incapable of supporting even mild respiratory failure. Hence, ascertaining the quantity of devices by functional ventilator category is necessary to determine US ventilator surge capacity.

The severity and duration of 2009 pandemic influenza A (H1N1)-associated respiratory failure highlighted the need for a more comprehensive understanding of the capability to provide respiratory support during emergencies in the United States. Because the supply and geographic distribution of different categories of mechanical ventilation capacity are of profound importance for planning and predicting responses to severe public health emergencies throughout the United States, we performed a survey to inventory PPV equipment at all of the US acute care and specialty hospitals.

## METHODS

### Survey

In collaboration with the American Association for Respiratory Care (AARC), we surveyed hospital-based owners of ventilators in the United States. The purpose of the survey was to inventory ventilators owned by US health care facilities serving patients with ARF. To be inclusive, we surveyed respiratory care managers at all US hospitals cataloged by the American Hospital Association (AHA) in the following categories (including pediatric subcategories when available): general medical and surgical, acute long-term care, cancer, chronic disease, heart, orthopedics, obstetrics and gynecology, rehabilitation, surgical, tuberculosis and other respiratory diseases, and other specialties.<sup>10</sup>

To ensure a robust response, sampling followed procedures outlined by Dillman et al.<sup>11</sup> First, potential respondents were sent a letter from the AARC executive director and president and one from the US Department of Health and Human Services Assistant Secretary for Preparedness and Response encouraging survey participation. These were accompanied by a worksheet to assist respondents with presurvey response data collection (see Supplementary Appendix at <http://www.dmphp.org/misc/rubinson.pdf>). Three weeks later, a follow-up request was mailed to nonresponding hospitals. Subsequently, the AARC contacted each nonresponding facility by telephone to promote participation. Through their network of affiliate state respiratory societies, the AARC selected state coordinators who assisted with telephone follow-up. Throughout the survey re-

sponse period, which began in August 2009 and ended in October 2009, emergency preparedness and critical care organizations assisted with an information campaign encouraging nationwide hospital response.

### Survey Instrument

Respondents were asked to report on the number and types of mechanical ventilators owned by their respective medical facilities in the following 10 categories, based on the framework of Rubinson et al<sup>1</sup>: full featured, high frequency, portable mechanical (pneumatic driven only), portable, basic emergency medical services transport, noninvasive, CPAP only, automatic resuscitators, neonatal-pediatric-specific and standby (no longer used for everyday patient care but maintained and available on site). The survey instrument was updated to include all mechanical ventilators and automatic resuscitators approved by the US Food and Drug Administration up until the date of the initial survey mailing. Manual resuscitators were not included. Also, anesthesia machines were not included, because respiratory care professionals were unlikely to be able to provide accurate information regarding anesthesia machine model, quantities, and functional capabilities.

The survey was pilot tested in 2 large metropolitan cities and field validated at 3 hospitals in advance of the national survey. The primary data collection was Internet based, although e-mail and paper options were available. The US Office of Management and Budget reviewed and approved the instrument with respect to the Paperwork Reduction Act.<sup>12</sup>

### Ventilator Inventory and Statistical Analysis

Positive pressure ventilation devices were tallied by category. There is no established methodology for estimating total ventilator numbers at all US acute care hospitals from partial respondent data. We theorized that the number of ventilators in a hospital would be proportional to 1 or all of the following hospital characteristics: number of staffed beds, adult intensive care unit (ICU) beds, and/or total ICU beds. To estimate the number of ventilators from nonresponding or partially responding hospitals, we calculated ratios of reported ventilators to these characteristics and applied the ratios to estimate the number of devices owned by all US acute care hospitals (see Supplementary Appendix for example of calculations at <http://www.dmphp.org/misc/rubinson.pdf>). We also accounted for missing or partial data using multiple imputation methods, with staffed hospital beds, adult ICU beds, total ICU beds, AHA hospital type, and critical access hospital status as variables.<sup>13</sup> These methods yielded similar results (Table 1), with estimations based on the reported ventilator-to-total ICU bed ratio giving the most conservative results. The estimates using the ventilator-to-total ICU bed ratio were used for subsequent analyses (Table 2 and Figure 1 and Figure 2). All of the analyses were performed using SAS version 9.2 (SAS Institute Inc, Cary, NC).

