1 **Demand for hospitalization services for COVID-19 patients in Brazil**

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Abstract

COVID-19 is now a pandemic and many of the affected countries face severe shortages of hospital resources. In Brazil, the first case was reported on February 26. As the number of cases grows in the country, there is a concern that the health system may become overwhelmed, resulting in shortages of hospital beds, intensive care unit beds, and mechanical ventilators. The timing of shortage is likely to vary geographically depending on the observed onset and pace of transmission observed, on the availability of resources, and on the actions implemented. Here we consider the daily number of cases reported in municipalities in Brazil to simulate twelve alternative scenarios of the likely timing of shortage, based on parameters consistently reported for China and Italy, on rates of hospital occupancy for other health conditions observed in Brazil in 2019, and on assumptions of allocation of patients in public and private facilities. Results show that hospital services could start to experience shortages of hospital beds, ICU beds, and ventilators in early April, the most critical situation observed for ICU beds. Increasing the allocation of beds for COVID-19 (in lieu of other conditions) or temporarily placing all resources under the administration of the state delays the anticipated start of shortages by a week. This suggests that solutions adopted by the Brazilian government must aim at expanding the available capacity (e.g., makeshift hospitals), and not simply prioritizing the allocation of available resources to COVID-19.

Introduction

On March 11 the World Health Organization characterized COVID-19 as a pandemic. Caused by the novel coronavirus SARS-CoV-2, it emerged in China and quickly spread across the country and beyond. As of March 27, it was present in 202 countries and territories, with 509,164 cases and 23,335 deaths reported.[1] The clinical course of COVID-19 poses serious challenges to the health system and may call for drastic rationing decisions.[2,3] Specifically, allocating hospital beds, intensive care unit (ICU) beds, and mechanical ventilators to COVID-19 patients, besides the ongoing demand driven by other conditions, is a real or soon to be a real problem.[4-6]

Brazil recorded the first COVID-19 case on February 26 and the first death on March 17, both in São Paulo. In 24 days, the disease had spread to every federal unit. As of March 27, 3,417 cases and 92 deaths had been reported. As the numbers increase across the country, so does the demand for hospital services, raising concerns of hospital capacity to cope with that demand.

Brazil has a hybrid health system.[7,8] On the one hand, every citizen has free access to the Unified Health System (SUS). On the other hand, the private sector offers services covered by out of pocket payments and private insurance plans. About 80% of the Brazilian population relies solely on SUS, but this number varies widely across the country reflecting striking inequalities.[9] The offer of hospital services is also unequal. As of December 2019, 67% and 48% of the total available hospital beds and ICU beds, respectively, were offered in the public system. Geographically, the distribution was also unequal, with 9 and 21 beds per 100,000 people in the North and Southeast regions, respectively.[10]

Here we address this concern and simulate the time it would take for hospitals to operate at capacity, given the current trajectory of COVID-19 in Brazil. We considered different scenarios of supply and demand and detailed the simulations by day and health macro-region. Since not all

58 services are available in each municipality, the Ministry of Health (MoH) considers the macro-

59 region to guide the regionalization of health services.

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Methods

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62 DATA SOURCES

63 Population by age group and the number of confirmed COVID-19 cases were obtained from the

64 MoH.[11] Information on available hospital beds, ICU beds, and mechanical ventilators as of

65 December of 2019 was extracted from the National Registry of Health Establishments (CNES,

66 http://cnes.datasus.gov.br/). We excluded pediatric and obstetric beds, and pediatric, neonatal,

67 and burn recovery ICU beds. We distinguished hospital beds and ICU beds by type of service

68 (private and public); this classification was not available for mechanical ventilators. Average

69 public hospital occupancy in 2019 (detailed by hospital beds and ICU beds) was obtained from

70 the hospitalization system of the MoH (http://sihd.datasus.gov.br/). There was no information on

71 the occupancy rate for private hospitals (here we assumed the same rate obtained for public

72 hospitals). Lastly, access to private health insurance in December 2019 was extracted from the

73 Brazilian Regulatory Agency (http://www.ans.gov.br/perfil-do-setor/dados-e-indicadores-do-

74 setor).

75

76 STATISTICAL ANALYSIS

77 We conducted forward simulations of the demand for hospital beds, ICU beds, and mechanical

78 ventilators by health macro-region in Brazil. In the initial phase of a new infectious disease

79 outbreak, the number of cases grows exponentially.[12,13] Using the number of cases reported to

80   date and estimates of doubling times from the outbreak in China,[14-16] we estimated the number of

81   future cases each day. As the outbreak spreads, the exponential model becomes less realistic,[13] so

82   we stopped the simulations once 10% of the population was estimated to be infected.

