CSP CADERNOS DE SAÚDE PÚBLICA
REPORTS IN PUBLIC HEALTH

ARTIGO
ARTICLE

The COVID-19 pandemic in Brazil: analysis of supply and demand of hospital and ICU beds and mechanical ventilators under different scenarios

Pandemia por COVID-19 no Brasil: análise da demanda e da oferta de leitos hospitalares e equipamentos de ventilação assistida segundo diferentes cenários

Pandemia por COVID-19 en Brasil: análisis de la demanda y oferta de camas hospitalarias, así como equipamientos de ventilación asistida, según diferentes escenarios

Kenya Valeria Micaela de Souza Noronha [1]
Gilvan Ramalho Guedes [1]
Cássio Maldonado Turra [1]
Mônica Viegas Andrade [1]
Laura Botega [1]
Daniel Nogueira [1]
Julia Almeida Calazans [1]
Lucas Carvalho [1]
Luciana Servo [2]
Monique Félix Ferreira [1,3]

doi: 10.1590/0102-311X00115320

Abstract

This study aims to analyze the pressure on the Brazilian health system from the additional demand created by COVID-19. The authors performed a series of simulations to estimate the demand for hospital beds (health micro-regions) as well as to ICU beds, and mechanical ventilators (health macro-regions) under different scenarios of intensity (infection rates equivalent to 0.01, 0.1, and 1 case por 100 inhabitants) and time horizons (1, 3, and 6 months). The results reveal a critical situation in the system for meeting this potential demand, with numerous health micro-regions and macro-regions operating beyond their capacity, compromising the care for patients, especially those with more severe symptoms. The study presents three relevant messages. First, it is necessary to slow the spread of COVID-19 in the Brazilian population, allowing more time for the reorganization of the supply and relieve the pressure on the health system. Second, the expansion of the number of available beds will be the key. Even if the private sector helps offset the deficit, the combined supply from the two sectors (public and private) would be insufficient in various macro-regions. The construction of field hospitals is important, both in places with a history of "hospital deserts" and in those already pressured by demand. The third message involves the regionalized organization of health services, whose design may be adequate in situations of routine demand, but which suffer additional challenges during pandemics, especially if patients have to travel long distances to receive care.

COVID-19; Pandemics; Health Services Accessibility; Unified Health System; Supplemental Health

Correspondence
K. V. M. S. Noronha
Centro de Desenvolvimento e Planejamento Regional, Faculdade de Ciências Econômicas, Universidade Federal de Minas Gerais.
Av. Presidente Antônio Carlos 6627, Belo Horizonte, MG 31270-901, Brasil.
knoronha@cedeplar.ufmg.br

[1] *Faculdade de Ciências Econômicas, Universidade Federal de Minas Gerais, Belo Horizonte, Brasil.*
[2] *Diretoria de Estudos e Políticas Sociais, Instituto de Pesquisa Econômica Aplicada, Brasília, Brasil.*
[3] *Secretaria de Estado de Saúde de Minas Gerais, Belo Horizonte, Brasil.*

Introduction

Since SARS-CoV-2 was first detected in December 2019, COVID-19 has spread across all the globe and has been declared a pandemic by the World Health Organization (WHO). According to the WHO, 80% of patients with COVID-19 present mild symptoms without complications, 15% evolve to hospitalization and require oxygen therapy, and 5% require treatment in intensive care units (ICUs) [1]. Depending on the pace of the novel coronavirus spread in the population, health systems can experience critical pressure from the extra demand created by COVID-19.

Various studies have evaluated hospital capacity in different countries. One of the main conclusions is that if no action is taken to expand the supply of beds or contain the virus, the rapid saturation of health systems is highly probable [2,3,4,5,6,7,8]. The demand for hospitalization of COVID-19 patients is influenced by various factors such as age and preexisting conditions, with different effects on societies as the pandemic progresses [2,3,4,5,6,7,9,10,11].

Studies on hospital capacity have also been done in Brazil, both at a national [12,13,14] and regional level [15,16,17,18]. Castro et al. [12] estimated the date of the health system's collapse in the macro-regions in which various Brazilian state capitals are located. However, the precision of the dates is susceptible to the various assumptions adopted by the simulations. Rache et. al. [13,14] identified the health regions with the greatest vulnerability to the COVID-19 pandemic and the greatest need for ICU beds. Their supply estimates only considered the beds in the Brazilian Unified National Health System (SUS) and did not take into account demographic factors associated with regional variation in cases.

The current study aims to analyze the pressure on the health system in Brazil resulting from the additional demand created by COVID-19. The services analyzed here are general hospital beds, ICU beds, and mechanical ventilators. The study performs two sets of simulations, one with the combined public (SUS) and private supply, and the other with only the SUS supply. The estimates consider the difference in age profile in relation to the infection and hospitalization rates. Different scenarios were defined for infection rates and time horizons, since the true progression of COVID-19 in Brazil's territory is still unknown. Since Brazil is a huge country that includes several remote areas, the inequalities in geographic access may pose serious barriers for obtaining care in the current pandemic scenario. For cases involving hospitalization, the care is not always provided in the same municipality (county) where the patient lives, thus requiring referral elsewhere. We thus analyzed the difficulty in access to care, based on the mean distance traveled between the patient's own municipality and the closest municipality with a hospital with ICU beds.

Methodology

The number of hospitalizations was estimated for the health micro-regions (general hospital beds) and macro-regions (ICU beds and mechanical ventilators), according to different scenarios of intensity and duration of COVID-19 infection. Regionalization was defined from the 2019 Master Plans for Regionalization of States (PDR in Portuguese), according to which Brazil's municipalities are divided into 450 health micro-regions and 118 health macro-regions. We excluded the Federal District due to its political and administrative specificities.

Three distinct functions were used to calculate the demand: (1) the estimated population for the year 2020 by age groups and health regions, (2) proportional age distribution of confirmed COVID-19 infection rates, and (3) specific rates by age group of general and ICU admissions for COVID-19. We used the population estimates by age and municipality reported by Freire [19].

The expected number of confirmed cases by age was calculated by multiplying the infection rates and the proportion of the population, both by age group, in each location analyzed. We subsequently normalized the values in order to obtain the total infection rates equivalent to 0.01%, 0.1%, and 1% of the population in each region. In the next stage, we calculated the total number of admissions in each age group by multiplying the expected number of cases by the age group-specific rates of general and ICU admissions. In this study, we assume that the estimated demand for mechanical ventilators is equal to the estimated demand for ICU beds.

Since COVID-19 testing coverage in the Brazilian population is still low, the information on confirmed cases of disease and general and ICU admissions by age groups may not be reliable for use in the simulations. Thus, the standards we adopted in this article are estimated age-specific rates for the United States [9] and Spain [20].

We used two official databases, the Brazilian Information System on Hospital Admissions (SIH in Portuguese) and the Brazilian National Registry of Healthcare Establishments (CNES in Portuguese). The data on hospitalizations refer to admissions in the public SUS for the entire year of 2019, while those on supply (CNES) are based on the records for December, 2019. We excluded obstetric, pediatric, day-hospital, and special beds (in the case of general hospital beds) and pediatric, neonatal, and burn-patient beds (in the case of ICU beds). Pediatric and neonatal beds were excluded because it is impossible to care for adult patients in those beds. Since the COVID-19 infection and admissions rates are quite low in children and adolescents, the inclusion of such beds would generate an overestimation of the available supply.

For each service *i* (hospital beds, ICU beds, and mechanical ventilators), we calculated the occupancy rate in each time scenario *m* (Equation 1).

$$Txo_i^m = \frac{P_i^m}{D_i^m} \qquad (1)$$

Where: D_i^m= number of available days in each service *i* in period *m*, where *m* = 1, 3, or 6 months; P_i^m= length-of-stay in number of days in each service *i* and time scenario *m*. For mechanical ventilators, we considered the length of ICU stay in number of days.

To estimate the extra demand generated by COVID-19, we calculated the total length-of-stay in days for each infection rate scenario ($P_i^{TI,m}$), which was added to the total length-of-stay in days in 2019 based on the SIH database (P_i^m) to result in the total simulated length-of-stay ($TP_i^{TI,m}$):

$$TP_i^{TI,m} = P_i^{TI,m} + P_i^m \qquad (2)$$

Where: *TI* = infection rate defined for each scenario (0.01%, 0.1%, and 1%); = total COVID-19 cases in each scenario multiplied by the mean length of hospital stay according to level of disease, i.e., 8 days for milder cases and 10 days for more serious cases [21].

