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Hospital characteristics associated with COVID-19 mortality: data from the multicenter cohort Brazilian Registry

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Abstract

The COVID-19 pandemic caused unprecedented pressure over health care systems worldwide. Hospital-level data that may influence the prognosis in COVID-19 patients still needs to be better investigated. Therefore, this study analyzed regional socioeconomic, hospital, and intensive care units (ICU) characteristics associated with in-hospital mortality in COVID-19 patients admitted to Brazilian institutions. This multicenter retrospective cohort study is part of the Brazilian COVID-19 Registry. We enrolled patients ≥ 18 years old with laboratory-confirmed COVID-19 admitted to the participating hospitals from March to September 2020. Patients' data were obtained through hospital records. Hospitals' data were collected through forms filled in loco and through open national databases. Generalized linear mixed models with logit link function were used for pooling mortality and to assess the association between hospital characteristics and mortality estimates. We built two models, one tested general hospital characteristics while the other tested ICU characteristics. All analyses were

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adjusted for the proportion of high-risk patients at admission. Thirty-one hospitals were included. The mean number of beds was 320.4 ± 186.6. These hospitals had eligible 6556 COVID-19 admissions during the study period. Estimated in-hospital mortality ranged from 9.0 to 48.0%. The first model included all 31 hospitals and showed that a private source of funding ($\beta = -0.37$; 95% CI −0.71 to −0.04; $p = 0.029$) and location in areas with a high gross domestic product (GDP) per capita ($\beta = -0.40$; 95% CI −0.72 to −0.08; $p = 0.014$) were independently associated with a lower mortality. The second model included 23 hospitals and showed that hospitals with an ICU work shift composed of more than 50% of intensivists ($\beta = -0.59$; 95% CI −0.98 to −0.20; $p = 0.003$) had lower mortality while hospitals with a higher proportion of less experienced medical professionals had higher mortality ($\beta = 0.40$; 95% CI 0.11–0.68; $p = 0.006$). The impact of those association increased according to the proportion of high-risk patients at admission. In-hospital mortality varied significantly among Brazilian hospitals. Private-funded hospitals and those located in municipalities with a high GDP had a lower mortality. When analyzing ICU-specific characteristics, hospitals with more experienced ICU teams had a reduced mortality.

Keywords COVID-19 · Healthcare · Hospital · Intensive care · Mortality

Background

Since the World Health Organization (WHO) announced the COVID-19 pandemic, hospitals worldwide have faced the challenging task of improving their capacity to handle the unusual influx of patients. Even though COVID-19 more frequently causes mild to moderate symptoms, this novel disease significantly increased hospital resource utilization in many countries [1].

The pressure over the health care system was especially challenging in low—and middle—income countries (LMICs), such as Brazil, where the pre-pandemic resources were already scanty [2, 3]. In this country, the system struggled to adapt to the higher rate of hospitalization. Reports of a shortage of equipment and medication throughout the country increased amid the second surge in 2021 [4]. As of March 2022, Brazil remains one of the countries most affected by the pandemic, ranking third in the number of cumulative confirmed cases, and in the number of cumulative deaths [5].

Previous studies explored different factors influencing COVID-19 mortality mostly at an individual level, such as increasing age, sex, genetics, race, socioeconomic status, and the presence of certain comorbidities [6–8]. At a hospital level, it is known from pre-pandemic studies that the way a hospital system is structured and organized may affect the quality of care and the patient outcome [9–11]. In the COVID-19 pandemic, variations in mortality across hospitals and intensive care units (ICU) have been described, however, the role of hospital characteristics on the patient outcome remains unclear [12, 13]. To this moment, few observational studies have examined one or more hospital-level variables and COVID-19 mortality, and all are from high-income countries [14–16], which may not fully translate to emerging countries. In LMICs, after thoroughly literature search, we could not find detailed data analyzing hospital-level characteristics associated with the outcome of COVID-19 patients. This information is essential to identify potentially modifiable factors related to organizational characteristics.

Therefore, this study sought to analyze regional socioeconomic, hospital and ICU-specific characteristics and their association with mortality in COVID-19 patients admitted to Brazilian hospitals.

Methods

Study design

This study is part of the Brazilian COVID-19 Registry, a multicenter retrospective cohort detailed in a previous report [17]. Hospitals were invited to participate with an open call sent through email, website, and radio. The registry is being conducted according to a predefined protocol in 37 Brazilian hospitals. We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational cohort studies (Supplementary Table 1) [18].

Study participants

We enrolled consecutive adult (≥ 18 years old) patients with laboratory-confirmed COVID-19 admitted to the participating hospitals from March 1 to September 30, 2020. Confirmatory COVID-19 diagnosis followed the World Health Organization guidance [19].

Patients transferred to step-down beds, such as hospice care, nursing homes, long-term stay care, or lower complexity hospitals, were considered discharged. We excluded patients who required transfer to a higher complexity care facility, such as larger hospitals with more infrastructure to deliver complex care. Between-hospital transfers were included if they occurred between participating institutions in the first three days of hospitalization, otherwise, the patient was excluded. In the case of transference, we considered the data from the receiving institution. All other patients who had been transferred to a non-participant institution were excluded, as well as patients who developed COVID-19 symptoms while admitted for other conditions. Finally, hospitals that did not complete at least 30 consecutive patients or did not comply with the study protocol were excluded (Fig. 1).