83   We used the age structure of each macro-region combined with age-specific attack and severity

84   rates drawn from the literature. We used attack rates by age from the outbreak in China,[17]

85   considering a range of ±3%, and considered that 86% of all infections were undocumented.[18]

86   Demand for hospitalization was calculated using the severity of cases by age from China.[17] Time

87   from illness to hospitalization was 3-7 days,[19,20] and length of hospitalization ranged from 7-15

88   days;[21] for ICU hospitalizations these parameters were 8-15,[19,20] and 7-15,[21,22] respectively. We

89   considered that 5% of the cases needed ICU admission[21,23] and half of those in ICU needed

90   mechanical ventilation[20,21] for an average of 5 days.[24] We also simulated an alternative scenario

91   based on Italy and assumed that 12% of the cases needed ICU admission.[4,6] These parameters

92   were combined with assumptions of hospital occupancy and type of service to produce twelve

93   scenarios, summarized in Table 1. We performed 1,000 runs for each scenario, drawing from the

94   ±3% uncertainty around attack rates, and considered the results that represented the median of

95   the distribution. All analyses were performed with the use of R software, version 3·6·3, and

96   Rstudio, version 1·2·5033 (R Foundation for Statistical Computing).

97

98   **Table 1. Parameters considered for simulated scenarios**

Scenarios	Assumptions		
	Hospital occupancy	**Demand for ICU beds**	**Public x Private Services**
1	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	5% of cases	Demand for public/private services apportioned by access to private health insurance in 2019

|			
2	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	5% of cases	80% of the demand is for public services
3	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	5% of cases	Private hospitals temporarily under the control of the state
4	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	12% of cases	Demand for public/private services apportioned by access to private health insurance in 2019
5	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	12% of cases	80% of the demand is for public services
6	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	12% of cases	Private hospitals temporarily under the control of the state
7	2019 occupancy reduced by 50%, and services allocated to COVID-19	5% of cases	Demand for public/private services apportioned by access to private health insurance in 2019
8	2019 occupancy reduced by 50%, and services allocated to COVID-19	5% of cases	80% of the demand is for public services
9	2019 occupancy reduced by 50%, and services allocated to COVID-19	5% of cases	Private hospitals temporarily under the control of the state
10	2019 occupancy reduced by 50%, and services allocated to COVID-19	12% of cases	Demand for public/private services apportioned by access to private health insurance in 2019
11	2019 occupancy reduced by 50%, and services allocated to COVID-19	12% of cases	80% of the demand is for public services
12	2019 occupancy reduced by 50%, and services allocated to COVID-19	12% of cases	Private hospitals temporarily under the control of the state

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Results

101 Figure 1 shows the fraction of public hospital beds and ICU beds in each health micro-region, as

102 well as the percentage of the population in those units that rely solely on the SUS. Inequities in

103 supply and demand exist, and mirror regional inequalities commonly found in social and health

104 indicators.[9]

105   As of March 27, 3.417 cases were confirmed in Brazil, 70% concentrated in nine cities: São

106   Paulo, Rio de Janeiro, Fortaleza, Brasília, Porto Alegre, Salvador, Belo Horizonte, Curitiba, and

107   Manaus. The growth pattern of the epidemic is not the same across the country. Therefore, we

108   chose to simulate scenarios for the nine health macro-regions associated with those cities;

109   combined these macro-regions represent 79·6% of reported cases. In the case of São Paulo and

110   Brasília, the macro-region includes only the municipality itself. Rio de Janeiro and Manaus have

111   only one macro-region for the entire state. Fortaleza, Porto Alegre, Belo Horizonte, Salvador,

112   and Curitiba are in macro-regions that comprise 44, 89, 103, 48, and 93 municipalities,

113   respectively.