The estimates of total demand ($P_i^{TI,m}$) for each service *i* in each time scenario (*m*) and infection scenario (*TI*) were obtained as follows:

$$DT_i^{TI,m} = \frac{TP_i^{TI,m}}{D_i^m} \qquad (3)$$

Note that in addition to the admissions due to COVID-19, the other causes of hospitalization were considered as sources of beds occupancy. Due to the lack of information for the private sector, we assumed that the occupancy rate of private beds was equal to the mean for each micro/macro-region estimated for SUS beds in 2019. To understand the private sector's importance in the expansion of the supply of these services, simulations were also performed with the exclusion of private-sector beds. An additional exercise considered the total infection rates observed on May 4, 2020, in each health micro/macro-region in Brazil, assuming that they were reached in three different time scenarios: 1, 3, and 6 months. The cases were adjusted assuming a diagnostic test coverage rate of 13% [22]. The methodological procedures to estimate the age-specific admissions rates in each locality were the same used for the simulations performed in this article.

In addition to the simulations, we characterized the supply of hospital services in Brazil by considering the total number of hospitals and separated by administrative format (public versus private). Since the high-complexity care is organized at the macroregional level, we also analyzed the minimum distance that individuals need to travel to obtain care outside of their home municipalities. For this calculation, we used the information on the patient's home municipality and the location of the hospital with ICU beds and the shortest distance considering multimodal transportation [23].

Results

Characterization of supply

In 2019, Brazil had 8,139 hospital establishments and 490,397 beds. This supply corresponds to approximately 2.3 beds per 1,000 inhabitants, half of the average number in OECD countries in 2017 [24]. Although far short of the average number of beds in OECD countries, the total supply of beds in Brazil is equivalent to that of nations such as Canada, United Kingdom, and Sweden, suggesting that Brazil's supply is relatively consistent with that of countries with mostly public and well-organized health systems. One important difference is the segmentation of the Brazilian system, which has consequences for the public-private composition of hospital care.

Brazil has 270,880 hospital beds (clinical and surgical) and 34,464 adult ICU beds, of which 66% and 48% are available for the public SUS, respectively. There is a high number of small-scale hospitals, namely 5,345 (66%), 70% of which have 29 beds or less. Only 10% of the hospital establishments are large-scale (more than 150 beds). Although fewer in number, these hospitals have 42% of the beds, followed by the medium-sized hospitals (51 to 150 beds), with 35%. The occupancy rate for hospital beds in the SUS is relatively low in the small hospitals, at 24% (up to 29 beds) and 32% (from 30 to 50 beds), compared to 75% in the large-scale hospitals. The supply of ICU beds points to even greater exhaustion of the health system, especially in the larger hospitals, with a mean occupancy rate of 60% in medium-sized hospitals and 77% in large hospitals.

Figure 1 shows the distribution of the supply of hospital beds, ICU beds, and mechanical ventilators per 10,000 inhabitants, available in Brazil in 2019 according to health micro/macro-region. Analyzing the total number hospital beds, there is at least some supply in all 449 micro-regions, but with a major spatial dispersion (Figure 1a). The mean number per 10,000 inhabitants is 12.2, ranging from 2.0 (in Sergipe) to 30.3 (in Goiás). The micro-regions with the lowest supply are concentrated in the states of Amazonas, Pará, Roraima, Minas Gerais, and Ceará. The population in these-regions represents 26% of the population of Ceará, 22% of Amazonas, and 20% of Pará. The micro-regions with the highest supply are located mainly in the states of Rio Grande do Sul, Santa Catarina, São Paulo, Mato Grosso, and Goiás.

Considering only the SUS hospital beds (Figure 1b), the mean number per 10,000 inhabitants drops to 9.1. Although there are beds in the SUS in all the micro-regions, the supply is uneven across the territory: 25% of the micro-regions with the lowest supply have fewer than 6.6 beds per 10,000 inhabitants, as opposed to more than 11 per 10,000 inhabitants in the highest quartile. In the states of Rondônia, Roraima, Piauí, Minas Gerais, and Rio Grande do Sul, more than 50% of the total population lives in micro-regions with a high supply of SUS beds.

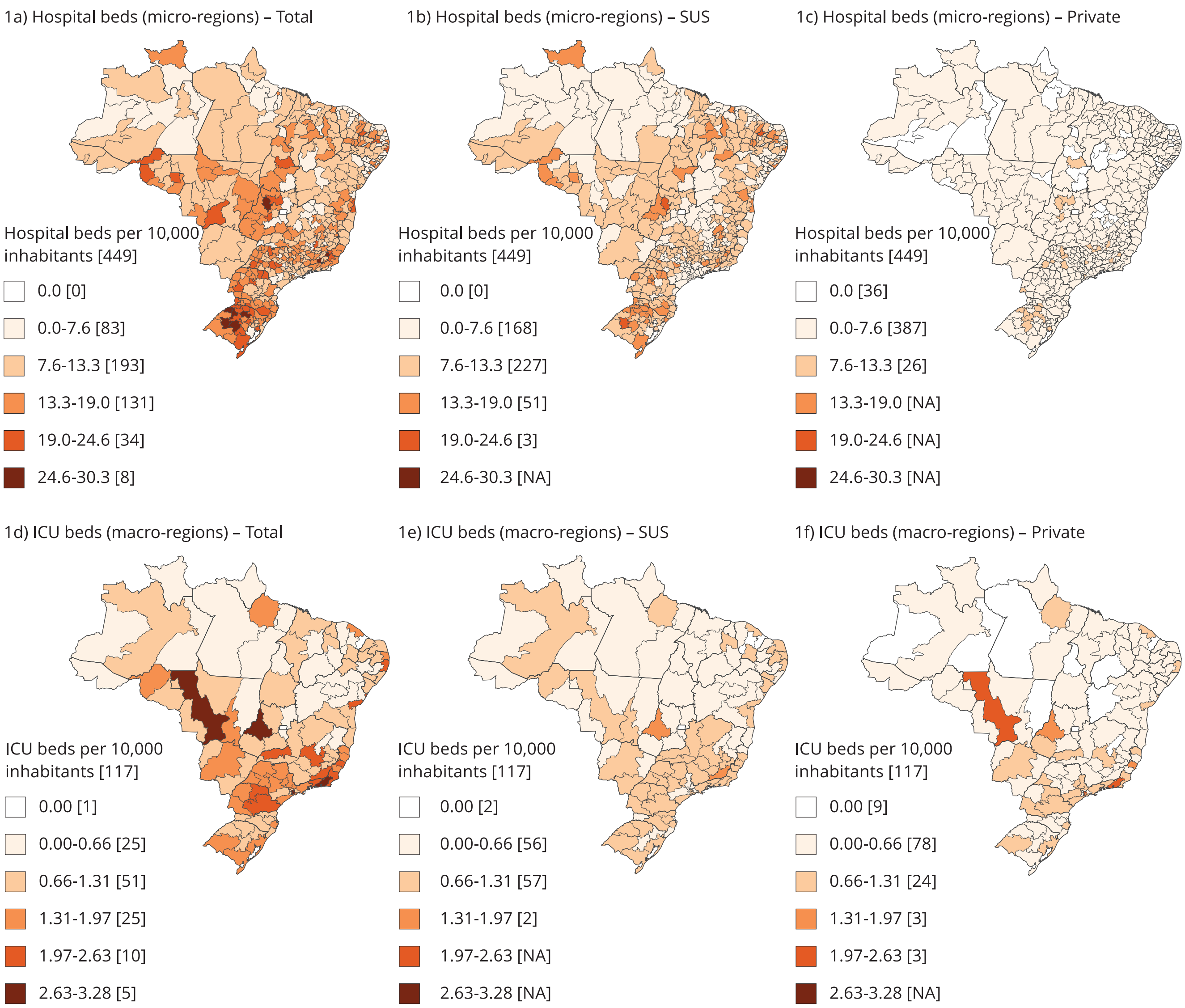
The private supply of beds is zero in 36 micro-regions and ranges from 0.03 beds per 10,000 inhabitants in São José de Mipibu in the state of Rio Grande do Norte to 11.5 in São José do Rio Preto, São Paulo (Figure 1c). The private sector's share is higher in micro-regions in the states of São Paulo, Paraná, Rio Grande do Sul, Minas Gerais, and Goiás.