United States Census estimates for 2008 were used to determine mechanical ventilators per 100 000 population.<sup>14</sup> To calculate the number of devices per pediatric population, the US

2008 Census estimate for people younger than 14 years was used. We separated adult from pediatric ventilators based on the ability to deliver a tidal volume below 300 cm<sup>3</sup>,<sup>15</sup> the median tidal volume needed to ventilate children aged 13 to 14 with acute respiratory distress syndrome based on 6 cm<sup>3</sup>/kg body weight using US growth charts.<sup>16</sup>

Institutional demographic data including hospital type and state as well as number of ICU beds and staffed hospital beds were ascertained from the 2007 AHA database.  $\chi^2$  tests were used to compare respondent vs nonrespondent summative characteristics. The Mann-Whitney *U* test was used to assess differences among institutional characteristics. Two-tailed *P* values  $\leq .05$  were considered statistically significant. Several hospitals not included in

the AHA database (owing to nonparticipation or recent changes in hospital ownership) learned of the survey through publicity efforts. For these few non-AHA database hospitals (ie, those hospitals who responded to our survey did not participate in the 2007 annual AHA survey), hospital demographics except for state location were not available for analysis.

**RESULTS**

Of the 5752 US acute care hospitals, 4305 (74.8%) responded to the survey and reported ownership of 52 118 full-feature mechanical ventilators. Responding hospitals were significantly larger (staffed hospital beds; median, interquartile range [IQR] 102 [40–230] vs 60 [28–149]; *P* < .0001; Table 2) and had more ICU beds (8 [0–26] vs 4 [0–13]; *P* < .0001) than did nonrespondents.

**TABLE 1**

Estimated Number of Full-Featured Mechanical Ventilators in US Acute Care Hospitals Using Various Estimation Methods					
Estimation Method	Respondent MV	Ratio of MV to Hospital Characteristic	Estimated MV for All US Acute Care Hospitals	Respondent MV Pediatric/Neonatal Capable	Estimated MV Pediatric/Neonatal Capable for All US Acute Care Hospitals
Ratio of MV to adult ICU beds	52 118	.958	62 433	24 204	28 994
Ratio of MV to total ICU beds*	52 118	.703	62 188	24 204	28 881
Ratio of MV to staffed hospital beds	52 118	.072	64 239	24 204	29 833
Multiple imputation†	52 118	N/A†	63 404	24 204	29 801
Average of 4 methods			63 066 (61 567-64 564,95%CI)		29 377 (28 566-30 189,95%CI)

CI=confidence interval; ICU=intensive care unit; MV=Full-feature mechanical ventilators

\*Considered by the authors to represent the best estimation method (see text).

†Multiple imputation estimation method considered the number of staffed hospital beds, number of adult ICU beds, number of total ICU beds, critical access hospital designation, and facility type.

