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Spatial analysis of hospital-related mortality due to COVID-19 among children and adolescents in Brazil

Análise espacial da mortalidade hospitalar por COVID-19 em crianças e adolescentes no Brasil

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Abstract *The objective was to perform a spatial analysis of the hospital mortality rate (HMR) due to severe acute respiratory syndrome (SARS) attributed to COVID-19 among children and adolescents in Brazil from 2020 to 2021. A cluster method was used to group federal units (FUs) based on HMR. In 2020, clusters with high HMRs were formed by north/northeast FUs. In 2021, there was a reduction in HMR. Clusters with higher rates remained in the N/NE region. Regional differences were observed in the HMR. The findings may reflect social inequalities and access to hospital care, especially in the under 1-year-old age group due to the severity of the disease in this group.*

Key words *Severe acute respiratory syndrome, Child, Adolescent, COVID-19, Spatial analysis*

Resumo *Objetivou-se realizar uma análise espacial da taxa de mortalidade hospitalar (TMH) por síndrome respiratória aguda grave (SRAG) atribuída à COVID-19 em crianças e adolescentes no Brasil no período de 2020 a 2021. Utilizou-se o método de cluster para agrupar as unidades federativas (UFs) com base na TMH. Em 2020, clusters com altas TMHs foram formados por UFs Norte/Nordeste. Em 2021, houve redução na TMH. Os clusters com maiores taxas permaneceram na região N/NE. Diferenças regionais foram observadas nas TMHs. Os achados podem refletir as desigualdades sociais e o acesso à atenção hospitalar, principalmente na faixa etária de menores de 1 ano pela gravidade da doença neste grupo.*

Palavras-chave *Síndrome respiratória aguda grave, Criança, Adolescente, COVID-19, Análise espacial*

Introduction

On January 30, 2020, the outbreak of the new coronavirus was declared a Public Health Emergency of International Importance. On March 11, 2020, COVID-19 was considered a pandemic by the World Health Organization[1]. In late May 2020, Latin America was declared the epicenter of the COVID-19 pandemic, mainly because of Brazil, one of the most severely affected countries by COVID-19 with more than 37 million cases and 699,634 deaths reported by March 2023[2].

COVID-19 is associated with severe acute respiratory syndrome (SARS), which can progress to death[3]. Since the beginning of the COVID-19 pandemic in March 2020, accumulated deaths due to SARS have increased among children and adolescents in Brazil[4]. As the pandemic of COVID-19 progressed, severe and fatal manifestations appeared, and the emergence of multiple variants, especially Delta and Omicron, contributed to an increase in the number of cases and pediatric hospitalizations[5].

A report published by the WHO points out that the risks due to exposure, biological factors, economic implications and social determinants show variability among those exposed to infection[1,6]. The pandemic is strongly influenced by social and economic inequalities, which increase the challenge for prevention and control of COVID-19[7]. In this context, looking at the territory allows us to recognize the particularities of the dynamics of the evolution of the pandemic, which favors the design of specific strategies for its confrontation in the territory[8]. In a pandemic, deaths reveal problems such as social inequalities and health inequalities, including difficulty accessing health services, care gaps, the low quality of outpatient and hospital care provided, and weaknesses in the death surveillance system[9].

Analyses of hospitalizations, deaths, and mortality rates are essential for developing preventive measures and coping with COVID-19, especially among hospitalized children and adolescents[10]. In addition, the results of such analyses can contribute to better allocation of resources for vaccination processes and COVID-19 hospital services for children and adolescents. The aim of this study was to perform a spatial analysis of the hospital mortality rate (HMR) due to SARS attributed to COVID-19 among children and adolescents per federal unit (FU) in Brazil.

Methods

This was an ecological study with spatial analysis of deaths by HMR for SARS attributed to COVID-19 among individuals 0-19 years of age. Data were obtained from hospitalization records in the Influenza Epidemiological Surveillance Information System (SIVEP-Gripe) from March 2020 (date of first case report) to December 2021 (for the first two years of the pandemic and the start of vaccination of children in the second half of 2021). The data were collected on February 27, 2023, on the portal https://opendatasus.saude.gov.br/dataset. SIVEP-Gripe is an official system of the Ministry of Health, with national coverage, for the registration of cases and deaths from SARS.

For notification purposes, individuals with a combination of the following symptoms are considered to be SARS cases and should be compulsorily notified: high fever (above 37.8 ºC) and cough or sore throat and respiratory distress or dyspnea or O_2 saturation <95% and requested hospitalization or died having presented the symptoms mentioned, regardless of hospitalization[11].