Patient-level data

We used Research Electronic Data Capture (REDCap®) online tool, hosted at the Telehealth Center, University Hospital, Universidade Federal de Minas Gerais [20, 21] to collect patient's data were obtained through hospital records. Data contained patients' demographics, clinical, laboratory

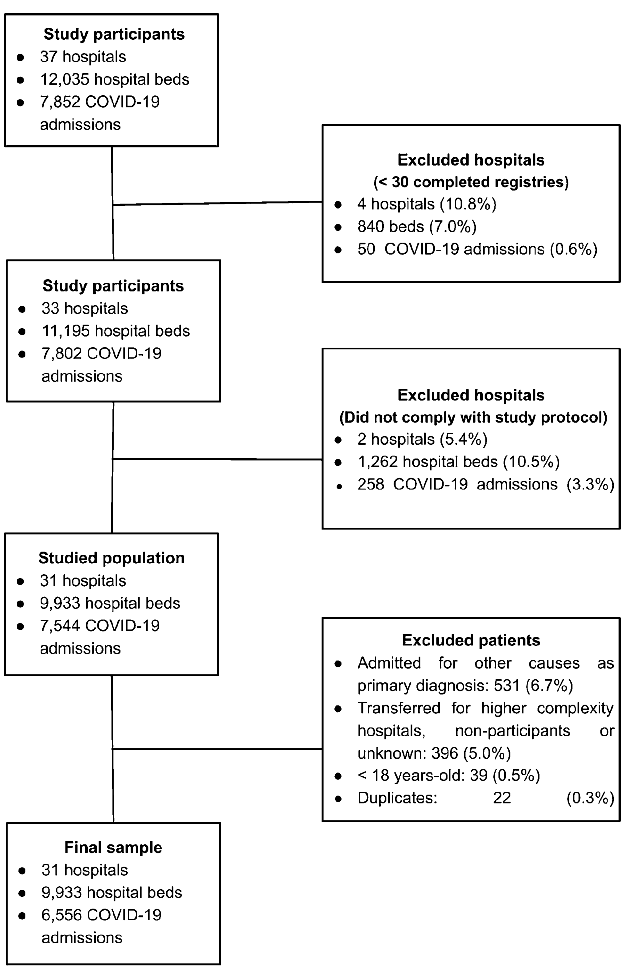

Fig. 1 Flowchart of hospitals and COVID-19 patients included in the study

and imaging findings, treatments, complications, and outcomes during the hospital stay. To assure data quality, all data underwent a series of manual and automated verifications to identify inconsistencies and non-conforming values, as previously described [17, 22].

Hospital-level data

Data regarding hospitals' characteristics were collected on forms filled by the hospital staff or managers, or on the open national database from Cadastro Nacional de Estabelecimentos da Saúde- CNES (National Registry of Health Facilities) [23] and from the Instituto Brasileiro de Geografia e Estatística-IBGE (Brazilian Institute of Geography and Statistics) [24]. We chose characteristics in accordance with the previous literature on the topic [10, 11, 25–27].

The first form contained information about hospitals' classification, structure, and location. It included source of income (public, mixed—partly public and partly private—or private), accreditation, academic status, number of COVID-19-specific beds (ward and ICU), and whether the institution had been selected as a COVID-19 reference center. If available, the information was cross-referenced against the one available in the open database. If any disagreement between sources were identified, we asked the hospital research team to re-check the information. In addition to that, we collected variables about the hospitals' location at a municipality-level to assess the socioeconomic characteristics of the population that attended these hospitals. For this purpose, we evaluated the size, geographic region, number of hospital beds per 1000 inhabitants, gross development product (GDP) per capita, and average human development index (HDI) of each municipality [24].

The second form contained information about ICU characteristics. Hospitals' supervisors retrieved the requested information in loco. The variables had two domains. The first one was staff information: previous experience in critical care of the medical staff (nurses and physicians) in a COVID-19 ICU work shift, staff availability (physicians, nurses, and technicians) per shift, and the need for emergency hiring of healthcare personnel to work with COVID-19 patients. The second one contemplated organizational characteristics, such as COVID-19-specific protocol for hospital and ICU admission, training of the healthcare team, implementation of daily clinical multidisciplinary rounds, and the number of implemented clinical protocols for the management of critical patients in the ICU.

To assess the previous experience in critical care of the medical staff, we considered as "experienced" the proportion of the staff (physicians or nurses) on COVID-19 ICU work shift that were board-certified specialists in intensive care or had more than 2 years of clinical experience in critical care. To identify less experienced professionals, we considered the proportion of medical doctors in training (residency or specialization) in the COVID-19 ICU work shift. We also created an intermediate category evaluating the proportion of staff transferred from other clinical or surgical areas to work in COVID-19 ICUs.

For assessing staff availability, we calculated the absolute number of professionals (physicians, nurses, and nurse technicians) in a COVID-19 ICU work shift on weekdays, weekends, and holidays at the month of the peak of the pandemic. Then, we calculated the bed-to-staff ratio using the weighted average of the number of professionals in a shift divided by the total number of available beds. We compared this ratio with the minimum standards recommended by the Brazilian legislation, which are, 10 beds per physician, 10 beds per nurse, and two beds per nurse technician [28]. Emergency hiring included physicians, nurses, nurse technicians, and other allied health professionals (physical therapists, pharmacists, nutritionists, social workers, or psychologists) who were hired under emergency hiring calls due to the pandemic.

Organizational processes inquired about the implementation of general and COVID-19 specific protocols. We also evaluated the number of clinical protocols for the critically ill patients fully implemented in the COVID-19 ICU. This included ten different protocols that showed association with mortality in a pre-pandemic study in Brazilian ICUs [11]: early mobilization, sedation, sepsis, lung protective mechanical ventilation, prevention of ventilator-associated pneumonia, prevention of central line-associated bloodstream infection, cardiorespiratory arrest, acute coronary syndrome, cerebrovascular accident. In addition, we also included a protocol regarding intubation and mechanical ventilation in COVID-19 patients.

Statistical analysis

Hospitals' categorical characteristics were described as absolute or relative frequency while the continuous ones were studied using central tendency statistics (mean and standard deviation, or median and quartiles according to the Shapiro–Wilk's test).

The main outcome was COVID-19 mortality that we estimated independently for each hospital. As the outcome was an aggregated data, we used generalized linear mixed models with logit link function to assess the association between hospital characteristics and mortality estimates. First, we constructed a forest plot to show the heterogeneity among the outcome in each hospital. Second, we built two independent models, using the same methodology: one for general hospital characteristics and another for ICU characteristics. The methodology was to test each hospital characteristics individually in a bivariate model (characteristic + proportion of high-risk patients). Then, variables that achieved $p < 0.20$ in the bivariate analysis were included in a multivariate analysis in a stepwise approach, dropping variables with the poorest performance on each step. As all variables analyzed in the multivariate analysis were categorical, thus collinearity was studied using cross-tabulation. A p value lower than 0.05 denoted significance in the final model. To adjust for patients' explanatory variables, we included the proportion of high-risk patients at admission. This variable was defined as those patients who scored more than 4 ("high risk" or "very high-risk") according to the ABC_2-SPH scoring system. This score predicts COVID-19 mortality using variables at hospital admission and was developed and externally validated from a sample of this cohort in a previous study, demonstrating high discriminatory capacity [22].