There is a supply of ICU beds in all the health macro-regions of Brazil, except in the Litoral Leste/Jaguaribe macro-region in the state of Ceará (Figure 1d), which has zero ICU beds. Among the macro-regions with a positive supply, the distribution ranges from 0.07 (western Amazonas state) to 3.3 (RRAS6 macro-region in São Paulo state). The macro-regions with the lowest supply of ICU beds are located mostly in the North and Northeast of Brazil. The 30 macro-regions with the highest supply are in the states of São Paulo, Paraná, Santa Catarina, Rio Grande do Sul, Mato Grosso do Sul, Mato Grosso, and Goiás. There is a complementary arrangement between the public and private sectors in the supply of ICU beds. The private share is only nonexistent in eight macro-regions, located mainly in states of the North (Figure 1f). In six macro-regions, the private supply accounts for 70% of the supply of ICU beds: Central-North (Mato Grosso), Macro-Region II (Rio de Janeiro), North (Espírito Santo), Northeast (Goiás), Semi-Arid (Piauí), and Sertão Central (Ceará).

The Figures 1g, 1h, and 1i show the distribution of the supply of mechanical ventilators across the health macro-regions. In 2019, Brazil had 57,303 ventilators, 72% of which were available to the public SUS. The mean number of ventilators in the macro-regions is 2.0 per 10,000 inhabitants, considering the entire supply, and 1.65 including only those available to the SUS. The public supply

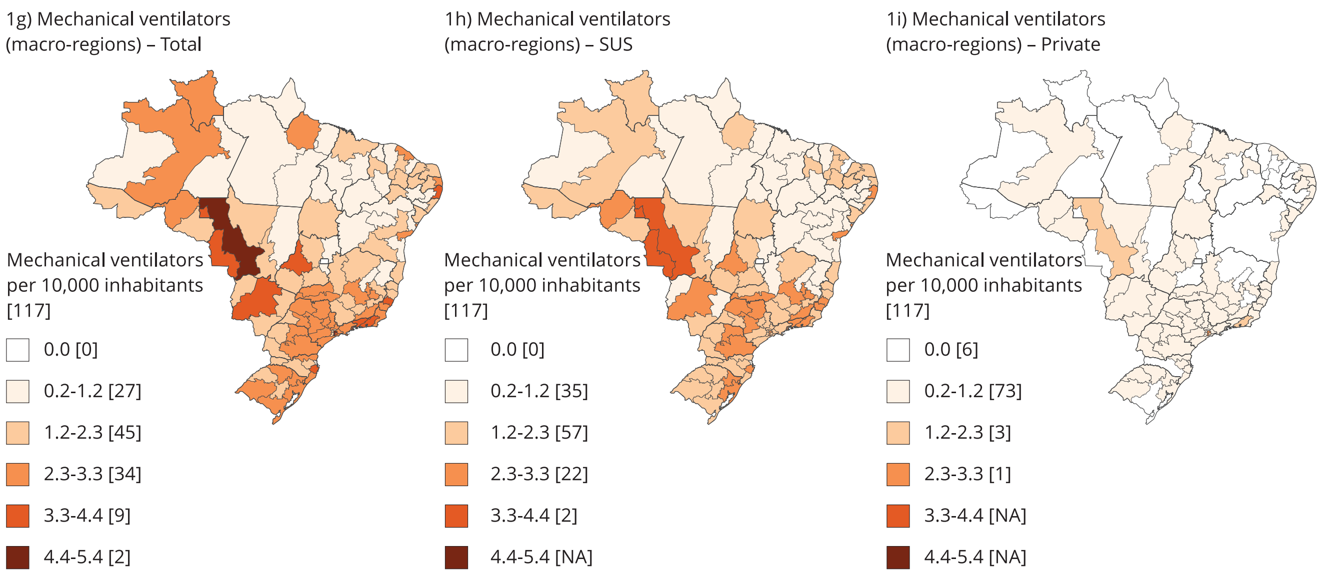
Figure 1

Distribution of the supply of hospital beds, intensive care unit (ICU) beds, and mechanical ventilators. Brazil, 2019.



(continues)

Figure 1 (continued)



NA: not available.

(Figure 1h) is present in all the health macro-regions, but with major dispersion across the territory. The lowest rate is in the Litoral Leste/Jaguaribe macro-region in the state of Ceará, with a negligible supply of 0.07 ventilators per 10,000 inhabitants, in the same macro-region with no ICU beds. The macro-regions with a supply of less than 0.5 ventilators per 10,000 inhabitants are the same ones with an insufficient supply of ICU beds. Those with the highest public SUS supply are northern and southern Mato Grosso state, Greater Metropolitan Vitória in Espírito Santo state, and Greater Metropolitan Florianópolis in Santa Catarina state. The private share of the supply of ventilators varies from zero to 55%, and is highest in the states of São Paulo, Mato Grosso, and Rio de Janeiro (Figure 1i).

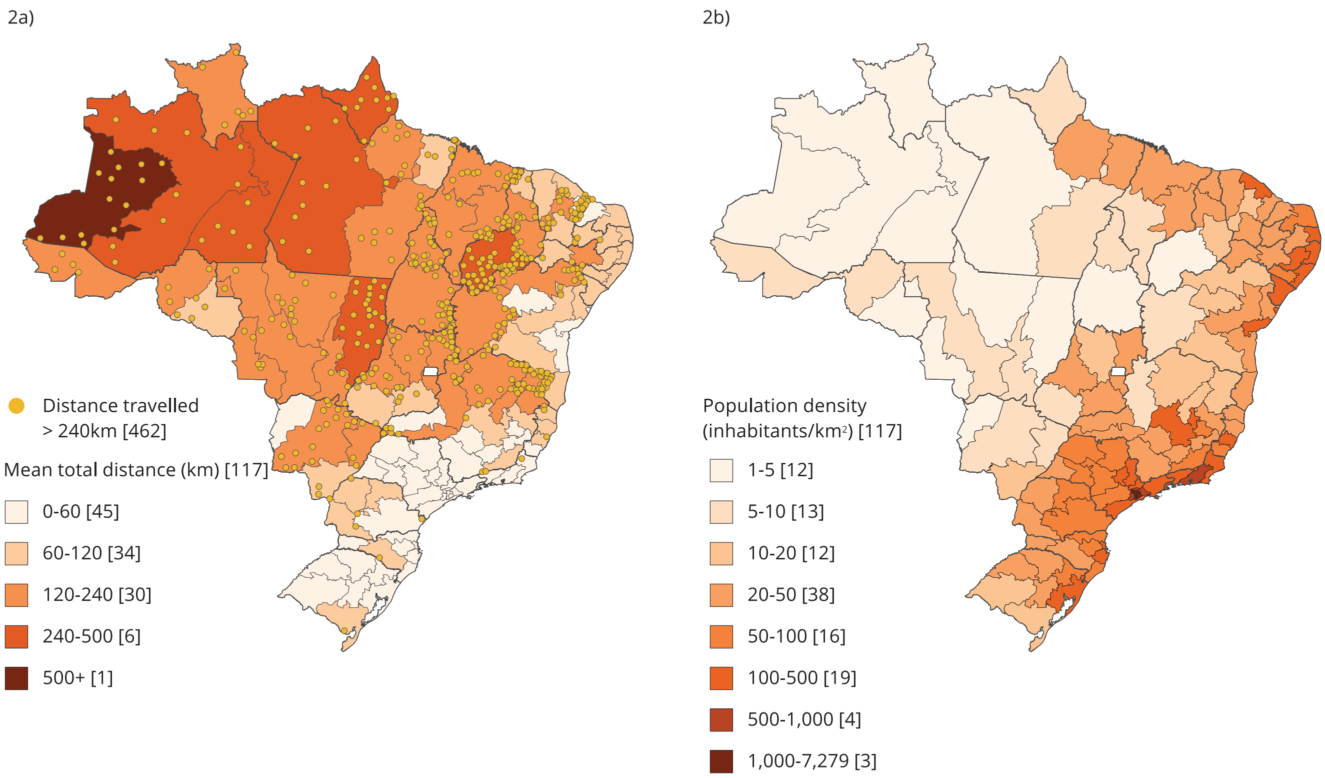
Figure 2a shows the shortest mean distance that residents need to travel to receive care with an ICU bed in the same macro-region where they live. The shortest distance is relatively low, 98km on average, the equivalent of an hour and a half by land transportation. However, the distribution of these distances is quite uneven between the macro-regions, with the longest distances in the North, Northeast, and Central of Brazil. Amazonas is the state with the largest distances, with a mean distance of 615km, followed by Amapá (259km). There may be difficulties in access in 8% of Brazil's municipalities, where patients would have to travel more than 240km to find an ICU bed. Of these municipalities, 126 are in the North (28% of the municipalities), 165 in the Northeast (9%), 63 in the Southeast (4%), 102 in the Central (22%), and 8 in the South (0.7%). These macro-regions are exactly the ones with the lowest population density (Figure 2b).