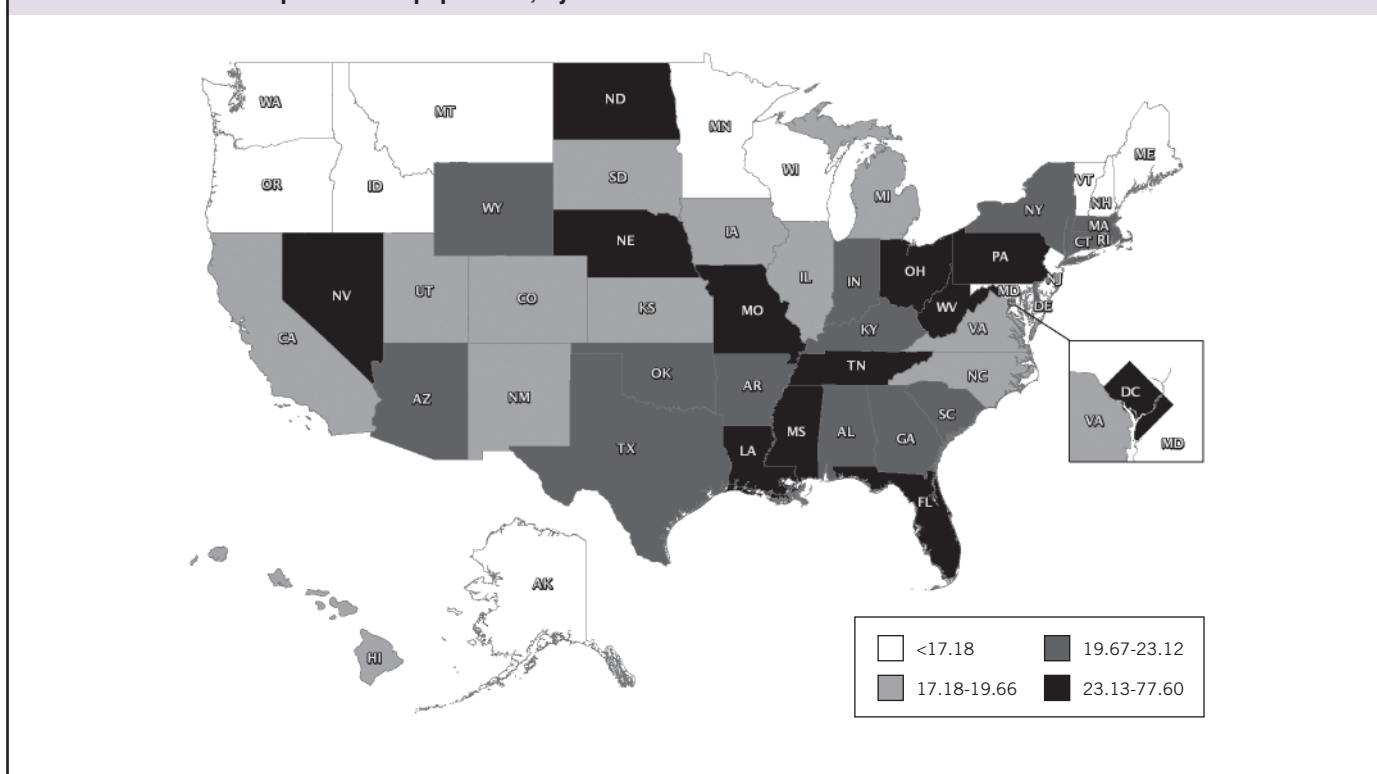
**TABLE 2**

Facility Type and Bed Type, by National Ventilator Inventory Response Status				
	Respondents (n = 4305)	Nonrespondents (n = 1447)	Total (n = 5752)	<i>P</i>
<b>AHA Facility Classification</b>				
General Medical and Surgical (%)	3741 (86.9)	1110 (76.7)	4851 (84.3)	<.001
Acute Long-Term Care (%)	179 (4.2)	152 (10.5)	331 (5.8)	<.001
Rehabilitation (%)	133 (3.1)	98 (6.8)	231 (4.0)	<.001
Pediatric (All Facilities) (%)	77 (1.8)	25 (1.7)	102 (1.8)	.88
Pediatric (General Medical/Surgical)	36	9	45	—
Pediatric (Acute Long-Term)	4	1	5	—
Pediatric (Chronic)	2	0	2	—
Pediatric (Orthopedic)	9	6	15	—
Pediatric (Rehabilitation)	7	4	11	—
Pediatric (Other Specialty)	19	5	24	—
Other (%)	102 (2.4)	51 (3.5)	153 (2.7)	.02
Unclassified (%)	7 (0.2)	3 (0.2)	10 (0.2)	.72
Non-AHA (%)	66 (1.5)	8 (0.6)	74 (1.3)	.004
<b>Additional facility characteristics</b>				
VA (%)	131 (3.0)	4 (0.3)	135 (2.4)	<.001
Critical access hospital designation (%)	976 (22.7)	302 (20.9)	1278 (22.2)	.5
<b>Bed Type</b>				
Staffed hospital beds, total (%)	719 902 (81.1)	167 429 (18.9)	887 331	<.001
Hospital median (IQR)	102 (40-230)	60 (28-149)	90 (35-211)	
<b>ICU</b>				
All, total (%)	74 175 (83.8)	14 332 (16.2)	88 507	<.001
Hospital median (IQR)	8 (0-26)	4 (0-13)	7 (0-24)	
Adult (%)	54 383 (83.5)	10 763 (16.5)	65 146	<.001
Pediatric (%)	3698 (85.1)	649 (14.9)	4347	<.001
Neonatal (%)	16 094 (84.6)	2920 (15.4)	19 014	<.001

AHA=American Hospital Association; ICU=intensive care unit; VA=Department of Veterans Affairs.