To calculate this score, seven variables are necessary, including age, the number of comorbidities, heart rate, FiO2/SpO2 rate, and laboratory values of serum urea, reactive C protein, and platelets [22]. Clinical and laboratory variables that had missing values were considered missing at random after a thorough analysis of missing data patterns. We used multiple imputations with chained equations (MICE) to handle these values. Ten imputed datasets were generated and combined using the mean proportion of high-risk patients per hospital in each dataset. Finally, we repeated the analysis only with the 3,728 patients who had complete information, after excluding patients with any missing (Supplementary Fig. 2).

We used the R project for statistical computing (version 4.0.3) to all analyses. Packages included *dplyr* (version 1.0.7), *ggplot2* (version 3.3.5), *meta* (version 4.18-2), and *metafor* (version 3.0–2).

Ethics approval and consent to participate

The Brazilian National Commission for Research Ethics approved the study protocol (CAAE: 30350820.5.1001.0008). This commission waived off the requirement for informed consent due to the severity of the pandemic circumstances and since we used only de-identified data based solely on medical records review.

Results

Thirty-one hospitals from 16 Brazilian cities in 4 states were included (Supplementary Fig. 2). These hospitals received COVID-19 patients from 370 municipalities across 12 different states (Supplementary Fig. 2).

Table 1 General hospital characteristics of the participating hospitals by main source of income (public or private)

General hospital characteristics	All hospitals (n = 31)	Public (n = 23)	Private (n = 8)
Number of ICU beds, median (IQR)	44.0 (31.0–60.0)	40.0 (30.0–60.0)	48.0 (41.0–59.3)
Number of COVID-19 ward beds, median (IQR)	40.0 (20.0–79.5)	42.0 (22.0–75.5)	25.0 (15.0–85.8)
Number of COVID-19 ICU beds, median (IQR)	21.0 (15.5–38.5)	20.0 (11.0–38.0)	24.0 (19.0–37.8)
Volume of COVID-19 patients, median (IQR)	244.0 (143.0–512.5)	244.0 (137.5–473.0)	252.0 (212.0–551.0)
Availability of mechanical ventilators in non-ICU units, n (%)	25 (80.6)	19 (82.6)	6 (75.0)
Proportion of ICU capacity to COVID-19, mean ± SD	0.57 ± 0.22	0.58 ± 0.23	0.55 ± 0.19
Classification of the hospital size, n (%)			
Medium (50–150 beds)	8 (25.8)	4 (17.4)	4 (50.0)
Large (150–500 beds)	17 (54.8)	13 (56.5)	4 (50.0)
Very large (> 500 beds)	6 (19.4)	6 (26.1)	0 (0.0)
Academic hospitals, n (%)	19 (61.3)	15 (65.2)	4 (50.0)
Accreditation, n (%)	13 (41.9)	7 (30.4)	6 (75.0)
COVID-19 reference center, n (%)	22 (71.0)	19 (82.6)	3 (37.5)
Proportion of patients from other municipalities, mean ± SD	0.35 ± 0.16	0.36 ± 0.16	0.31 ± 0.19
Hospital location (city-level)			
Brazilian geographic region, n (%)			
Southeast	21 (67.7)	16 (69.6)	5 (62.5)
South	9 (29.0)	6 (26.1)	3 (37.5)
Northeast	1 (3.2)	1 (4.3)	0 (0.0)
Metropolitan areas, n (%)	21 (67.7)	13 (56.5)	8 (100.0)
GDP per capita higher than national average, n (%)	24 (77.4)	16 (69.6)	8 (100.0)
HDI per capita higher than national average, n (%)	25 (80.6)	18 (78.3)	7 (87.5)
Hospital beds/1000 inhabitants, mean ± SD	3.48 ± 0.94	3.41 ± 0.97	3.70 ± 0.88

Results for continuous numbers are expressed as mean ± standard deviation or median (interquartile range). Categorical variables are expressed in counts (percentage)

ICU intensive care unit, *GDP* gross domestic product, *HDI* human development index

General and ICU characteristics stratified by the hospital main source of income (public or private) are summarized in Tables 1 and 2. For ICU characteristics, 23 hospitals answered the form (15 provided complete information and 8 partial information). Regarding the characteristics of the studied population, 6556 patients were eligible. Overall, 54.6% were male and the median age was 61 (IQR 48–72) years old. Hypertension (54.8%), diabetes mellitus (29.2%) and obesity (17.8%) were the most frequent comorbidities. Of all admitted patients, 38.1% needed critical care support, 28.0% required invasive mechanical ventilation and 20.8% (CI 95% 18.0 to 24.0%) died (Supplementary Table 1).

Mortality estimation

Mortality was 21.0% (95% CI 18.0–24.0%) with high heterogeneity (I^2 = 87%; $p < 0.01$) in the mortality estimates among hospitals (between 9.0 and 48.0%). Hospitals with the lowest mortality were private, but also had a lower proportion of high-risk patients, whilst the eight hospitals with higher mortality were public, but had a higher proportion of high-risk patients (Fig. 2). A positive, linear, and significant ($p < 0.001$) correlation was found between the proportion of high-risk patients and the logit of the mortality (Supplementary Fig. 2B).