114   Our simulated scenarios indicate that hospital services could start to experience shortages of

115   hospital beds, ICU beds, and ventilators across macro-regions as early as April (Figure 2). ICU

116   beds are, by far, the most pressing need. The supply of hospital beds is likely to face shortages

117   after April 21 and of mechanical ventilators just a few days afterward. The two scenarios for ICU

118   admission (5% and 12% of the total cases) resulted in about 4-6 days difference. With a 12%

119   assumption, Brasília would face a shortage of ICU beds by the end of March. Making 50% of

120   usual occupancy dedicated to COVID-19 postpones shortages for less than a week, and placing

121   all resources under state control shifts the capacity threshold by up to one week for hospital beds

122   and mechanical ventilators, and by up to four days for ICU beds. Considering alternative

123   hypothesis of access to public resources, scenarios 2, 5, 8, and 11 assumed that 80% of the

124   demand would come from individuals that solely rely on SUS. Since the offer of SUS services

125   presents regional inequities (Figure 1), the timing of shortage depends both on the share public x

126   private in each area.

127

128 **Figure 1. Percentage of the population that relies solely on the SUS, percentage of beds**
129 **available in each health macro-region that are allocated to, and location of the simulated**
130 **micro-regions.** Thicker black lines define the boundaries of the federal units. Selected health
131 macro-regions are named after the capital city, and the ID code is also provided.
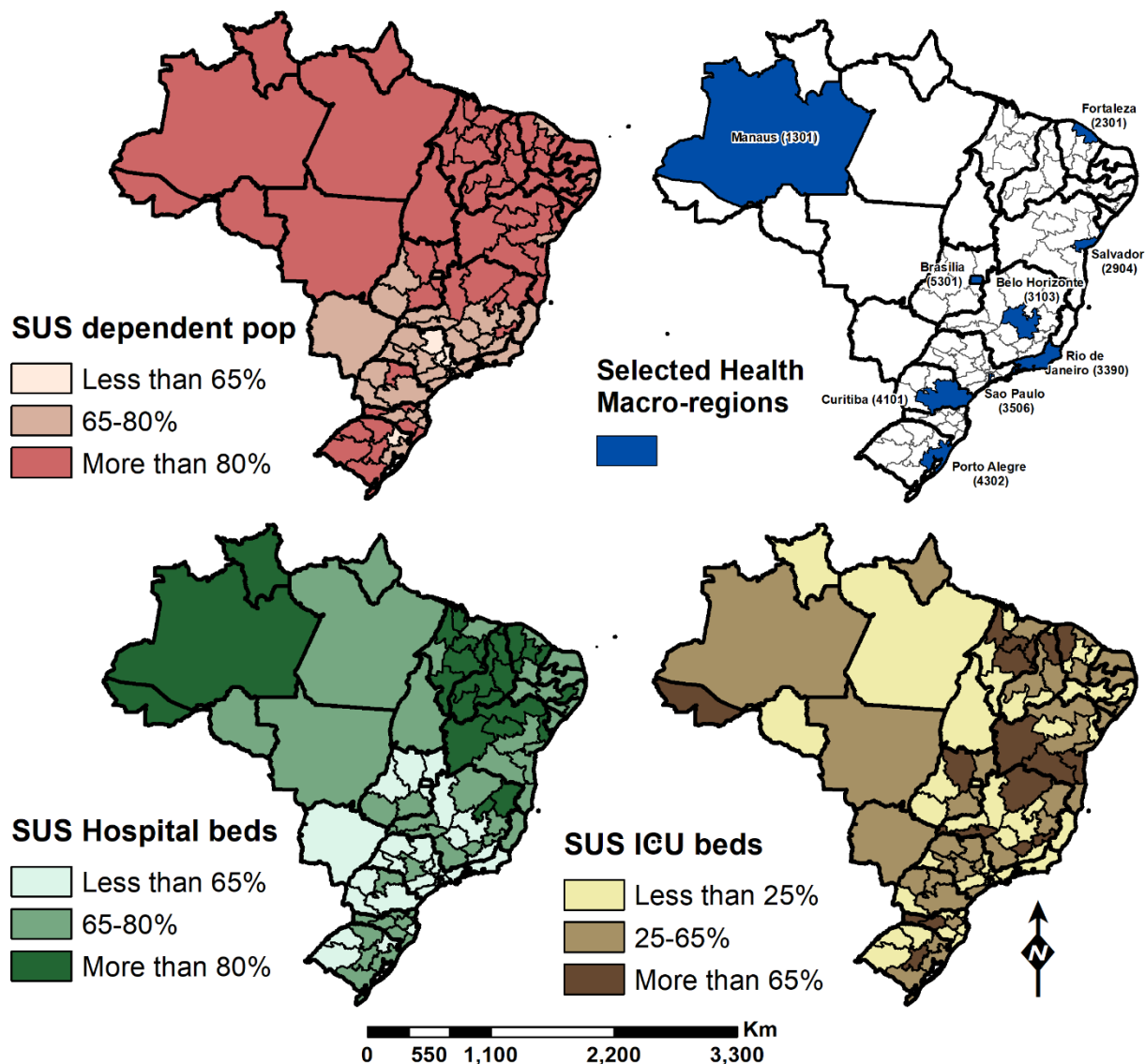
132
133