FIGURE 1

Full-feature ventilators per 100 000 population, by state.



Responding hospitals represent 81.1% of the total US staffed hospital beds including 83.5% of adult ICU, 85.1% of pediatric ICU, and 84.6% of neonatal ICU beds. The respondent and nonrespondent groups included similar proportions of facilities with critical access hospital designation ( $P = .15$ ).

Based on all 4 calculation methods, US hospitals own an estimated 63 066 (95% confidence interval, 61 567–64 564) full-feature mechanical ventilators. (Table 3) Using the most conservative estimation method (the reported ventilator-to-total ICU bed ratio), we estimate that there are at least 62 188 of these devices in the United States, or approximately 20.5/100 000 population. The ratios of full-feature intensive care unit ventilators to staffed hospital beds, adult ICU beds, and total ICU beds are 0.072, 0.958, and 0.703, respectively. Quantities of full-feature ventilators per population varied across states (range, 11.9–77.6) with a state median population of 19.7/100 000 (IQR, 17.2–23.1) (Figure 1, Table 4).

Almost half (46.4%) of these full-feature devices either have baseline capability or were purchased with modification for ventilating pediatric and neonatal patients. This translates to an estimated 28 811 pediatric-capable full-feature ventilators in US hospitals, or 50.7/100 000 population younger than 14 years. Across states, the estimated range of pediatric-neonatal-capable full-feature mechanical ventilators per 100 000 population younger than 14 years was 22.1 to 206.2 per state with a

state median of 52.3 (IQR, 43.1–63.9) (Figure 2). Respondents reported an additional 82 755 PPV devices (Table 3). The estimated quantity of these 9 additional categories of PPV devices in all US acute care hospitals is 98 738.