Association between general hospital characteristics and mortality estimates

A total of 31 hospitals were included in this analysis. Five from the 15 general hospital characteristics tested in the bivariate model achieved a $p < 0.20$ and were included in the multivariate analysis (Table 3). After a stepwise exclusion, two variables remained independently associated with mortality. Hospitals with a private source of income had a lower mortality compared to a public one ($\beta = -0.37$; 95% CI -0.71 to -0.04; $p = 0.029$). Hospitals located in municipalities with a GDP per capita lower than the Brazilian average had a higher mortality compared to locations with a

Table 2 ICU-specific characteristics of the participating hospitals by main source of income (public or private)

ICU-specific characteristics	All hospitals	Public	Private
Experience of staff on duty, *n* (%)	*n* = 16	*n* = 14	*n* = 2
> 50% experienced physicians	12 (75.0)	10 (71.4)	2 (100.0)
> 50% redeployed physicians	4 (25.0)	4 (28.6)	0 (0.0)
> 10% medical residents	6 (35.3)	6 (42.9)	0 (0.0)
> 50% experienced nurses	9 (60.0)	8 (61.5)	1 (50.0)
> 50% redeployed nurses	4 (26.7)	4 (30.8)	0 (0.0)
Staff availability, *n* (%)	*n* = 19	*n* = 14	*n* = 5
≤ 10 beds per physician	19 (100.0)	14 (100.0)	5 (100.0)
≤ 10 beds per nurse	18 (94.7)	13 (92.9)	5 (100.0)
≤ 2 beds per nurse technician	13 (68.4)	8 (57.1)	5 (100.0)
Protocols, *n* (%)	*n* = 22	*n* = 16	*n* = 6
Hospital admission	19 (86.4)	13 (81.2)	6 (100.0)
ICU admission	19 (86.4)	14 (87.5)	5 (83.3)
Number of protocols, median (IQR)	9.0 (7.0–10.0)	8.0 (7.0–10.0)	9.0 (8.0–10.0)
Clinical processes, *n* (%)	*n* = 18	*n* = 15	*n* = 3
Clinical training	18 (100.0)	15 (100.0)	3 (100.0)
Daily multidisciplinary rounds	18 (100.0)	15 (100.0)	3 (100.0)
Emergency hiring, *n* (%)	*n* = 20	*n* = 15	*n* = 5
Physicians	19 (95.0)	14 (93.3)	5 (100.0)
Nurses	20 (100.0)	15 (100.0)	5 (100.0)
Nurse technicians	20 (100.0)	15 (100.0)	5 (100.0)
Other healthcare professionals	18 (90.0)	13 (86.7)	5 (100.0)

GDP higher than the country's average ($\beta = -0.40$; 95% CI −0.72 to −0.08; $p = 0.014$).

Association between ICU characteristics and mortality estimates

A total of 23 hospitals were included in this analysis. Four from the 11 ICU-specific characteristics tested in the bivariate model achieved a $p < 0.20$ and were included in the multivariate analysis (Table 3). The variables "daily multidisciplinary rounds" and "staff training" could not be tested, because all hospitals gave the same answer. Two variables remained independently associated with mortality. Hospitals with more than 50% of experienced medical professionals on the COVID-19 ICU team had lower mortality ($\beta = -0.59$; 95% CI −0.98 to −0.20; $p = 0.003$) while hospitals with less experienced medical professionals (> 10% of medical residents or trainees) on COVID-19 ICU duty had higher mortality ($\beta = 0.40$; 95% CI 0.11–0.68; $p = 0.006$). The β's estimates are in the logit scale of mortality. Negative values mean reduced mortality while positive ones mean an increased mortality. Also, higher values in modulus mean greater impact (Table 4).

Supplementary Figs. 3 and 4, and Supplementary Table 2 show the results of the multivariate model in the mortality scale. Mortality increased with the proportion of high-risk patients. Furthermore, regardless of the proportion of high-risk patients, mortality was lower depending on whether a hospital has less than 50% of intensivists and more than 10% of medical residents. For example, if the proportion of high-risk patients estimated in a hospital was 40%, mortality was estimated as 14.4% for scenario 1 (high experience: < 10% residents and > 50% intensivists), 20.0% for scenario 2 (moderate experience: > 10% residents and > 50% intensivists), 23.3% for scenario 3 (low experience: < 10% residents and < 50% intensivists) and 31.1% for scenario 4 (very low experience: > 10% residents and < 50% intensivists) (Supplementary Fig. 4).

Discussion

In this study, we investigated whether regional socioeconomic, general and ICU hospital characteristics were associated with mortality in a Brazilian multicenter study of COVID-19 patients. Mortality varied significantly across the institutions, ranging from 9.0 to 48.0%. Private hospitals, as

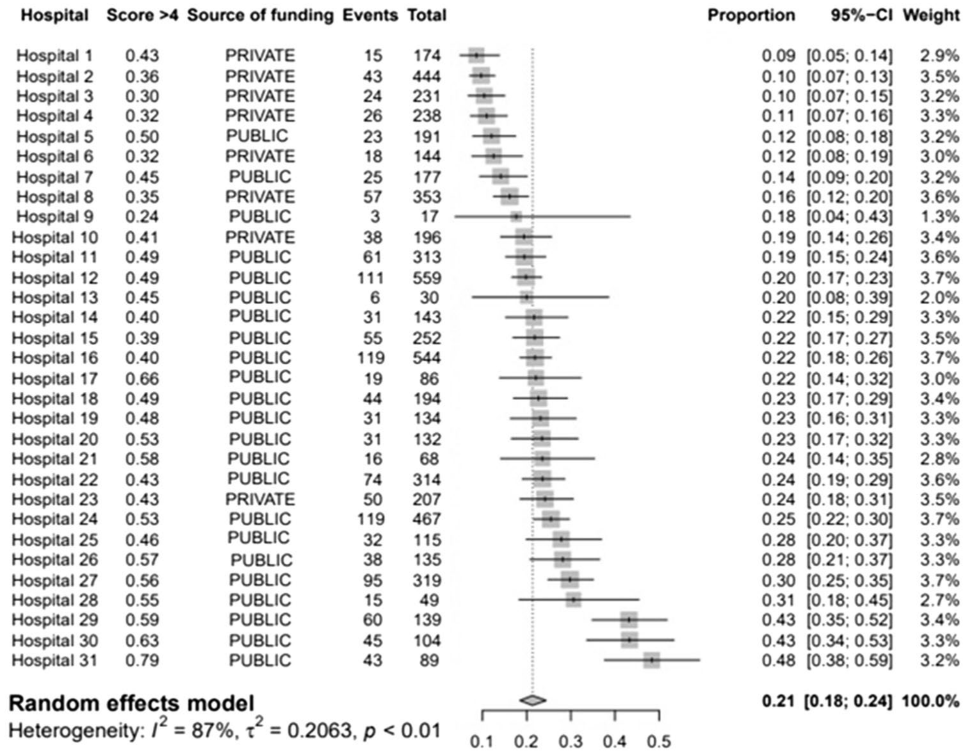

Fig. 2 Forest plot showing the mortality estimated (with 95% CI) for each hospital, their main source of funding and the proportion of high-risk patients

well as those located in areas with a high GDP per capita, had lower mortality. In the analysis of ICU characteristics, hospitals with a less experienced critical care team had higher mortality.

