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Letter to the Editor

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COVID-19 mortality in ICUs associated with critical care staffing

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To the Editor

Coronavirus disease 2019 (COVID-19) has been around for over a year since December 2019, and the global outlook is not optimistic. Because of its high transmissibility and high mortality, management of the COVID-19 pandemic has become a major challenge for health systems globally, especially for critical care.

However, the level of demand for physicians and nurses in intensive care units (ICUs) to manage critical patients with highly infectious diseases (such as COVID-19) is still unclear [1, 2]. Care for critically ill patients with highly communicable diseases may require more intensive care personnel than for non-communicable diseases. Therefore, we investigated ICU staffing in this cross-sectional survey from January 18 to March 14, 2020. A total of 58 ICUs were invited to participate, including 41 ICUs from Hubei Province and 17 ICUs from the other 11 provinces or municipalities in China. All ICUs included were only applicable for COVID-19 adult patients. In addition, a descriptive analysis of the reinforcements for care of critically ill patients was carried out and the epidemiological data on COVID-19 in Hubei Province was overlaid with this survey. No personal data was analyzed in this study. The data used in this study are considered a part of the public health outbreak investigation. Informed consent and approval was waived by the Institutional Review Board.

A total of 2635 COVID-19 patients were admitted to 58 ICUs with 1340 ICU beds. The number of physicians per bed and nurses per bed in these ICUs were 1.1(0.7, 1.8) and 3.5(2.3, 4.2), respectively. The average age of patients was 62.0 years (56.7 years, 65.0 years), and the proportion of male patients was 24.0% (12.0%, 43.0%). The overall mortality and 95% confidence interval (CI) was 23.6% (22.0%, 25.3%). Mortality in these ICUs ranged from 0.0% to 67.3%. This was divided into low mortality group (n = 19, mortality <7.7%), medium mortality group (n = 20, mortality 7.7–21.2%) and high mortality group (n = 19, mortality >21.2%). The differences in patient characteristics in the three groups were analysed (Table 1). The average age of the middle mortality and high mortality groups was significantly higher than that of the low mortality group ($p = 0.04$). The proportion of male patients, patients receiving mechanical ventilation (MV), or continuous renal replacement therapy (CRRT), and use of vasopressors also showed significant differences among the three groups. The ICU staffing is shown

Table 1. Critical care resources and characteristics of patient admissions in the recruited ICUs stratified by mortality[a]

	Total ICUs (n = 58)	Low mortality (19 ICUs)	Middle mortality (20 ICUs)	High mortality (19 ICUs)	*P* value
Critical care resources					
ICU beds	22.0(12.0, 32.0)	12.0(8.0, 24.0)	21.0(13.0, 30.0)	30.0(20.0, 40.0)	0.022
Physicians per bed	1.1(0.7, 1.8)	1.2(0.9, 1.8)	1.1(0.7, 1.9)	0.8(0.6, 1.3)	0.157
ICU-physician (%)	57.7(46.9, 72.2)	60.0(33.3, 75.9)	54.0(48.7, 71.8)	60.0(46.9, 76.2)	0.917
Nurses per bed	3.5(2.3, 4.2)	4.0(3.3, 5.7)	3.3(2.4, 4.2)	2.6(1.9, 4.0)	0.017
ICU-nurse (%)	58.3(45.3, 80.0)	63.2(40.0, 83.3)	51.7(42.7, 60.6)	62.8(46.4, 83.3)	0.242
Physician shifting (hour)	8.0(4.0, 8.0)	8.0(4.0, 12.0)	8.0(4.0, 12.0)	6.0(6.0, 8.0)	0.360
Nurse shifting (hour)	4.0(4.0, 6.0)	4.0(4.0, 6.0)	5.0(4.0, 6.0)	4.0(4.0, 6.0)	0.474
Inpatients per bed per month	1.1(0.7, 1.6)	1.0(0.6, 1.7)	1.0(0.7, 1.4)	1.4(1.0, 1.7)	0.180
Characteristics of ICU admissions					
Average admissions (n)	31.0(17.0, 70.0)	17.0(14.0, 36.0)	31.0(18.5, 50.0)	80.0(25.0, 89.0)	<0.001
Average age (y)	62.0(56.7, 65.0)	56.7(46.5, 62.0)	62.5(56.0, 65.0)	63.0(60.9, 67.0)	0.004
Proportion of males (%)	24.0(12.0, 43.0)	13.0(9.0, 31.0)	22.0(10.0, 35.0)	45.0(16.0, 58.0)	0.002
HFNC only (%)	22.7(11.8, 36.4)	34.6(18.8, 55.6)	31.7(17.4, 40.0)	11.8(4.0, 13.8)	0.660
MV proportion (%)	60.7(47.1, 68.8)	54.5(35.3, 64.3)	59.5(46.9, 69.4)	67.8(60.0, 75.3)	0.008
NIV only (%)	22.6(7.7, 32.5)	25.0(0.0, 35.3)	23.4(11.8, 33.9)	20.0(7.7, 25.0)	0.030
Receiving IMV (%)	38.2(22.6, 45.7)	28.6(20.0, 43.8)	30.3(17.2, 41.5)	46.6(40.0, 66.7)	<0.001
Receiving ECMO (%)	0.0(0.0, 5.4)	0.0(0.0, 18.2)	2.8(0.0, 6.4)	0.0(0.0, 2.1)	0.535
Receiving CRRT (%)	12.9(7.1, 21.7)	9.1(0.0, 18.8)	12.9(9.6, 24.8)	17.3(7.1, 22.2)	0.007
Use of vasopressors (%)	33.3(19.4, 52.8)	30.0(16.4, 45.0)	27.3(15.5, 40.2)	52.8(41.7, 62.5)	<0.001