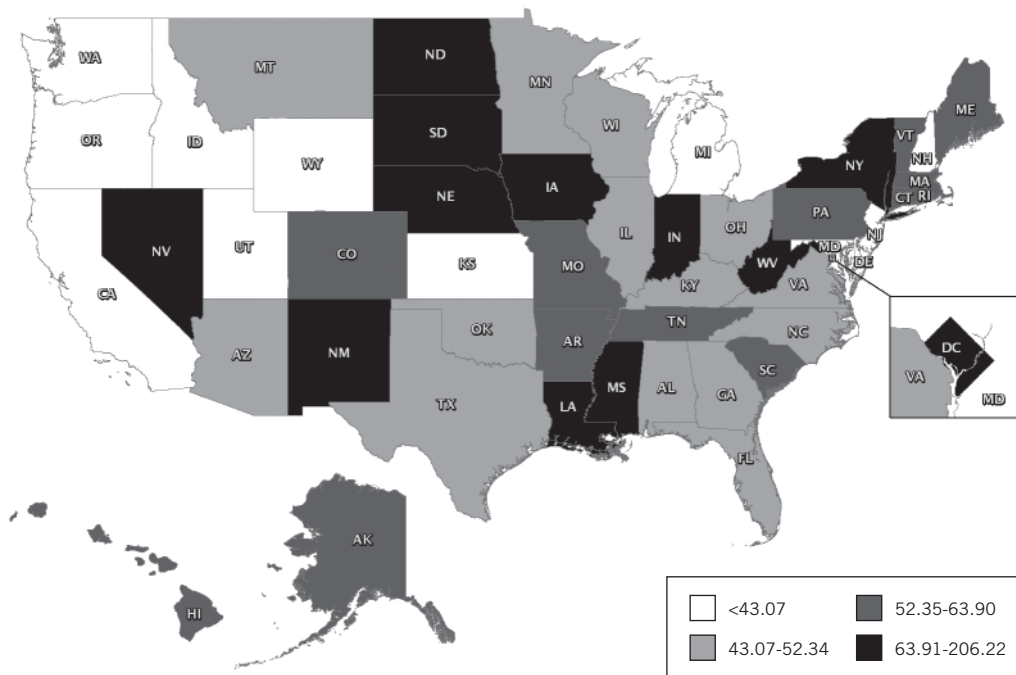
**COMMENT**

This survey is the first reliable national estimate of mechanical ventilators owned by US acute care hospitals and provides 3 important policy-related findings. First, with an estimated 20.5 full-feature ventilators per 100 000 population, the United States has proportionally more per capita PPV capacity than published available data demonstrates for other developed countries.<sup>17,18</sup> For comparison, these numbers are considerably higher than those published for Australia and New Zealand (a mean of 5.4 ICU beds with mechanical ventilation capability per 100 000 population) as well as the Canadian province of Ontario (8.7/100 000).

Emergency planners have lacked a simple and accurate way to predict quantities of mechanical ventilators at hospitals within their jurisdictions and nationwide. This study provides robust ratios to estimate the number of full-feature ventilators based on the number of staffed beds, adult ICU beds, and/or total ICU beds. The strength of the estimates presented here derives from a validated survey instrument that included well-defined PPV device definitions, a sampling frame including all acute care US

**FIGURE 2**

**Pediatric-capable full-feature ventilators per 100 000 population younger than 14 years old, by state.**



hospitals, and a high survey response rate. Our estimate of full-feature mechanical ventilators is slightly higher than Niska and Burt’s estimate<sup>6</sup> and far less than that reported by Osterholm.<sup>7</sup> Osterholm’s methodology has not been published. Niska and Burt’s estimate was derived from 739 hospital respondents from a sampling frame of 874 hospitals.

Second, nearly half of all US full-feature ventilators are reported to be able to ventilate small pediatric and neonatal patients. The actual size of the pediatric population that cannot be ventilated by an adult-only ventilator is likely smaller than the conservative cutoff of 14 years old (<50 kg) we used, so the relative ratio of pediatric-capable full-feature ventilators to pediatric and neonatal populations is probably even higher than we report. However, the number of devices owned by US hospitals that are capable of ventilating small children does not ensure that surge mechanical ventilation for pediatric and neonatal populations is no longer a challenge. Pediatric capability of the ventilator does not guarantee that the device will be available and unassigned (eg, to an adult) if, when, and where there is a surge of pediatric ARF. In addition, although hospitals may own pediatric-capable ventilators, they may not stock sufficient supplies of ancillary equipment (eg, pediatric-appropriate ventilator circuits, humidification equipment, closed-circuit suction catheters), rendering the PPV devices less useful for pedi-

**TABLE 3**

**Reported and Estimated Number of Positive Pressure Ventilation Devices, by Category**

	Respondents	Estimated *
Ventilator Category	N	N
Full-feature mechanical	52 118	62 188
First-line surge mechanical ventilators		
Portable mechanical gas	8164	9745
Standby	3265	3894
Additional surge mechanical ventilators		
Portable mechanical pneumatic	7955	9488
Noninvasive	19 254	22 976
Select-population surge mechanical ventilators		
High frequency	2963	3531
Neonatal pediatric	4887	5833
CPAP	7182	8567
Limited-functionality surge devices		
Automatic resuscitator	27 376	32 668
Basic EMS transport	1709	2036
Total	134 873	160 923

CPAP=continuous positive airway pressure; EMS=emergency medical services.

\*The estimation method used was the ratio of the number of full-feature mechanical ventilators to the number of total intensive care unit beds.

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atric and neonatal patients. Finally, the presence of the device alone does not guarantee availability of skilled staff.