134 The timing of shortage varied by health macro-region. It depends on the observed onset and pace

135 of transmission. For example, although the first case in Fortaleza was reported on March 15, 18

136 days after the first case was reported in the country, it took eight days to reach to 100 cases. In

137 São Paulo, where the first case was reported, the first 100 cases were recorded in 19 days.

138 **Figure 2. Date when hospital services will be at capacity in each simulated scenario.**
139 Numbers on the left represent each of the 12 simulated scenarios described in Table1. Names on
140 top indicate the municipality of reference to the health macro-region. HB = hospital beds. ICUB
141 = ICU beds. MV = mechanical ventilators. Numbers on the table refer to day of the month, and
142 cell colors indicate the month. Results reflect the median after 1,000 runs of the model.
143

Scenario	Metric	São Paulo	Rio de Janeiro	Brasília	Fortaleza	Belo Horizonte	Porto Alegre	Curitiba	Salvador	Manaus
1	HB	15	20	13	16	27	20	23	26	26
1	ICUB	12	15	3	8	6	13	13	13	12
1	MV	26	29	20	20	24	24	24	29	1
2	HB	13	19	12	16	27	20	22	27	27
2	ICUB	10	14	3	9	6	13	13	13	13
2	MV	24	28	19	21	24	23	23	29	2
3	HB	17	21	14	17	29	21	23	27	27
3	ICUB	17	21	11	11	11	15	13	18	16
3	MV	26	30	21	21	25	23	27	30	2
4	HB	14	20	13	16	27	20	23	27	27
4	ICUB	7	10	29	5	1	8	8	8	8
4	MV	20	24	15	16	19	19	18	24	26
5	HB	12	19	12	16	27	20	22	27	27
5	ICUB	5	10	29	5	1	7	7	8	8
5	MV	18	23	14	17	18	18	17	24	26
6	HB	16	21	14	17	29	21	23	28	27
6	ICUB	11	16	6	7	6	10	8	13	11
6	MV	21	25	16	17	19	18	21	25	26
7	HB	17	22	16	22	30	22	25	29	30
7	ICUB	14	17	5	13	7	15	15	14	14
7	MV	28	1	22	26	27	26	26	1	4
8	HB	15	21	15	18	29	22	25	29	30
8	ICUB	12	16	4	10	7	15	14	15	14
8	MV	26	30	21	22	26	25	25	1	4
9	HB	19	23	16	19	1	23	26	30	30
9	ICUB	19	23	13	13	13	17	15	20	18
9	MV	29	2	23	23	28	25	29	2	4
10	HB	17	22	16	22	30	22	25	29	30
10	ICUB	9	13	31	9	1	10	9	9	9
10	MV	23	26	17	22	21	21	20	26	28
11	HB	16	21	15	18	29	22	25	29	30
11	ICUB	7	12	30	6	1	9	9	10	9
11	MV	21	25	16	18	21	20	20	27	29
12	HB	19	23	16	19	1	23	26	30	30
12	ICUB	14	18	8	9	7	12	10	15	13
12	MV	23	27	18	19	22	21	23	27	29

Legend: ■ March   ■ Apr 1-15   ■ April 19-30   □ May

144

Discussion

146 Our simulated scenarios show that, if no change in trajectory is observed, around early April

147 Brazil would start to face shortages of hospital beds, ICU beds, and ventilators, with ICU beds

148 being the most immediate problem. The timing of shortages across the country depends on the

149 onset and the intensity of transmission. Also, the population that relies solely on SUS may bear

150 the largest burden, further exacerbating the existing inequalities, which calls for a reflection

151 around equity and ethics in service allocation. Avoiding this scenario is the paramount task of the

152 MoH.

153 It is unreasonable to expect that all hospital resources could be entirely dedicated to COVID-19.

154 Although elective procedures can be postponed, other health emergencies compete for resources.

155 For example, dengue transmission is presently intense and increasing; until March 14 there were

156 390,684 cases and 106 deaths (60·4% of them among individuals aged 60 or more). In 2019,

157 with more than 1·5 million cases of dengue reported, 4% (n=55,235) required hospitalization.