Pressure from extra demand generated by COVID-19

The results presented in this section were estimated using the age-specific infection and hospitalization rates from the United States. The results with the parameters from Spain are shown in the Supplementary Material (http://cadernos.ensp.fiocruz.br/static/arquivo/suppl-e00115320-en_7370.pdf). The choice of the international standard has little impact on the regional distribution and demand, especially for ICU beds and mechanical ventilators, and the overall conclusions are maintained regardless of which country is selected as the standard.

Figure 2

Distributions of the average total distance travelled to receive intensive care unit (ICU) care within the patient's macro-region of residence and mean population density per macro-region. Brazil, 2019.



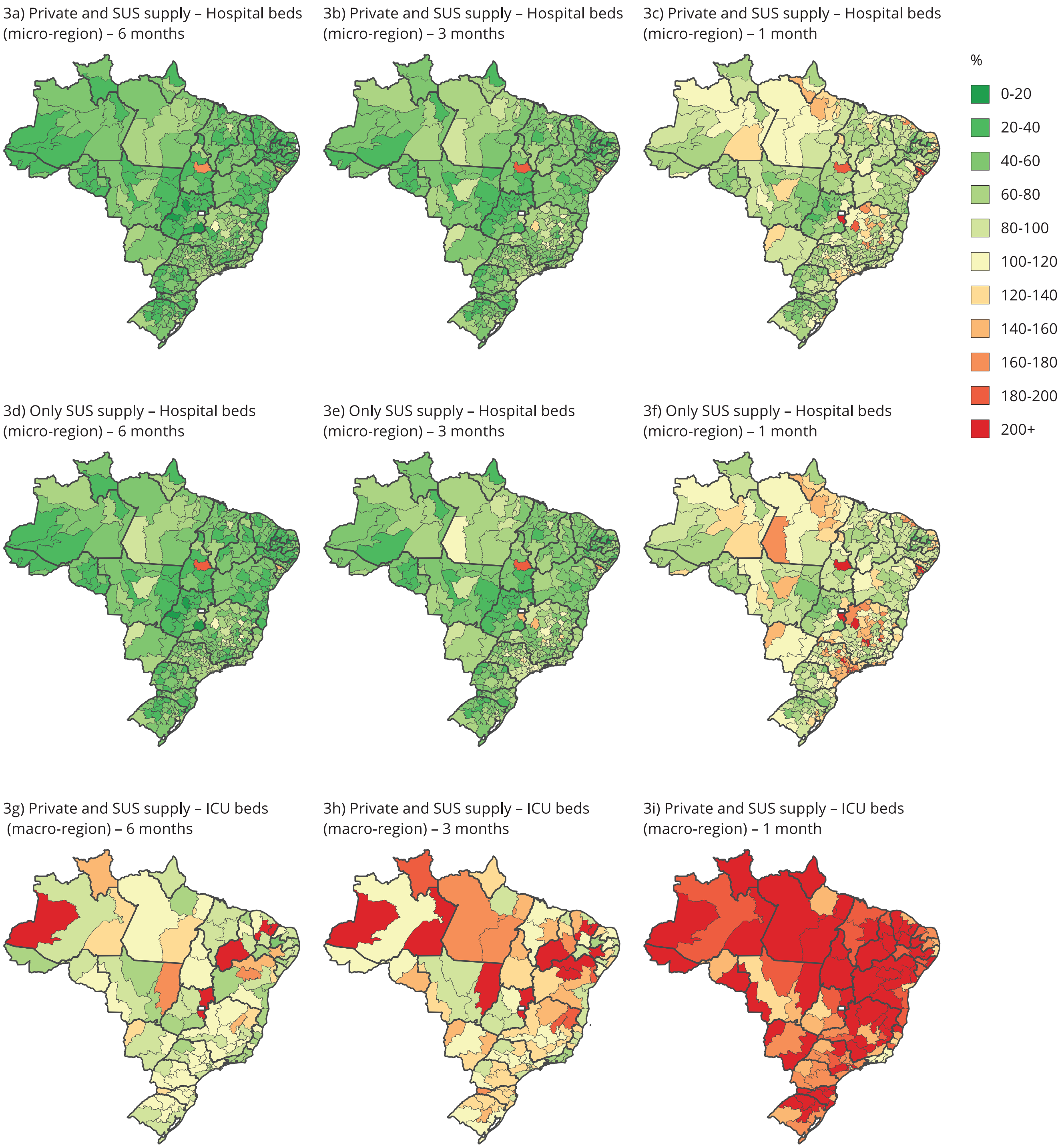
- **General hospital beds**

Considering the private and public (SUS) supply of hospital beds, the main problems would begin to emerge when the infection rate reaches 1% of the population. At lower rates, 0.01% and 0.1%, independently of the time horizon, practically all of the 449 micro-regions would be operating within their capacity (results available, but not shown). If the COVID-19 infection rate reaches 1% in 1 month, 136 health micro-regions in Brazil (30%) would exhaust their capacity (Figures 3a, 3b, and 3c).

Excluding private beds, the situation would become even more serious. At an infection rate of 1% in 1 month, the system would collapse in all the major regions (Figures 3d, 3e, and 3f). In the North of Brazil, 49% of the 45 micro-regions would exhaust their capacity if only the SUS beds were considered. By incorporating private beds, this percentage would decrease, but even só, an important share of the micro-regions (38%) would have difficulty fully meeting the demand. In the Northeast, if only the SUS beds are considered, 34% of the micro-regions would exhaust their supply in the test scenario. This proportion would decrease to 26% if the supply of private beds were included. In the Southeast, the private sector's importance is even more evident. Considering only the SUS supply, some 67% of the health micro-regions would not have enough supply to treat the patients. The inclusion of private hospital beds would decrease this proportion to 42%. In the South and Central regions of Brazil, the supply would be exhausted in 29% and 32% of the micro-regions if only SUS beds were considered. These proportions would decrease to 13% and 16%, respectively, if the system could include the private supply.

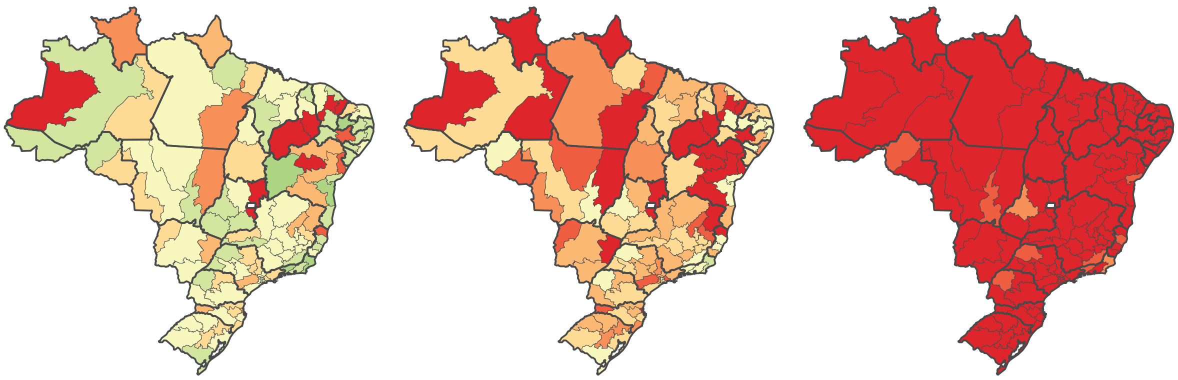
Figure 3

Percentage of occupied hospital beds and intensive care unit (ICU) beds in each health micro/macro-region considering COVID-19 infection rates of 1% of the population and three different time horizons: 6 months, 3 months, and 1 month. Brazil.



(continues)

Figure 3 (continued)



- **ICU beds**

The simulation's results show a more worrisome situation in relation to ICU beds. These results however, depend on the pace of the infection's spread in each health macro-region. In a more optimistic scenario (0.01% infection rate in 6 months), relying on both the SUS and private supply, an overload would be seen in only 5 health macro-regions, one of which located in the state of Minas Gerais (Triângulo do Norte), two in Santa Catarina (Planalto Norte/Nordeste and Foz do Rio Itajaí), and two in Ceará (Sertão Central e Litoral Leste/Jaguaribe) (results available, but not shown). In the Sertão Central macro-region, the supply of ICU beds would only be from the private sector (30 beds), with no ICU beds available to the public SUS. The Litoral Leste/Jaguaribe macro-region in the state of Ceará did not have a single ICU bed registered in December 2019 in the CNES registry.