[a] The 58 ICUs were stratified into: low mortality (<7.7%), middle mortality (7.7%–21.2%), and high mortality (>21.2%) groups, respectively

Data are presented as median (interquartile range)

HFNC high-flow nasal cannula oxygen therapy, *NIV* noninvasive ventilation, *IMV* invasive mechanical ventilation, *ECMO* extracorporeal membrane oxygenation, *CRRT* continuous renal replacement therapy, *ICU* intensive care unit

in Table 1. The higher mortality group showed more ICU beds ($p = 0.022$) and more ICU admissions ($p < 0.001$) than the low mortality group. The proportion of nurses per bed in the high mortality group was significantly lower than that in the low and middle mortality groups ($p = 0.017$).

To explore the relationship between the mortality of COVID-19 patients and ICU staffing, two probit regression models were established. Potential confounding factors such as mean age, proportion of males, use of MVs or CRRT or vasopressors (considered to indicate severity of patient illness) and inpatients per bed per month (used as ICU beds) were adjusted (Table 2). Both models showed that there was a negative correlation between the number of physicians per bed or nurses per bed and the mortality of patients with severe COVID-19. In addition, the average age, proportion of males, MV ratios, and inpatients per bed per month were significant impact factors. The multivariable probit regression models were also used to estimate the allocation needs of ICU staff for COVID-19 patients (Figure 1a, b). The estimated numbers (95% CI) of physicians per bed and nurses per bed were 5.7 (3.9, 13.8), 3.8 (2.7, 8.5), 2.5 (1.9, 5.0), 1.5 (1.2, 2.3), and 15.8 (11.0, 35.4), 10.6 (7.7, 22.0), 7.0 (5.4, 13.0), 4.2 (3.3, 6.2), respectively, with an ICU mortality rate of 5%, 10%, 15%, and 20%, respectively.

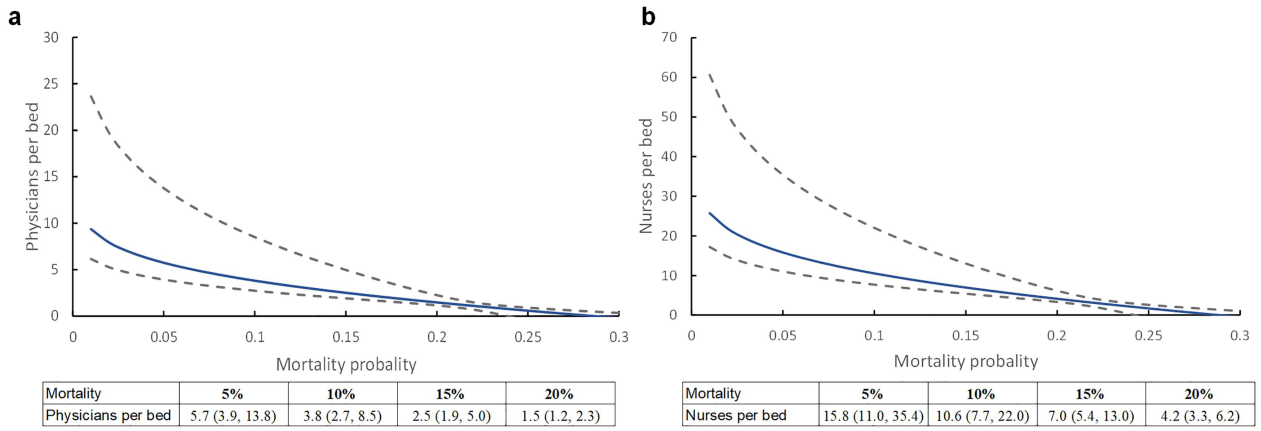
According to the reports from the National Health Commission of the People's Republic of China (NHCPRC), the number of critically ill cases that remained in designated hospitals, the daily death toll and the daily death rate in Hubei Province as of March 14, 2020 are shown in Figure 2. The daily death rate varied from 20.5% in late January to 1.6% by March 14, 2020. The reinforcements of physicians and nurses at 41 ICUs in Hubei Province were recorded. A large number of ICU medical staff who were not responsible for the admission of COVID-19 patients were recruited nationwide. After the second reinforcement teams were dispatched to Hubei Province on January 28, 2020, the daily mortality of critically ill patients showed a downward trend.