The association between hospital characteristics with COVID-19 mortality have not been previously extensively explored. Most studies on this topic focused on limited aspects of care. For instance, two studies explored the association between the pressure on hospital capacity imposed by the pandemic and the increased mortality but did not assess other topics such as resource availability and other organizational aspects [14, 16]. A French study found that in-hospital mortality of COVID-19 patients was higher during weekends, which could be partially explained by the lower availability of staff on weekends, although this parameter was not directly measured by the authors [15]. This study also evaluated the ICU team experience on critical care and mortality in COVID-19 patients, but did not find an association, which contrasted with our finding. These discordant results, however, might be related to the different definition of staff experience used in that study and ours. While Rimmelé et al. [15] considered staff experience as the number of COVID-19 patients admitted by the ICU team during the study period, we assessed the professional background of each staff on COVID-19 ICU duty. As for the other variables analyzed, we did not find any study assessing those detailed metrics, such as the implementation of protocols, clinical rounds, or staff training, which could be associated with in-hospital mortality according to pre-pandemic evidence [9, 15, 29]. On top of that, it is noteworthy that all studies on this topic were from high-income countries and no studies analyzed the association of hospital-level characteristics and COVID-19 mortality in LMICs.

In this study, mortality varied remarkably between hospitals. Although previous studies reported the overall COVID-19 mortality in Brazil ranging from 22.0 to 38.0% [17, 30], at a hospital-level, we observed a wider variation, with mortality estimates reaching up to 48.0%. Earlier patient-level analyses of this cohort showed considerable differences in patient's characteristics depending on the hospital's main source of funding, such as advanced age and a higher number of comorbidities that were observed in public hospitals [17]. Conversely, in the present study, the analysis of the patient's explanatory variables at a hospital-level showed that public hospitals had a higher proportion of high-risk patients. We hypothesize that patients admitted to public hospitals tend to present a more severe condition when compared to patients from private hospitals due to the unequal provision of hospital beds between the two healthcare systems, with private hospitals having more beds available [31, 32]. However, even after adjusting for disease severity, the increased mortality observed in public hospitals persisted, indicating that aspects other than those related to the patient influenced COVID-19 mortality.

Previous studies showed that socioeconomic status is an independent risk factor for COVID-19 mortality [8, 33–35].

Table 3 General hospital characteristics and city-level variables associated with mortality in the bivariate and multivariate analysis ($n = 31$)

Variables	Bivariate analysis		Multivariate analysis	
	β* (95% CI)	*p* value	β* (95% CI)	*p* value
GDP per capita higher than the Brazilian average	−0.39 (−0.72; −0.06)	0.019	−0.40 (−0.72; −0.08)	0.014
Source of income				
Private	−0.37 (−0.73; −0.01)	0.044	−0.37 (−0.71; −0.04)	0.029
Mixed (public and private)	−0.20 (−0.48; 0.07)	0.148	−0.20 (−0.46; 0.06)	0.127
Public	Reference category	NA	Reference category	NA
> 50% Patients admitted from other municipalities	0.25 (−0.02; 0.51)	0.070	0.14 (−0.14; 0.43)	0.3244
Academic hospitals	0.17 (−0.07; 0.41)	0.168	0.07 (−0.19; 0.34)	0.5841
COVID-19 reference center	−0.10 (−0.22; 0.41)	0.556		
Accreditation	−0.03 (−0.28; 0.21)	0.805		
Hospital size				
150–500 beds	−0.04 (−0.32; 0.24)	0.771		
> 500 beds	0.16 (−0.18; 0.50)	0.348		
50–150 beds	Reference category	NA		
Proportion COVID-19 ICU beds	0.23 (−0.36; 0.82)	0.440		
Number of COVID-19 ICU beds	0.002 (−0.007; 0.01)	0.719		
Number of COVID-19 ward beds	−0.001 (−0.004;0.002)	0.421		
Volume of COVID-19 patients	0.0002 (−0.0004; 0.0004)	0.909		
Geographic region				
South region	0.09 (-0.17; 0.35)	0.503		
Southeast region	Reference category	NA		
Metropolitan	−0.13 (−0.40; 0.15)	0.371		
HDI per capita less than the Brazilian average	−0.05 (−0.37; 0.27)	0.762		
Beds per 1000 inhabitants	0.06 (−0.07; 0.19)	0.339		

GDP gross development product, *ICU* intensive care unit, Analyses were adjusted by the proportion of high-risk patients. *HDI* human development index

*Estimates are reported in the logit scale of the in-hospital mortality.

In Brazil, there are reports of higher mortality in socioeconomically deprived populations, residents in the Brazilian poorest regions (North and Northeast of the country), and in black and *pardo* people [30, 33]. Our findings reiterate those associations, public hospitals and in the municipalities with a GDP per capita lower than the Brazilian average presented higher mortality. In this country, public hospitals are managed by the Brazilian Unified Health System (SUS—Sistema Único de Saúde) which is a universal health system implemented since the 1988 healthcare reform [36]. Currently, approximately 77% of the Brazilian population depends exclusively on this modality of health system. Private healthcare is represented by out-of-pocket services and paid by health insurance. This modality covers about 23% of the population, and, as it is a paid system, most of the insured people are in the wealthiest areas of the country [37]. Although SUS is paramount for the goal of achieving universal healthcare for the Brazilian population, this system has been underfunded and understaffed for years [36, 38]. When the COVID-19 pandemic struck, there was immediate concern about how the public health system would respond to the overwhelming demand. The situation was particularly pressing for hospitals and ICUs because of the low availability and uneven distribution of critical care resources across the country [32].