A more dramatic scenario would be experienced with a higher infection rate, with 1% in 1 month (Figures 3g, 3h, and 3i). In this case, the system would collapse, with 100% of the macro-regions operating beyond their capacity. In 102 macro-regions, the excess demand would be more than 50%, further revealing the weakness of the supply of ICU beds in Brazil. The macro-regions with the largest supply deficits would be located in the states of Amazonas, Goiás, Ceará, Piauí, Bahia, Pernambuco, and Mato Grosso. Considering only the SUS supply, this situation would be exacerbated (Figures 3j, 3k, and 3l). In the more pessimistic scenario, the proportion of the unmet extra demand would be smaller if the system could rely on the supply of private beds. Two results stand out in this scenario: Macro-Region RRAS6, which includes the city of São Paulo, and Macro-Region II, which includes the city of Rio de Janeiro. Without the private beds, the demand generated by COVID-19 would exceed the available supply by 202% and 245%. Considering both the SUS and private supply, the excess demand would be much smaller, 13% and 4.5%, respectively.

- **Mechanical ventilators**

For mechanical ventilators, we considered the combined public and private supply. Although it was possible to identify the ventilators in the CNES according to administrative format (public versus private), this information may not reflect their availability exactly in the public or private sector, due to the way the two sectors interact in the Brazilian health system. Although less severe, the results are also worrisome. In the more pessimistic scenario, 97% of the macro-regions would exhaust their capacity for care. In 51 macro-regions, the health system would be unable to care for more than 50%

of the patients. The Northeast (64%) and North (57%) of Brazil would show the highest proportion of macro-regions in this critical situation (Figure 4).

Simulations with the observed infection levels in each health micro/macro-region

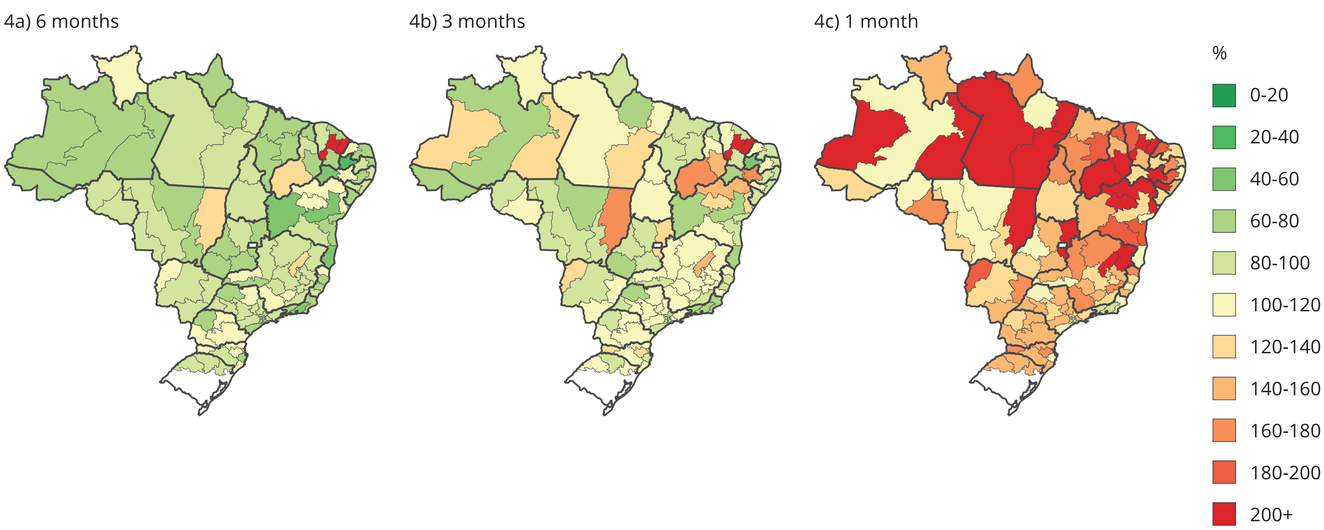
This section presents the simulations based on the actual infection rates observed on May 4, 2020, in each location, correcting for underreporting of COVID-19 cases. The objective is to assess the current stage of spread and its unequal distribution across Brazil's territory. Considering the heterogeneous infection rates between regions, these simulations allow controlling indirectly for other factors that affect the pace of spread. We compare three different time scenarios, considering the joint supply of public and private beds, to assess the degree to which flattening the curve would relieve the pressure on the health system. The analysis maintains the supply and occupancy rate of beds at 2019 levels. Since the first confirmed case of COVID-19 in Brazil was on February 26, the time elapsed to reach these rates in each location of Brazil was less than 3 months. In Brazil, as of the date analyzed, 6.7% of the health micro-regions had no reports of COVID-19 infection. Among those with cases, the infection rates ranged from 0.007% to 2.3%. Approximately 49% of the micro-regions had rates less than 0.1%, while 3% were experiencing rates greater than 1%, located mainly in the states of Amazonas and Amapá.

Analyzing the pressure from demand on hospital beds (Figures 5a, 5b, and 5c), 19 micro-regions, located in the states of Amazonas (5), Amapá (2), Tocantins (1), Maranhão (1), Ceará (3), Sergipe (2), and São Paulo (6), would be operating beyond their capacity if the infection rates reached the observed level in just 1 month. Considering the longer time scenarios (3 or 6 months), only 2 micro-regions would suffer this collapse.

For ICU beds (Figures 5d, 5e, and 5f), if the infection rates reached the observed level in 1 month, the health system would collapse in 55% of the macro-regions. This situation would be more critical in 18 macro-regions, where the demand would exceed the existing supply by 50%. Of these, 7 would be in the North and 6 in the Northeast of Brazil. Considering the 6-month scenario, the proportion

Figure 4

Percentage of occupied mechanical ventilators per health macro-region considering COVID-19 infection rates of 1% in the population and three different time horizons: 6 months, 3 months, and 1 month. Brazil.



of macro-regions with their ICU beds exhausted would be smaller (10%), with only 3 macro-regions presenting excess demand greater than 50%. The results for mechanical ventilators are similar to the estimates for ICU beds (Figures 5g, 5h, and 5i).

Discussion

The results show a critical situation in the health system for meeting the potential demand created by the COVID-19 pandemic. The situation is worrisome, because it results in an increase in mortality in places where the supply of services is not sufficiently prepared. When combining the public and private supply, various health micro-regions and macro-regions would be operating beyond their capacity, jeopardizing the care, especially for patients with more severe symptoms. The scenario is worst for ICU beds in the North and Northeast of Brazil. The presence of "hospital deserts" may lead the system's collapse, even with lower infection rates. Despite the supply problems detected here, the later spread of COVID-19 into the interior of Brazil creates an important window of opportunity for reorganizing the local health systems and the adoption of measures to mitigate the infection's spread. For some locations in the North and Northeast however, the virus' spread is already a reality and has