Our main finding was that the level of ICU staffing was associated with mortality in ICUs for critically ill COVID-19 patients. Mortality was negatively correlated with the proportion of physicians or nurses per bed in these ICUs. It is important to note that higher numbers of intensive care personnel may be needed to reduce mortality in patients with COVID-19 in ICUs. For instance, even if the target mortality is as high as 20%, the estimated demand for physicians and nurses per bed is 1.5 (95% CI: 1.2, 2.3) and 4.2 (95% CI: 3.3, 6.2), which is far higher than the recommended values (0.8–1:1 and 2.5–3:1) for conventional ICUs [3]. However, in the early stages of the COVID-19 epidemic in Hubei Province, intensive care personnel in designated hospitals were very scarce. In fact, according to the 2016 Hubei Provincial Critical Care Development Report, the percentage of ICU beds at that time was only 1.49% [4], which has not exceeded the national rate. However, intensive care comprised 2.1% of total bed numbers in China in 1999 [5]. The Guideline

Table 2. Factors associated with risk-adjusted ICU mortality in the probit regression models

Model/Variables	Estimate	95% CI	Z value	*P* value
Physicians per bed model				
Physicians per bed	-0.188	(−0.307, −0.069)	-3.093	0.002
Average age (y)	0.017	(0.005, 0.030)	2.715	0.007
Proportion of males (%)	0.003	(0, 0.006)	2.042	0.041
MV proportion (%)	0.017	(0.012, 0.021)	7.382	<0.001
Receiving CRRT (%)	-0.004	(−0.010, 0.001)	-1.505	0.132
Use of vasopressors (%)	0.003	(−0.001, 0.006)	1.501	0.133
Inpatients per bed per month	0.202	(0.088, 0.315)	3.474	0.001
Nurses per bed model				
Nurses per bed	-0.069	(−0.110, −0.027)	-3.232	0.001
Average age (y)	0.015	(0.002, 0.028)	2.282	0.022
Proportion of males (%)	0.004	(0.001, 0.007)	2.746	0.006
MV proportion (%)	0.017	(0.013, 0.022)	7.554	<0.001
Receiving CRRT (%)	-0.003	(−0.009, 0.002)	-1.128	0.259
Use of vasopressors (%)	0.003	(0, 0.006)	1.728	0.084
Inpatients per bed per month	0.159	(0.062, 0.256)	3.199	0.001

CI confidence interval, *MV* mechanical ventilation, *CRRT* continuous renal replacement therapy



Mortality	5%	10%	15%	20%
Physicians per bed	5.7 (3.9, 13.8)	3.8 (2.7, 8.5)	2.5 (1.9, 5.0)	1.5 (1.2, 2.3)

Mortality	5%	10%	15%	20%
Nurses per bed	15.8 (11.0, 35.4)	10.6 (7.7, 22.0)	7.0 (5.4, 13.0)	4.2 (3.3, 6.2)

Figure 1. Estimation of the requirement (95% CI) for critical care staffing for the given probability of mortality. The requirements for physician and nurse staffing for different probability of mortality in the participating ICUs were estimated using probit regression models. Horizontal axis: probability of mortality. Vertical axis: estimated number of physicians per bed **(a)**, and nurses per bed **(b)**, and 95% CI. Data are presented as median (interquartile range). *CI* confidence interval

on the Construction and Management of Critical Care Units (Trial) issued by the Ministry of Health of China in 2009 requires that the ratio of ICU beds to hospital beds should be 2–8% [6]. However, intensive care comprised 8% of total bed numbers in the United States in 1991 [7]; compared with 1∼2% in the United Kingdom [8]. A review showed that the mean ratio of ICU beds to hospital beds was 1.5% from 15 low-income countries [9]. In fact, the problem in Wuhan is that there are not enough physicians and nurses, and the number of ICU beds is estimated to be insufficient.

Importantly, our findings further demonstrated that the trend in daily death rate decreased when reinforcement teams were introduced into designated hospitals in Hubei Province (Figure 2); while the number of patients and the proportion of professional ICU staffing were comparable, and mortality was negatively correlated with the ratio of physicians or nurses per bed in 58 ICUs, especially nationwide (Table 2). These findings confirmed that ICU staffing was one of the important determinants for mortality in ICUs during the epidemic of a highly infectious disease.