The second analysis provided detailed information on ICU characteristics showing that a higher medical staff experience in critical care was associated with lower mortality. As the pandemic evolved, countries needed to expand hospital and ICU capacity to supply the demands. However, creating new hospital beds, especially in the ICU, is a complex process that requires infrastructure expansion, new equipment, medications, and qualified professionals [39–41]. To meet the health care needs in an emergency scenario, such as the COVID-19 pandemic, increasing the number of personnel is one of the most intricate adaptations, especially where the number of skilled professionals had already been scarce before the event [2]. Current guidelines recommend that alternatives must be employed, such as anticipating graduation from final-year health students,

Table 4 ICU-specific characteristics associated with in-hospital mortality

Variables	*N*	Bivariate models		Multivariate model	
		β* (CI 95%)	*p* value	β* (CI 95%)	*p* value
> 50% of intensivists	16	− 0.69 (− 1.17; − 0.20)	0.005	− 0.59 (− 0.98; − 0.20)	0.003
> 10% medical residents	17	0.45 (0.12; 0.79)	0.008	0.40 (0.11; 0.68)	0.006
> 50% intensivist nurses	15	0.15 (− 0.32; 0.62)	0.520		
> 50% redeployed physicians	16	0.15 (− 0.36; 0.67)	0.559		
> 50% redeployed nurses	15	0.19 (− 0.41; 0.79)	0.537		
< 10 protocols implemented	21	− 0.30 (− 0.63; 0.04)	0.080	0.03 (− 0.34; 0.40)	0.8635
Bed to nurse ratio ≤ 10	19	− 0.10 (− 0.84; 0.63)	0.788		
Bed to nurse technician ≤ 2	19	− 0.23 (− 0.63; 0.16)	0.250		
Hospital admission protocol	22	− 0.18 (− 0.66; 0.30)	0.457		
ICU admission protocol	22	0.12 (− 0.33; 0.57)	0.593		
Emergency contract of staff	20	0.35 (− 0.14; 0.84)	0.157	0.08 (− 0.40; 0.55)	0.7519

*Estimates are reported in the logit scale of the in-hospital mortality. *ICU* intensive care unit; Analyses are adjusted by the proportion of high-risk patients

redeploying staff from other sectors, hiring new staff, having volunteers from other states or countries, and calling upon retired professionals [39, 40]. Implementing these strategies, however, create a situation where professionals may lack the ideal training to deal with the novel situation, which can compromise the quality of care [40, 42]. This is especially true for environments such as ICUs where practical skills to perform invasive procedures are often needed [40, 42]. In addition to that, taking into consideration, the worker's perspective, training is a way to support and make them more confident [43, 44]. In a systematic review that analyzed the workers' experiences and views during the pandemic, frontline staff reported the feeling of not being prepared and having insufficient training and support to deal with the novel situation [43]. In our cohort, even though hospitals that had a less experienced ICU medical team had a worse outcome, hospitals managers answered that all frontline workers had training for the management of COVID-19 patients. More studies are needed to investigate how and how often they trained, and even what training strategy is more effective.

Some pre-pandemic studies, including one in Brazilian ICUs, found an association between the implementation of clinical protocols in the ICU and mortality [10, 11, 45]. In the present study, even though the number of protocols implemented in ICUs was included in the multivariate analysis, this variable did not remain in the final model. We believe that could be because most hospitals in our cohort reported a high number of protocols implemented, hampering the analysis of a possible association in our sample. This same situation applies to the analysis of staff availability, with a high number of hospitals complying with the Brazilian recommendation guidelines [28]. In addition to that, the evidence from previous studies of an association of staff availability with mortality showed mixed results, and the optimal bed-to-staff ratio is yet to be determined [27, 46].

This study provided a detailed examination of the variability in the COVID-19 in-hospital mortality in a Brazilian cohort. As the pandemic continues to spread around the world due to the surge of new variants of concern and low immunization coverage due to vaccine hesitancy in several countries, it is paramount to continue the investigation of potentially modifiable factors that can help to reduce mortality. As this study showed that the professional experience of the medical team was associated with lower mortality, investing in training and senior supervision of the medical team could improve outcomes in emergency situations, such as the COVID-19 pandemic. Different training and organizational strategies could be employed, such as supervision from senior staff, the use of simulators for training, and implementing tele-strategies in the ICU, and the use of daily checklists and multidisciplinary rounds [42, 45, 47, 48].

This study has limitations. This cohort of hospitals is small and mostly located in the wealthiest areas of the country, thus, it is not possible to state that it is representative of the Brazilian reality. We sought to analyze detailed organizational metrics which have not been examined to this point. However, despite our efforts to obtain detailed information from all participating ICU, both in loco and through open databases, eight hospitals partially responded to the questionnaire, mostly because of the difficulties in gathering staff information. Some information, such as bed occupancy rates, had significant heterogeneity in the data quality, with many cities having very limited and incomplete data for our study period. Thus, we did not report this information to avoid selection bias.

Conclusion

In-hospital mortality varied significantly among Brazilian hospitals. Private-funded hospitals located in cities with high GDP per capita had lower mortality. In the ICU, a more experienced critical care medical team assisting COVID-19 patients were associated with lower mortality.

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Data availability statement Data is available upon reasonable request.

Data access, responsibility, and analysis The lead authors (MVRSS, MSM and PKZ) had full access to all the data in the study and took responsibility for the integrity of the data and the accuracy of the data analysis.