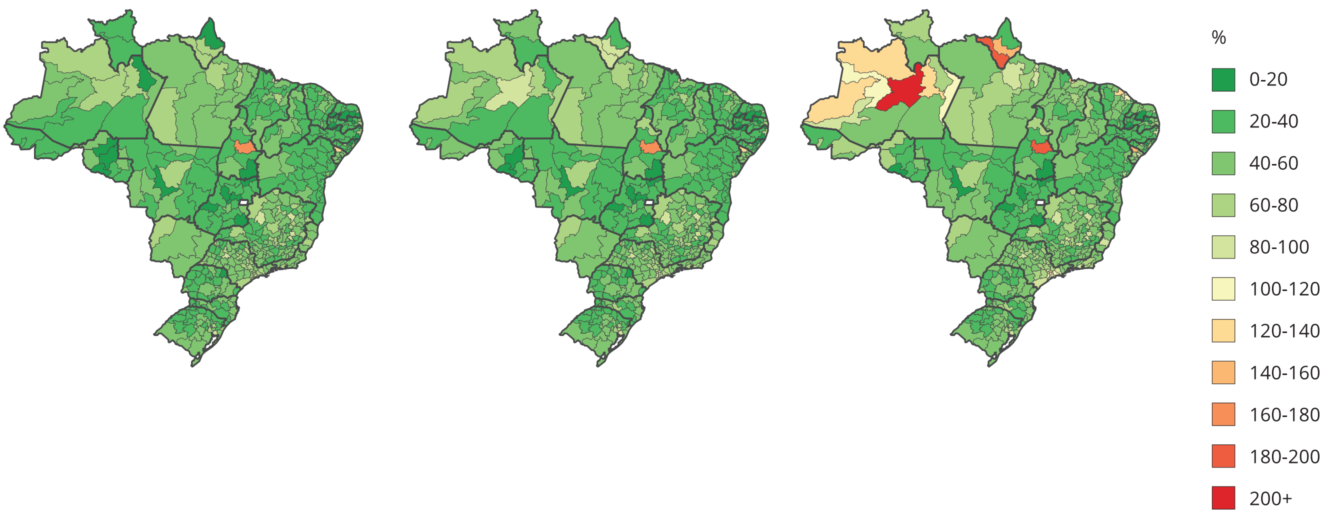
Figure 5

Percentage of occupied hospital beds, intensive care unit (ICU) beds, and mechanical ventilators considering observed COVID-19 infection rates (corrected for underreporting) in each health micro/macro-region and three different time horizons: 6 months, 3 months, and 1 month. Brazil.

5a) Private and SUS supply – Hospital beds (micro-region) – 6 months

5b) Private and SUS supply – Hospital beds (micro-region) – 3 months

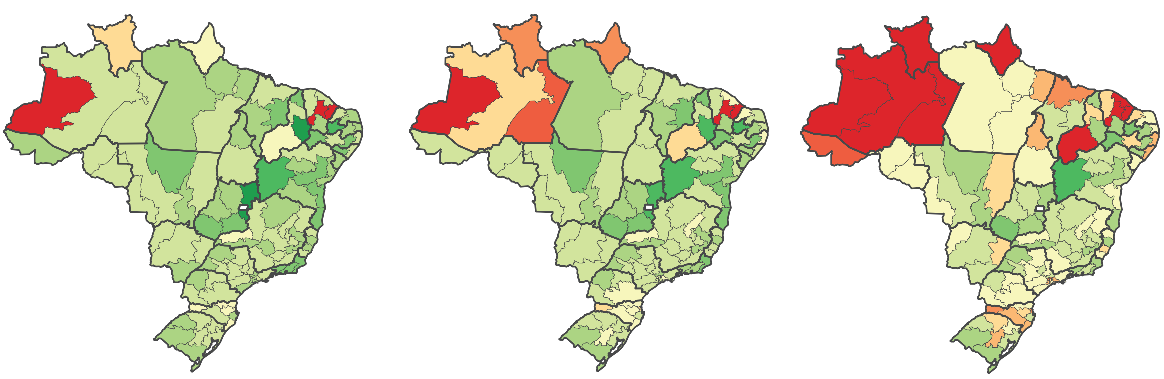
5c) Private and SUS supply – Hospital beds (micro-region) – 1 month



5d) Private and SUS supply – ICU beds (macro-region) – 6 months

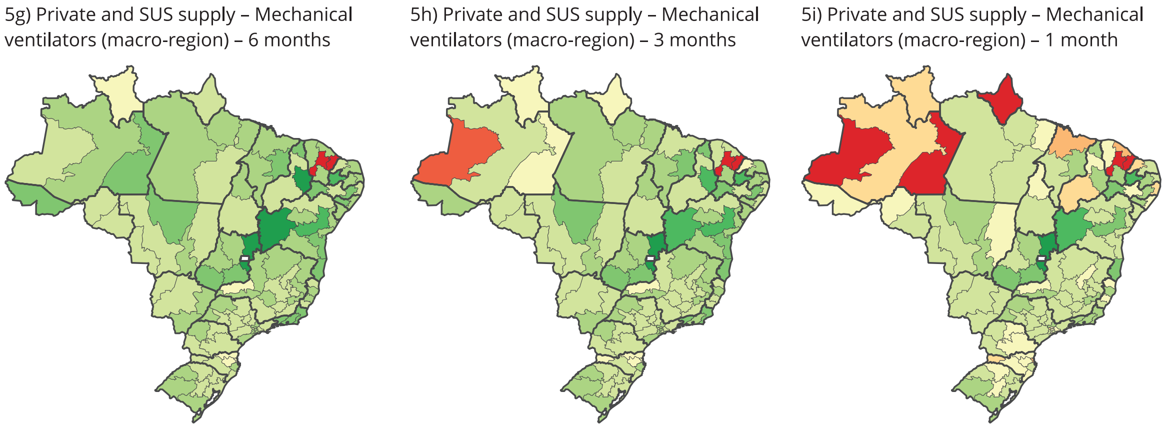
5e) Private and SUS supply – ICU beds (macro-region) – 3 months

5f) Private and SUS supply – ICU beds (macro-region) – 1 month



(continues)

Figure 5 (continued)



been detected at a relatively fast pace, creating pressure from demand, as in Manaus (Amazonas) and Fortaleza (Ceará) [25]. Our simulations based on the infection rates observed as of May 4 confirm the vulnerability of supply in these two regions, associated with accelerated spread of the disease. In the Southeast, despite the greater availability of supply, the rates and pace of infection in some locations are higher [25]. In São Paulo and Rio de Janeiro, in addition to the pressure from demand, an important issue is the private sector's role, crucial for expanding the supply.

The study has three relevant messages for the health system in the context of the pandemic. The first regards the need to reduce the pace of COVID-19 spread in the Brazilian population. It will be key to contain the spread to relieve the pressure on the health system and allow more time to reorganize the supply. Given the regional heterogeneity in both the supply and the infection rates, it will not be possible to a adopt a single form of containment of COVID-19 spread in Brazil. Different containment measures are being implemented in the international scenario. The way these measures have been adopted varies greatly between countries, depending on the stage and speed of the disease's spread, specificities in the health system, and social, economic, and political issues [26]. According to Canabarro et al. [27], the measures already implemented in some Brazilian cities and states, such as cancellation of classes at all levels, social distancing, and voluntary quarantine, have helped reduce the number of cases of infection and postpone the peak transmission. Due to economic issues, there is pressure to suspend these measures. If this process is not done gradually and with coordination, considering the specificities of each municipality and region, the health impacts may be catastrophic. The healthcare system's capacity in each location must be assessed, monitoring the SARS-CoV-2 basic reproduction number and expanding the laboratory testing for screening and isolation of confirmed cases [27,28]. Mass testing allows implementing a more optimal strategy for mitigating spread of the disease, avoiding more drastic actions that would have more serious consequences for the productive sector [28]. In addition, without this information, it is difficult to estimate the demand in each location in order to adjust the supply. Due to the difficulties faced by countries with continental dimensions such as Brazil, widespread testing would not be a feasible option. However, higher test coverage could help slow the pace of spread and the economic consequences for the country. Compared to other countries, the total testing rates in Brazil are still very low [26,29].

The second message refers to the need to expand the available beds. The private sector contributes to buffering the deficit, but in various macro-regions, depending on how fast the infection spreads, the combined supply by both sectors would not be sufficient. In this scenario, some measures can contribute to expanding the supply of hospital services, besides collaboration with the private sector.

The immediate construction of field hospitals is necessary and should be accompanied by a policy for allocation of health professionals and adequate inputs, especially where the supply is incipient. The expansion of supply has already occurred in various places in Brazil. As of April 20, according to the CNES, 80 field hospitals had been organized, resulting in an increase of some 6,300 beds. In this expansion of the supply, the Federal Government's role is crucial, especially on three issues: standardization of a single rule for the public-private relationship; economies of scale and bargaining gains in purchases of inputs; and direct provision in regions that lack the capacity to leverage this supply immediately.

To estimate the supply in the long term, it is also necessary to consider the system's usual demand flow in which there is a time limit for postponing elective hospitalizations without jeopardizing the health of these patients. Our simulations discounted the beds that are used to treat other diseases, based on the occupancy rate in 2019. This procedure is important, since we cannot assume that the demand from other causes will not occur or will not be treated because of COVID-19.

It is also important to highlight the role of small hospitals, which represent approximately 66% of the hospital establishments in Brazil. These hospitals operate at a very low occupancy rate (26%), as opposed to occupancy in the large hospitals (75%). An idle capacity thus exists in the hospital system, but it exists more intensely in hospitals with lower case-resolution capacity [30]. The small hospitals are not prepared to treat patients with more severe symptoms of COVID-19, due to the high degree of specialization of the necessary resources. Therefore, the expansion of supply via small hospitals may be limited.