Our aim was to estimate the number of ICU staff needed to reduce mortality in ICUs of hospitals designated for COVID-19. Based on the increasing data, the ICU design and management guidelines recommend that each bed be equipped with 0.8–1 physicians and 2.5–3 nurses [3, 10]. Meanwhile, there was limited evidence on the requirements of ICU staffing for a highly infectious disease. Management of COVID-19 patients may require more ICU staffing than management of ordinary critically ill patients. Based on probit regression models, the estimated values of physicians (nurses) per bed were 5.7 (15.8), 3.8 (10.6), 2.5 (7.0), and 1.5 (4.2), respectively, while ICU mortality rates were 5%, 10%, 15%, and 20%, respectively (Figure 2).

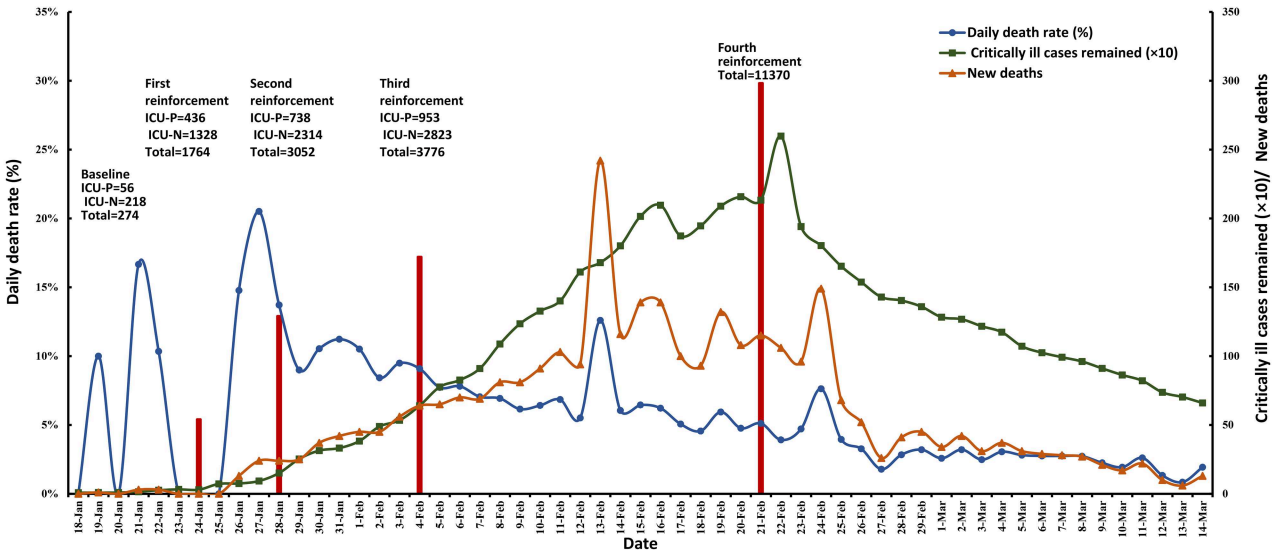


Figure 2. Reinforcements of critical care staffing versus critically ill patient deaths during the outbreak of COVID-19 in Hubei Province. Data represents the number of critically ill cases with COVID-19 who remained in designated hospitals (green line) reported on the websites of the National Health Commission of the People's Republic of China (http://www.nhc.gov.cn) and the Health Commission of Hubei Province (HCHP, http://wjw.hubei.gov.cn) from January 18 to March 14, 2020. Each spot represents the reported data by 0:00 o'clock every day. The brown line shows the new deaths per day; and the blue line shows the daily death rate (%). The red columns represent four reinforcements of critical care staffing labeled with the numbers of ICU physicians and nurses. *ICU* intensive care unit, *P* physicians, *N* nurses

In conclusion, our results showed a significant correlation between critical care staffing and the mortality of critically ill patients during the early COVID-19 epidemic in China. The COVID-19-specific ICUs required a higher number of intensive care personnel to reduce mortality. Finally, increasing the number of ICU beds is required in the development of ICUs in Hubei Province.

Abbreviations

CI: confidence interval; CRRT: continuous renal replacement therapy; ECMO: extracorporeal membrane oxygenation; HFNC: high-flow nasal cannula oxygen therapy; ICU: intensive care unit; IMV: invasive mechanical ventilation; MV: mechanical ventilation; NIV: noninvasive ventilation

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Authors' contributions

JX, LZ and SL drafted the manuscript and conducted the analyses. PM and LZ created the idea of the study. PM critically reviewed the manuscript and agreed with the final version and findings. All the authors read and approved this manuscript.

Conflicts of interest

None declared.

Ethics approval and consent to participate

No personal data was analyzed in this study. The data used in this study are considered a part of the public health outbreak investigation. Informed consent and approval was waived by the Institutional Review Board of Peking University Third Hospital.

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