Third, US hospitals own a significant number of additional PPV devices that can be used to augment ventilator surge capacity beyond the baseline ratio of approximately 0.7 full-feature ventilators per ICU bed. Expert panels such as the Task Force for Mass Critical Care have recommended using sophisticated por-

table ventilators, which are normally used during patient transport, for augmentation of PPV equipment when there are insufficient full-feature ventilators.<sup>9</sup> We estimate that nearly 20 000 of these devices are owned by US hospitals. A total of 3894 “standby” ventilators are also owned by US hospitals. These devices are generally older-generation ICU machines that are no longer routinely used but are maintained for use in an emergency. These 3 categories of devices (2 categories of transport

### TABLE 4

#### Quantities of Full-Feature Ventilators per Population, by State

	Estimated No. Full-Feature Mechanical Ventilators	Estimated No. Full-Feature Mechanical Ventilators per 100 000 Population	Estimated No. Pediatrics-Capable Full-Feature Mechanical Ventilators	Estimated No. Full-Feature Mechanical Ventilators, Pediatrics Capable per 100 000 Population <14 y
United States (excluding territories)	62 188	20.5	28 881	50.7
Alabama	920	19.7	375	43.4
Alaska	104	15.2	88	63.9
Arizona	1309	20.1	629	46.8
Arkansas	633	22.2	313	57.5
California	6589	17.9	2584	35.9
Colorado	913	18.5	593	62.7
Connecticut	688	19.7	383	62.2
Delaware	200	22.9	41	25.8
District of Columbia	459	77.6	179	206.2
Florida	4307	23.5	1527	49.6
Georgia	2093	21.6	887	44.5
Hawaii	241	18.7	127	57.4
Idaho	182	11.9	80	24.8
Illinois	2311	17.9	1276	52.0
Indiana	1472	23.1	862	70.5
Iowa	542	18.1	375	68.6
Kansas	514	18.3	217	39.8
Kentucky	949	22.2	335	43.1
Louisiana	1109	25.2	680	79.8
Maine	214	16.2	112	54.4
Maryland	953	16.9	345	33.7
Massachusetts	1408	21.7	670	61.7
Michigan	1847	18.5	660	36.6
Minnesota	811	15.5	445	46.1
Mississippi	769	26.2	396	66.8
Missouri	1437	24.3	685	62.9
Montana	158	16.3	86	51.6
Nebraska	466	26.1	337	97.0
Nevada	753	29.0	338	64.4
New Hampshire	207	15.7	73	33.3
New Jersey	1487	17.1	622	39.7
New Mexico	366	18.4	254	65.3
New York	4506	23.1	2252	67.2
North Carolina	1782	19.3	901	51.5
North Dakota	180	28.1	75	68.2
Ohio	2729	23.8	920	44.2
Oklahoma	740	20.3	350	49.6
Oregon	503	13.3	216	32.4
Pennsylvania	3013	24.2	1248	59.9
Rhode Island	196	18.7	99	57.4
South Carolina	949	21.2	435	53.0
South Dakota	149	18.6	116	76.0
Tennessee	1517	24.4	724	63.4
Texas	5419	22.3	2777	52.3
Utah	503	18.4	182	26.7
Vermont	90	14.5	58	60.9
Virginia	1334	17.2	738	52.3
Washington	836	12.8	366	30.9
West Virginia	550	30.3	263	89.0
Wisconsin	864	15.4	481	47.9
Wyoming	117	22.0	22	22.1

ventilators and standby) have many features that are similar to modern full-feature ventilators and represent a reasonable surge option for less-severe ARF without deviating significantly from standard respiratory practice.

Further surge capacity is indicated by the estimated 22 976 non-invasive devices owned by US acute care hospitals that may be used to provide standard noninvasive ventilation for appropriate types of ARF<sup>19</sup> as well as repurposed for invasive ventilation. The estimated 8567 CPAP devices and 5833 neonatal-pediatric specific devices have less general surge value but still may be useful for select subpopulations (eg, moderately ill infants). It is important to note, however, that CPAP-only devices have little utility for ARF.

The clinical implications of the relatively high US per capita PPV capacity can be understood in relation to Australia and New Zealand's experience with H1N1. These countries experienced the influenza pandemic during their traditional influenza season, reporting peak critical care needs by patients with 2009 H1N1 of between 0.63 and 1.06 ICU beds per 100 000 population.<sup>20</sup> Their ICUs were challenged by the severity of illness, but in light of the fact that fewer than 25% of their total ICU beds were occupied with H1N1-associated critical illness, and 64.6% of these patients required PPV, it is not surprising that there were no widespread reports of ventilator shortages. And since the Northern Hemisphere pandemic influenza disease burden remained similar to the Southern Hemisphere experience, US PPV availability generally met the need, even for states at the lower range of ventilators per capita.