158 Most importantly, 45% of the dengue hospitalizations occurred between March and May (21%

159 just in May, the month when most likely the hospitals will be operating at capacity because of

160 COVID-19). In addition, the influenza season is starting, and in 2019 the peak of hospitalizations

161 occurred in May. Besides beds and ventilators, the stress imposed on the health system

162 compromises the overall care, which may result in deterioration of the treatment of other

163 conditions followed by increases in incidence. This scenario was observed during the 2013-14

164 Ebola outbreak.[25]

165 Shifts in the current trajectory of the epidemic in Brazil may anticipate or postpone the stress on

166 health services. Importantly, our results are sensitive to assumptions about key parameters in the

167   model, including the doubling time, underreporting rate, age-specific attack and severity rates,

168   time from illness to hospitalization and ICU, and length of stay estimates. By drawing on

169   available evidence of how COVID-19 has and is evolving across the globe, our results rely on

170   and reflect the limitations of the parameters observed in China and on unique patterns reported in

171   Italy. Given the significant uncertainty in parameter estimates at this phase of the epidemic and

172   the simplifying assumptions of an exponential model, results from our simulated scenarios

173   should not be used as precise estimates for the exact timing and extent of capacity thresholds

174   being reached. Instead, they aim to inform planning and prompt response and do send three

175   important messages.

176   First, the epidemic of COVID-19 is likely to exacerbate existing inequalities if those that solely

177   rely on the SUS are hit the hardest. In communities with high population density and poor

178   infrastructure, it is unfeasible to practice social isolation. In those areas, the transmission is likely

179   to occur fast and the population mostly relies only on the SUS, quickly overwhelming the health

180   system. One alternative to alleviate the is to temporarily put all private hospitals under the

181   control of the state, a measure adopted by Spain.[26] Yet, our results show that this would postpone

182   shortages by about a week. In fact, solutions that do not involve the opening of new facilities will

183   have a very short effect on the timing of shortage.

184   Second, there is a short window of opportunity to prepare. The response must be immediate, and

185   it will demand a concerted effort from society. Repurposing large spaces (e.g., arenas,

186   convention centers) to build makeshift hospitals for additional beds is critical. Calling on the

187   industry to produce the necessary equipment (e.g., ventilators, masks, gloves, protective gown,

188   etc) and to provide it to hospitals at minimum or no cost would also contribute to mitigating the

189   stress on the system, and to safeguarding the working conditions of health care professionals.

190   Mobilizing community leaders, artists, athletes, and local role models would help to convey a

191   unique message to the population, and to gather support from the wealthy that could provide

192   resources to expand the production of medical equipment.

193   Third, additional actions to contain the transmission and to change the current trajectory of the

194   epidemic must be taken. Partial shutdown has been initiated in many Brazilian cities, but

195   compliance is far from ideal. Increasing the availability of tests would allow the government to

196   comprehensively trace and test all contacts of positive cases, a strategy successfully adopted by

197   South Korea.[27] Without intensified actions, or even worse, if current actions are loosened, Brazil

198   may face the need to implement guidelines for rationing health resources,[2] which invariantly call

199   for difficult decisions.

200

201   **Conclusion**

202   Brazil is, in theory, uniquely equipped to respond to the COVID-19 epidemic. It has a free and

203   universal health system,[7] it has one of largest community-based primary care delivery programs

204   that serves 74·8% of the population,[28] it can learn from the mistakes and success that other

205   countries hit by COVID-19 have made, and it has a history of responding to health threats by

206   implementing governmental action and by generating high-quality scientific evidence, such as

207   was done when Zika virus hit the country.[29] Yet, the current moment is unique. It requires a

208   unified message from the country's leadership at various levels: federal, state, and municipal. It

209   requires the industry to work in solidarity to produce needed inputs without aiming profit but the

210   collective wellbeing. It requires the population to realize the importance and the urgency to

211   comply. We hope our results will help to move forward this agenda.

212

213 **Contributors**

214 MCC conceived the original, was responsible for data analysis, data interpretation, data

215 visualization, and wrote the manuscript. LRC was responsible for data curation, data analysis,

216 programming, and contributed to writing. RK and TC were responsible for programming and

217 contributed to writing. GVAF, EMM, and WKO were responsible for data curation and

218 interpretation. All authors approved the final version of the manuscript.

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