The third message refers to the organization of health services supply, which is regionalized. In situations of routine demand, this design is adequate due to the existence of scale economies. But the same design may be inadequate in pandemic situations if the patient has to travel far for care, given the rapid evolution of COVID-19. The current study shows that for 8% of Brazil's municipalities, the mean distance travelled for intensive care is more than 240km. The longest distances are in the North, especially in the states of Amazonas and Amapá. It is thus necessary to organize the referral of patients in adequate conditions and in timely fashion to contain the clinical progression of the disease. This will depend on both an adequate supply of land or air transportation and the capacity of the reference municipalities in the micro/macro-region to absorb this demand. In this context, it will be key to have a dynamic system for regulating the supply of beds to optimize and coordinate the referral of demand within each region. Due to the rapid evolution of serious cases, it is essential to organize the logic of referrals to avoid waiting time, which can result in the patients' death. The main problem is when the health macro-region has a deficit in beds, as detected in the simulation exercises performed here.

The estimates produced by our simulations present at least three limitations. The first is the use of international parameters to estimate the demand for hospital and ICU admissions. We are assuming that the age-specific rates of hospital and ICU admissions due to COVID-19 in Brazil are equal to those in the United States and Spain, both in terms of level and age profile. Although there is information on infection rates and hospitalizations by age group in Brazil, the coverage is still low. Preliminary analyses indicate similarity with the United States in the distribution of age-specific infection rates. Spain presents relatively higher rates and in relatively older patients (Supplementary Material; http://cadernos.ensp.fiocruz.br/static/arquivo/suppl-e00115320-en_7370.pdf). Thus, since disaggregation by age group is a methodological feature of this study, we opted to maintain the international parameters, focusing the analysis of estimates based on the US case.

The second limitation refers to the spatial heterogeneity of morbidity rates, which can affect the outcomes of COVID-19 admissions in each micro-region [31]. To a certain extent, part of this variation was captured in our study via the population's age distribution. However, even considering that the health transition and demographic transition may be correlated, regional variations in morbidity may remain within the age groups.

Finally, our study does not take into account the demand for health professionals directly involved in patient care or for workers involved in support and sanitization, who are essential for the hospitals' adequate functioning in response to the pandemic. Despite these limitations, our results provide an important diagnosis of the supply situation in Brazil at the beginning of the pandemic and of the extent to which the spread of SARS-CoV-2 has affected the healthcare system's capacity in each locality.

Contributors

K. V. M. S. Noronha, G. R. Guedes, C. M. Turra, and M. V. Andrade participated in all stages of the study's execution, including the conception, design, organization of the databank, estimation of the results, and writing and revision of the manuscript. L. Botega, D. Nogueira, and L. Carvalho participated in the organization of the datasets, estimation of the results, and writing and revision of the manuscript. J. A. Calazans participated in the writing and revision of the manuscript, organization of the datasets, and estimation of the results. L. Servo and M. F. Ferreira participated in the writing and revision of the manuscript.

Additional informations

ORCID: Kenya Valeria Micaela de Souza Noronha (0000-0002-7174-6710); Gilvan Ramalho Guedes (0000-0001-8231-238X); Cássio Maldonado Turra (0000-0003-4051-3567); Mônica Viegas Andrade (0000-0002-6821-1598); Laura Botega (0000-0001-6030-4100); Daniel Nogueira (0000-0002-3206-7782); Julia Almeida Calazans (0000-0002-6215-3251); Lucas Carvalho (0000-0002-3618-3967); Luciana Servo (0000-0003-0770-7378); Monique Félix Ferreira (0000-0003-2513-4382).

Acknowledgments

The study received financial support from the Brazilian Graduate Studies Coordinating Board (CAPES; funding code 001). K.V.M.S.N., G.R.G., M.V.A., and C.M.T. wish to thank the Brazilian National Research Council (CNPq) for supporting this study with research scholarships. J.A.C. also thanks the CNPq for granting a PhD scholarship. All the authors thank Pedro Amaral (Federal University of Minas Gerais – UFMG) for his insightful comments and Jeferson Andrade (UFMG) for his technical assistance.

References

1. World Health Organization. Oxygen sources and distribution for COVID-19 treatment centres: interim guidance, 4 April 2020. Geneva: World Health Organization; 2020.
2. Sarkar J, Chakrabarti P. A machine learning model reveals older age and delayed hospitalization as predictors of mortality in patients with COVID-19. medRxiv 2020; 30 mar. https://www.medrxiv.org/content/10.1101/2020.03.25.20043331v1.
3. Zhang T, McFarlane K, Vallon J, Yang L, Xie J, Blanchet J, et al. A model to estimate bed demand for COVID-19 related hospitalization. medRxiv 2020; 26 mar. https://www.medrxiv.org/content/10.1101/2020.03.24.20042762v1.
4. IHME COVID-19 Health Service Utilization Forecasting Team; Murray C. Forecasting COVID-19 impact on hospital bed-days, ICU-days, ventilator-days and deaths by US state in the next 4 months. medRxiv 2020; 30 mar. https://www.medrxiv.org/content/10.1101/2020.03.27.20043752v1.
5. Waldman A, Shaw A, Ngu A, Campbell S. Are hospitals near me ready for coronavirus? Here are nine different scenarios. ProPublica 2020; 17 mar. https://projects.propublica.org/graphics/covid-hospitals.
6. Moghadas SM, Shoukat A, Fitzpatrick MC, Wells CR, Sah P, Pandey A, et al. Projecting hospital utilization during the COVID-19 outbreaks in the United States. Proc Natl Acad Sci U S A 2020; 117:9122-6.
7. Verhagen MD, Brazel DM, Dowd JB, Kashnitsky I, Mills M. Predicting peak hospital demand: demographics, spatial variation, and the risk of "hospital deserts" during COVID-19 in England and Wales, 2020. OSFPreprints 2020; 27 mar. https://osf.io/g8s96/.
8. Walker PGT, Whittaker C, Watson O, Baguelin M, Ainslie KEC, Bhatia S, et al. The global impact of COVID-19 and strategies for mitigation and suppression. https://spiral.imperial.ac.uk:8443/handle/10044/1/77735 (accessed on 31/Mar/2020).