Declarations

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References

1. Wiersinga WJ, Rhodes A, Cheng AC, Peacock SJ, Prescott HC (2020) Pathophysiology, transmission, diagnosis, and treatment of coronavirus disease 2019 (COVID-19): a review. JAMA 324(8):782–793. https://doi.org/10.1001/jama.2020.12839
2. Walker PGT, Whittaker C, Watson OJ, Baguelin M, Winskill P, Hamlet A et al (2020) The impact of COVID-19 and strategies for mitigation and suppression in low- and middle-income countries. Science 369(6502):413–422. https://doi.org/10.1126/science.abc0035
3. Noronha KVMS, Guedes GR, Turra CM, Andrade MV, Botega L, Nogueira D et al (2020) The COVID-19 pandemic in Brazil: analysis of supply and demand of hospital and ICU beds and mechanical ventilators under different scenarios. Cad Saude Publica 36(6):e00115320. https://doi.org/10.1590/0102-311X00115320
4. Alves L (2021) Brazilian ICUs short of drugs and beds amid COVID-19 surge. Lancet 397(10283):1431–1432. https://doi.org/10.1016/S0140-6736(21)00836-9
5. World Health Organization (2021) WHO Coronavirus (COVID-19) Dashboard. Avaliable from: https://covid19.who.int. Accessed: 27 Dec 2021
6. Zheng Z, Peng F, Xu B, Zhao J, Liu H, Peng J et al (2020) Risk factors of critical & mortal COVID-19 cases: a systematic literature review and meta-analysis. J Infect 81(2):e16–e25. https://doi.org/10.1016/j.jinf.2020.04.021
7. Izcovich A, Ragusa MA, Tortosa F, Lavena Marzio MA, Agnoletti C, Bengolea A et al (2020) Prognostic factors for severity and mortality in patients infected with COVID-19: a systematic review. PLoS ONE 15(11):e0241955. https://doi.org/10.1371/journal.pone.0241955
8. Magesh S, John D, Li WT, Li Y, Mattingly-App A, Jain S et al (2021) Disparities in COVID-19 outcomes by race, ethnicity, and socioeconomic status: a systematic-review and meta-analysis. JAMA Netw Open 4(11):e2134147. https://doi.org/10.1001/jamanetworkopen.2021.34147
9. Weled BJ, Adzhigirey LA, Hodgman TM, Brilli RJ, Spevetz A, Kline AM et al (2015) Critical care delivery: the importance of process of care and ICU structure to improved outcomes: an update from the American College of Critical Care Medicine Task Force on Models of Critical Care. Crit Care Med 43(7):1520–1525. https://doi.org/10.1097/CCM.0000000000000978
10. Sakr Y, Moreira CL, Rhodes A, Ferguson ND, Kleinpell R, Pickkers P et al (2015) The impact of hospital and ICU organizational factors on outcome in critically ill patients: results from the extended prevalence of infection in intensive care study. Crit Care Med 43(3):519–526. https://doi.org/10.1097/CCM.0000000000000754
11. Soares M, Bozza FA, Angus DC, Japiassú AM, Viana WN, Costa R et al (2015) Organizational characteristics, outcomes, and resource use in 78 Brazilian intensive care units: the ORCHESTRA study. Intensive Care Med 41(12):2149–2160. https://doi.org/10.1007/s00134-015-4076-7
12. Qian Z, Alaa AM, van der Schaar M, Ercole A (2020) Between-centre differences for COVID-19 ICU mortality from early data in England. Intensive Care Med 46(9):1779–1780. https://doi.org/10.1007/s00134-020-06150-y
13. Danesh V, Arroliga A (2020) Hospital characteristics and COVID-19: hidden figures in COVID-19 risk models. Heart Lung 49(6):873–874. https://doi.org/10.1016/j.hrtlng.2020.09.003