Our finding of considerable variation across states in the number of full-feature devices per adult and pediatric populations is in line with previous findings such as the Fisher et al report regarding wide variation in many aspects of health care supply.<sup>21</sup> Although the cause of this variation is not clarified by the study, its implications for regional preparedness for widespread ARF are important enough to warrant further investigation.

Despite the strengths of the methodology for this study, a number of limitations warrant highlighting. We counted a large number of devices. Still, these numbers are lower than the actual numbers of PPV devices across the United States because they do not include those rented by hospitals, those at facilities not captured within the AHA database and not responding to the survey, and those used at nursing facilities other than long-term ventilator and rehabilitation facilities, or those used by schools for respiratory care. Furthermore, devices owned by intrastate regions, states, and federal agencies such as the Strategic National Stockpile were not captured by this survey because we requested only counts of devices owned by the responding facility. The survey also did not capture PPV devices used in the community. There are an estimated 10 000 individuals using mechanical ventilation at home<sup>22</sup>; many have a primary ventilator and a back-up device. The features of de-

vices used for home ventilation vary considerably, and these devices are usually assigned to a patient, so their utility for surge mechanical ventilation is difficult to estimate.

Respondents and nonrespondents differed by hospital bed numbers, presence of critical care units, and numbers of ICU beds, as well as by makeup by AHA facility classification. To account for these differences, we used the multiple imputations method to ascribe quantities of ventilators to nonrespondent hospitals based on the known quantities of ventilators at respondent hospitals with matching characteristics. The estimate of total full-feature ventilators in US acute care hospitals derived from the multiple imputations method was reassuringly similar to the results from additional methods, which did not directly account for facility classification differences (Table 1). Still, our study cannot determine whether ventilator numbers at respondent hospitals are inherently different from those at nonrespondent hospitals, even if the facilities are matched for size and facility type; this limitation leaves the possibility of residual inaccuracies in our estimate of devices in all hospitals. The potential influence of response bias is, however, tempered by our high response rate.

We sought PPV data from all US acute care hospitals; the response bias toward larger hospitals with more critical care capacity is not necessarily undesirable. Our goal was to count PPV devices at facilities where patients with ARF would be most likely treated during emergencies, in other words, facilities with ICUs. The vast majority of US hospitals with critical care capability responded to the survey, therefore we have an accurate count of ventilators at those facilities most likely to care for the majority of victims with ARF during an emergency.

Our study does not discern whether the PPV devices counted in our survey were available for use or were already assigned to a patient, so we are not certain how many could actually be used immediately. Moreover, there may be many total devices in the United States, but if the devices are not in the same location as patient demand, then surge mechanical ventilation response activities still may be necessary. Recognizing this vulnerability, contingency planning for worsening of the current influenza pandemic or a future event has led the US Department of Health and Human Services to continue to expand the number of PPV devices in the Strategic National Stockpile and support the development of novel surge mechanical ventilators.<sup>23</sup>

Positive pressure ventilation devices alone do not ensure mechanical ventilation capability. Expert and experienced staff who know how to care for critically ill patients are essential. Positive pressure ventilation devices are durable medical equipment, but they require ancillary equipment, most of which are consumable, to function. Our study did not assess the quantities of ventilator circuits, humidification equipment, suction equipment, physiologic monitors, medical gas, and airway interfaces. This additional information is important for an accurate determination of mechanical ventilation capability; the

complexity of collecting these data for the entire country and our desire to maximize response rate led to our excluding this information for the present study.

In conclusion, the present study provides the first comprehensive snapshot of mechanical ventilators at US acute care hospitals. Compared to published reports from the Southern Hemisphere, this study suggests that the United States has sufficient mechanical ventilators for an event of similar severity to the current influenza pandemic. Counts of devices are necessary but not sufficient, however, for a true determination of mechanical ventilation capability. Future studies should address both the supply and geographic distribution of staff and ancillary equipment, utilization rates, and appropriateness of PPV use, as well as standardization of PPV device functional capabilities and staff training.

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