9. CDC COVID-19 Response Team. Severe outcomes among patients with coronavirus disease 2019 (COVID-19). MMWR Morb Mortal Wkly Rep 2020; 69:343-6.
10. Petrilli CM, Jones SA, Yang J, Rajagopalan H, O'Donnell LF, Chernyak Y, et al. Factors associated with hospitalization and critical illness among 4,103 patients with COVID-19 disease in New York City. medRxiv 2020; 11 apr. https://www.medrxiv.org/content/10.1101/2020.04.08.20057794v1.
11. Rentsch CT, Kidwai-Khan F, Tate JP, Park LS, King Jr. JT, Skanderson M, et al. Covid-19 testing, hospital admission, and intensive care among 2,026,227 United States veterans aged 54-75 years. medRxiv 2020; 14 apr. https://www.medrxiv.org/content/10.1101/2020.04.09.20059964v1.
12. Castro MC, Carvalho LR, Chin T, Kahn R, Franca G, Macario EM, et al. Demand for hospitalization services for COVID-19 patients in Brazil. medRxiv 2020; 1 apr. https://www.medrxiv.org/content/10.1101/2020.03.30.20047662v1.
13. Rache B, Nunes L, Rocha R, Lago M, Fraga A. Como conter a curva no Brasil? Onde a epidemiologia e a economia se encontram. São Paulo: Instituto de Estudos para Políticas de Saúde; 2020. (Nota Técnica, 4).
14. Rache B, Rocha R, Nunes L, Spinola P, Massuda A. Para além do custeio: necessidades de investimento em leitos de UTI no SUS sob diferentes cenários da Covid-19. São Paulo: Instituto de Estudos para Políticas de Saúde; 2020. (Nota Técnica, 7).
15. Departamento de Economia e Estatística, Secretaria de Planejamento, Orçamento e Gestão. Coronavírus: exercícios de projeções de casos para o Rio Grande do Sul. https://colunadonene.com.br/wp-content/uploads/2020/03/Coronavirus-Exerc%C3%ADcio-de-Proje%C3%A7%C3%A3o-de-casos-no-Rio-Grande-do-Sul.pdf (accessed on 19/Mar/2020).
16. Batista A, Antunes B, Faveret G, Peres I, Dantas L, Bastos L, et al. Dimensionamento de leitos para os casos de infecção por COVID-19 no Estado do Rio de Janeiro para o dia 04 de abril de 2020. Rio de Janeiro: Núcleo de Operações e Inteligência em Saúde; 2020. (Nota Técnica, 2).
17. Batista A, Antunes B, Faveret G, Peres I, Dantas L, Bastos L, et al. Dimensionamento de leitos para os casos de infecção por COVID-19 nas Regiões de Saúde do Sudeste de Minas Gerais (Juiz de Fora e região) para o dia 09 de abril de 2020. Rio de Janeiro: Núcleo de Operações e Inteligência em Saúde; 2020. (Nota Técnica, 2.1).
18. Noronha K, Guedes G, Turra CM, Andrade MV, Botega L, Nogueira D, et al. Pandemia por COVID-19 em Minas Gerais, Brasil: análise da demanda e da oferta de leitos e equipamentos de ventilação assistida considerando os diferenciais de estrutura etária, perfil etário de infecção, risco etário de internação e distâncias territoriais. São Paulo: Instituto de Estudos para Politicas de Saúde; 2020. (Working Paper Series, 4).
19. Freire FHMA. Projeção populacional municipal com estimadores bayesianos, Brasil 2010 – 2030. In: Sawyer DO, coordenador. Seguridade social municipal. Projeto Brasil 3 Tempos. Brasília: Secretaria Especial de Assuntos Estratégicos da Presidência da República/Programa das Nações Unidas para o Desenvolvimento/Centro Internacional de Políticas para o Crescimento Inclusivo; 2019.
20. Dirección General de Salud Pública, Calidad e Innovación, Secretaria General de Sanidad, Ministerio de Sanidad. Actualización nº 85. Enfermedad por el coronavirus (COVID-19). 24.04.2020 (datos consolidados a las 21:00 horas del 23.04.2020). https://www.mscbs.gob.es/profesionales/saludPublica/ccayes/alertasActual/nCov-China/documentos/Actualizacion_85_COVID-19.pdf (accessed on 27/Apr/2020).
21. Ferguson NM, Laydon D, Nedjati-Gilani G, Imai N, Ainslie K, Baguelin M, et al. Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand. London: Imperial College COVID-19 Response Team; 2020.
22. Ribeiro LC, Bernardes AT. Estimate of underreporting of COVID-19 in Brazil by acute respiratory syndrome hospitalization reports. Belo Horizonte: Centro de Desenvolvimento e Planejamento Regional, Universidade Federal de Minas Gerais; 2020. (Nota Técnica).
23. Carvalho LR. Distribuição espacial da oferta de saúde no Brasil no contexto do mix público-privado [Dissertação de Mestrado]. Belo Horizonte: Universidade Federal de Minas Gerais; 2017.
24. Organisation for Economic Cooperation and Development. Health at a glance 2019: OECD indicators. Paris: OECD Publishing; 2019.
25. Ministério da Saúde. Situação epidemiológica: doença pelo coronavírus 2019. Boletim COE COVID-19 2020; (13). https://portalarquivos.saude.gov.br/images/pdf/2020/April/21/BE13---Boletim-do-COE.pdf.

26. Pescarini J, Aquino E, Silveira I, Aquino R, Souza-Filho J. Medidas de distanciamento social no controle da pandemia de COVID-19: potenciais impactos e desafios no Brasil. SciELO Preprints 2020; 20 apr. https://preprints.scielo.org/index.php/scielo/preprint/view/116/version/121.
27. Canabarro A, Tenorio E, Martins R, Martins L, Brito S, Chaves R. Data-driven study of the COVID-19 pandemic via age-structured modelling and prediction of the health system failure in Brazil amid diverse intervention strategies. medRxiv 2020; 15 apr. https://www.medrxiv.org/content/10.1101/2020.04.03.20052498v2.
28. Barreto ML, Barros AJD, Carvalho MS, Codeço CT, Hallal PRC, Medronho RA, et al. O que é urgente e necessário para subsidiar as políticas de enfrentamento da pandemia de COVID-19 no Brasil? Rev Bras Epidemiol 2020; 23:e200032.
29. Global Business Data Platform. Rate of coronavirus (COVID-19) tests performed in the most impacted countries worldwide as of May 25, 2020 (per million population). https://www.statista.com/statistics/1104645/covid19-testing-rate-select-countries-worldwide/ (accessed on 05/May/2020).
30. Botega LA, Andrade MV, Guedes GR. Brazilian hospitals' performance: an assessment of the Unified Health System (SUS). Health Care Manag Sci 2020; [Online ahead of print].
31. Borges GM. Health transition in Brazil: regional variations and divergence/convergence in mortality. Cad Saúde Pública 2017; 33:e00080316.

Resumo

O objetivo deste estudo é analisar a pressão sobre o sistema de saúde no Brasil decorrente da demanda adicional gerada pela COVID-19. Para tanto, foi realizado um conjunto de simulações para estimar a demanda de leitos gerais (microrregiões de saúde), leitos de UTI e equipamentos de ventilação assistida (macrorregiões de saúde) em diferentes cenários, para intensidade (taxas de infecção equivalentes a 0,01, 0,1 e 1 caso por 100 habitantes) e horizontes temporais (1, 3 e 6 meses). Os resultados evidenciam uma situação crítica do sistema para atender essa demanda potencial, uma vez que diversas microrregiões e macrorregiões de saúde operariam além de sua capacidade, comprometendo o atendimento a pacientes principalmente aqueles com sintomas mais severos. O estudo apresenta três mensagens relevantes. Em primeiro lugar, é necessário reduzir a velocidade de propagação da COVID-19 na população brasileira, permitindo um tempo maior para a reorganização da oferta e aliviando a pressão sobre o sistema de saúde. Segundo, é necessário expandir o número de leitos disponíveis. Ainda que o setor privado contribua para amortecer o déficit de demanda, a oferta conjunta dos dois setores não seria suficiente em várias macrorregiões. A construção de hospitais de campanha é importante, tanto em locais onde historicamente há vazios assistenciais como também naqueles onde já se observa uma pressão do lado da demanda. A terceira mensagem diz respeito à organização regionalizada dos serviços de saúde que, apesar de adequada em situações de demanda usual, em momentos de pandemia este desenho implica desafios adicionais, especialmente se a distância que o paciente tiver de percorrer for muito grande.

COVID-19; Pandemias; Acesso aos Serviços de Saúde; Sistema Único de Saúde; Saúde Suplementar

Resumen

El objetivo de este estudio es analizar la presión sobre el sistema de salud brasileño, ocasionada por la demanda adicional de camas hospitalarias y equipos de ventilación mecánica, generada por el COVID-19. Para tal fin, se realizó un conjunto de simulaciones, con el fin de estimar la demanda de camas generales (microrregiones de salud), camas de UTI y equipamientos de ventilación asistida (macrorregiones de salud) en diferentes escenarios, según la intensidad (tasas de infección equivalentes a 0,01, 0,1 y 1 caso por 100 habitantes) y horizontes temporales (1, 3 y 6 meses). Los resultados evidencian una situación crítica del sistema para atender esa demanda potencial, ya que diversas microrregiones y macrorregiones de salud operarían más allá de su capacidad, comprometiendo la atención a pacientes principalmente aquellos con los síntomas más graves. El estudio presenta tres mensajes relevantes. En primer lugar, es necesario reducir la velocidad de propagación del COVID-19 en la población brasileña, permitiendo un tiempo mayor para la reorganización de la oferta y aliviando la presión sobre el sistema de salud. En segundo lugar, es necesario expandir el número de camas disponibles. A pesar de que el sector privado contribuya a amortiguar el déficit de demanda, la oferta conjunta de los dos sectores no sería suficiente en varias macrorregiones. La construcción de hospitales de campaña es importante, tanto en lugares donde históricamente existen lagunas asistenciales, como también en aquellos donde ya se observa una presión por parte de la demanda. El tercer mensaje se refiere a la organización por regiones de los servicios de salud que, a pesar de ser adecuada en situaciones de demanda habitual, en momentos de pandemia, este diseño implica desafíos adicionales, especialmente si la distancia que el paciente tuviera que recorrer fuera muy lejana.

COVID-19; Pandemias; Accesibilidad a los Servicios de Salud; Sistema Único de Salud; Salud Complementaria

Submitted on 07/May/2020
Final version resubmitted on 11/May/2020
Approved on 12/May/2020