14. Churpek MM, Gupta S, Spicer AB, Parker WF, Fahrenbach J, Brenner SK et al (2021) Hospital-level variation in death for critically ill patients with COVID-19. Am J Respir Crit Care Med. https://doi.org/10.1164/rccm.202012-4547OC
15. Rimmelé T, Pascal L, Polazzi S, Duclos A (2021) Organizational aspects of care associated with mortality in critically ill COVID-19 patients. Intensive Care Med 47(1):119–121. https://doi.org/10.1007/s00134-020-06249-2
16. Taccone FS, Van Goethem N, De Pauw R, Wittebole X, Blot K, Van Oyen H et al (2021) The role of organizational characteristics on the outcome of COVID-19 patients admitted to the ICU in Belgium. Lancet Reg Health Europe. https://doi.org/10.1016/j.lanepe.2020.100019
17. Marcolino MS, Ziegelmann PK, Souza-Silva MVR, do Nascimento IJB, Oliveira LM, Monteiro LS et al (2021) Clinical characteristics and outcomes of patients hospitalized with COVID-19 in Brazil: results from the Brazilian COVID-19 Registry. Int J Infect Dis. https://doi.org/10.1016/j.ijid.2021.01.019
18. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP et al (2007) Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. BMJ 335(7624):806–808. https://doi.org/10.1016/j.jclinepi.2007.11.008
19. World Health Organization (2020) Laboratory testing strategy recommendations for COVID-19: interim guidance, 21 March 2020. Geneva: World Health Organization. Contract No.: WHO/2019-nCoV/lab_testing/2020.1.
20. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG (2009) Research electronic data capture (REDCap)–a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform 42(2):377–381. https://doi.org/10.1016/j.jbi.2008.08.010
21. Harris PA, Taylor R, Minor BL, Elliott V, Fernandez M, O'Neal L et al (2019) The REDCap consortium: Building an international community of software platform partners. J Biomed Inform 95:103208. https://doi.org/10.1016/j.jbi.2019.103208
22. Marcolino MS, Pires MC, Ramos LEF, Silva RT, Oliveira LM, Carvalho RLR et al (2021) ABC2-SPH risk score for in-hospital mortality in COVID-19 patients: development, external validation and comparison with other available scores. Int J Infect Dis 110:281–308. https://doi.org/10.1016/j.ijid.2021.07.049
23. Cadastro Nacional dos Estabelecimentos de Saúde. Available from: http://cnes.datasus.gov.br/. Accessed 21 Nov 2021
24. IBGE—Cidades. Available from: https://cidades.ibge.gov.br/. Acessed 21 Nov 2021
25. Machado FR, Cavalcanti AB, Bozza FA, Ferreira EM, Angotti Carrara FS, Sousa JL et al (2017) The epidemiology of sepsis in Brazilian intensive care units (the Sepsis PREvalence Assessment Database, SPREAD): an observational study. Lancet Infect Dis 17(11):1180–1189. https://doi.org/10.1016/S1473-3099(17)30322-5
26. Lam MB, Figueroa JF, Feyman Y, Reimold KE, Orav EJ, Jha AK (2018) Association between patient outcomes and accreditation in US hospitals: observational study. BMJ 363:k4011. https://doi.org/10.1136/bmj.k4011
27. Gershengorn HB, Harrison DA, Garland A, Wilcox ME, Rowan KM, Wunsch H (2017) Association of intensive care unit patient-to-intensivist ratios with hospital mortality. JAMA Intern Med 177(3):388–396. https://doi.org/10.1001/jamainternmed.2016.8457
28. Ministério da Saúde (2004) Portaria GM - MS n1044. Brazil
29. Kim MM, Barnato AE, Angus DC, Fleisher LA, Fleisher LF, Kahn JM (2010) The effect of multidisciplinary care teams on intensive care unit mortality. Arch Intern Med 170(4):369–376. https://doi.org/10.1001/archinternmed.2009.521
30. Ranzani OT, Bastos LSL, Gelli JGM, Marchesi JF, Baião F, Hamacher S et al (2021) Characterisation of the first 250,000 hospital admissions for COVID-19 in Brazil: a retrospective analysis of nationwide data. Lancet Respir Med 9(4):407–418. https://doi.org/10.1016/S2213-2600(20)30560-9
31. Conde KA, Silva E, Silva CO, Ferreira E, Freitas FG, Castro I et al (2013) Differences in sepsis treatment and outcomes between public and private hospitals in Brazil: a multicenter observational study. PLoS ONE 8(6):e64790. https://doi.org/10.1371/journal.pone.0064790
32. Palamim CVC, Marson FAL (2020) COVID-19—the availability of ICU beds in Brazil during the onset of pandemic. Ann Glob Health 86(1):100. https://doi.org/10.5334/aogh.3025
33. Baqui P, Bica I, Marra V, Ercole A, van der Schaar M (2020) Ethnic and regional variations in hospital mortality from COVID-19 in Brazil: a cross-sectional observational study. Lancet Glob Health 8(8):e1018–e1026. https://doi.org/10.1016/S2214-109X(20)30285-0
34. Bambra C, Riordan R, Ford J, Matthews F (2020) The COVID-19 pandemic and health inequalities. J Epidemiol Community Health 74(11):964–968. https://doi.org/10.1136/jech-2020-214401
35. Gutierrez JP, Bertozzi SM (2020) Non-communicable diseases and inequalities increase risk of death among COVID-19 patients in Mexico. PLoS ONE 15(10):e0240394. https://doi.org/10.1371/journal.pone.0240394
36. Massuda A, Hone T, Leles FAG, de Castro MC, Atun R (2018) The Brazilian health system at crossroads: progress, crisis and resilience. BMJ Glob Health 3(4):e000829. https://doi.org/10.1136/bmjgh-2018-000829
37. Souza Júnior PRB, Szwarcwald CL, Damacena GN, Stopa SR, Vieira MLFP, Almeida WDS et al (2021) Health insurance coverage in Brazil: analyzing data from the National Health Survey, 2013 and 2019. Cien Saude Colet 26(suppl 1):2529–2541. https://doi.org/10.1590/1413-81232021266.1.43532020
38. Castro MC, Massuda A, Almeida G, Menezes-Filho NA, Andrade MV, de Souza Noronha KVM et al (2019) Brazil's unified health system: the first 30 years and prospects for the future. Lancet 394(10195):345–356. https://doi.org/10.1016/S0140-6736(19)31243-7
39. Aziz S, Arabi YM, Alhazzani W, Evans L, Citerio G, Fischkoff K et al (2020) Managing ICU surge during the COVID-19 crisis: rapid guidelines. Intensive Care Med 46(7):1303–1325. https://doi.org/10.1007/s00134-020-06092-5
40. Sprung CL, Zimmerman JL, Christian MD, Joynt GM, Hick JL, Taylor B et al (2010) Recommendations for intensive care unit and hospital preparations for an influenza epidemic or mass disaster: summary report of the European Society of Intensive Care Medicine's Task Force for intensive care unit triage during an influenza epidemic or mass disaster. Intensive Care Med 36(3):428–443. https://doi.org/10.1007/s00134-010-1759-y
41. Sandrock C (2010) Chapter 4. Manpower. Recommendations and standard operating procedures for intensive care unit and hospital preparations for an influenza epidemic or mass disaster. Intensive Care Med 36(Suppl 1):S32–S37. https://doi.org/10.1007/s00134-010-1767-y
42. Li L, Xv Q, Yan J (2020) COVID-19: the need for continuous medical education and training. Lancet Respir Med 8(4):e23. https://doi.org/10.1016/S2213-2600(20)30125-9
43. Billings J, Ching BCF, Gkofa V, Greene T, Bloomfield M (2021) Experiences of frontline healthcare workers and their views about support during COVID-19 and previous pandemics: a systematic review and qualitative meta-synthesis. BMC Health Serv Res 21(1):923. https://doi.org/10.1186/s12913-021-06917-z

44. Fernandez R, Lord H, Halcomb E, Moxham L, Middleton R, Alananzeh I et al (2020) Implications for COVID-19: a systematic review of nurses' experiences of working in acute care hospital settings during a respiratory pandemic. Int J Nurs Stud 111:103637. https://doi.org/10.1016/j.ijnurstu.2020.103637
45. Barcellos RA, Chatkin JM (2020) Impact of a multidisciplinary checklist on the duration of invasive mechanical ventilation and length of ICU stay. J Bras Pneumol 46(3):e20180261. https://doi.org/10.36416/1806-3756/e20180261
46. Wortel SA, de Keizer NF, Abu-Hanna A, Dongelmans DA, Bakhshi-Raiez F (2021) Number of intensivists per bed is associated with efficiency of Dutch intensive care units. J Crit Care 62:223–229. https://doi.org/10.1016/j.jcrc.2020.12.008
47. Kumar S, Merchant S, Reynolds R (2013) Tele-ICU: efficacy and cost-effectiveness approach of remotely managing the critical care. Open Med Inform J 7:24–29. https://doi.org/10.2174/1874431101307010024
48. Subramanian S, Pamplin JC, Hravnak M, Hielsberg C, Riker R, Rincon F et al (2020) Tele-critical care: an update from the society of critical care medicine tele-ICU committee. Crit Care Med 48(4):553–561. https://doi.org/10.1097/CCM.0000000000004190

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