The final SARS classification in SIVEP-Gripe is based on the following criteria: laboratory, clinical-epidemiological; clinical-only, and clinical-imaging. One can then classify SARS according to the etiologic agent: 1) influenza virus; 2) other respiratory virus; 3) other etiologic agent; 4) unspecified; or 5) SARS by COVID-19, and only the latter was used in this study; additionally, the option "death" of the evolution field of the Individual Record Form - hospitalized SARS cases was used. Cases that progressed to cure, deaths from other causes, and unknown progression were not considered. The analyses were carried out by place of residence, considering that there are few municipalities of reference for SARS hospitalization[12].

The outcome of interest was HMR by FU among individuals aged 0-19 years according to the World Health Organization classification[13], subdivided into 0-28 days, 29-11 months, 1-2 years, 3-5 years, 6-9 years, 10-14 years and 15-19 years. All registered cases with ages from 0 days to 19 years were considered. From these patients, 162 cases with ages recorded with negative numbers and with inconsistencies between the information on birth dates and recorded ages were excluded.

Deaths attributed to COVID-19 caused by SARS were aggregated by the FU. The HMR was calculated from the ratio of the number of deaths to the number of cases multiplied by 100. Subsequently, the rates were smoothed using Local empirical Bayes estimates to reduce random variations HMR. Smoothed local rates are more stable because they consider both the population of the FU and that of neighboring states[14].

Cluster analysis was used to group the FUs using HMR. This analysis aimed to identify patterns of similarity among FUs, considering the variables used in this study. This type of analysis classifies all elements into groups that are similar to each other, seeking to homogenize each group and heterogenize all groups, that is, the objects in each group are similar to each other but different from objects in other groups[15].

Hierarchical and k-means clustering methods were used. The hierarchical method is based on the definition of a hierarchy that seeks to aggregate similar elements (FUs) in the same group using a similarity criterion, forming a graphical reproduction (dendrogram)[15]. Three linkage methods were tested using the hierarchical technique: complete linkage, average linkage, and Ward linkage.

K-means is a non-hierarchical method that partitions elements to form clusters with less internal heterogeneity[15]. Clusters were selected using the highest value of the ratio of the total sum of squares. Statistical analyses were performed using the Stata® 16.0, QGIS 3.6.0, and Geoda 1.14.

The study was approved by the Research Ethics Committee (CEP) of the University Hospital of the Federal University of Maranhão (HUUFMA) and by the National Research Ethics Committee (CONEP) under Ruling number: 4.098.427 and CAAE 32206620.0.0000.5086, dated June 19, 2020, according to the requirements demanded by Resolution No. 466/2012 of the National Health Council.

Results

Between March 2020 and December 2021, 56,468 cases and 3,958 deaths due to COVID-19 were recorded in Brazil among individuals 0-19 years of age. The description of the number of cases and deaths, HMR per FU, by age group, and year of occurrence are presented in Table 1.

The K-means clustering method identified five HMR clusters in 2020/2021 (Table 2). In 2020, the clusters with high HMRs comprised mainly the UFs in the North/Northeast (N/NE) regions (Figure 1). The age groups clustered with the highest HMRs were 0 to 28 days, 29 days to under 1 year, and 1 year to 2 years (Table 2). The age group from 0 to 28 days showed the highest number of FHUs grouped in the High HMR Cluster (Table 2), they are: Amazonas, Pará, Roraima and Acre in the North and Maranhão, Piauí and Pernambuco in the Northeast of the country (Figure 1). Roraima was evidenced in the Clusters with high HMR in the age groups highlighted in 2020 and the UF Santa Catarina composing the cluster with the highest HMR in the age group of 3 to 5 years (Figure 1).

In 2021, the clusters with the highest rates remained especially in the Northeast region. The age groups clustered with the highest HMRs were 0 to 28 days, 29 days to under 1 year, and 3 to 5 years (Table 2). There was an increase in the HMRs in 2021 for all age groups, except for the age groups 1 to 2 years and 10 to 14 years, in the country (Table 2). However, fewer FHUs were found in the cluster with high HMR in the 0 to 28-day age group (Table 2), composed of the following FHUs: Ceará, Paraíba, and Pernambuco in the Northeast of the country (Figure 1).

Discussion

The analysis of the first two years of the pandemic in Brazil shows that children from 29 days to 1 year of age are the most vulnerable and account for almost half of the deaths among children under 5 years of age[16]. Pereira *et al.*[17], when describing cases of SARS by COVID-19 in newborns in the country, showed the severity of COVID-19 from the proportion of ICU admissions and deaths. These data reinforce the importance of analyses in this age group, despite the possible occurrences of under-recording of deaths due to difficulties in confirming the diagnosis of SARS-COVID-19, especially in poorer regions and with care gaps.

Based on the results of the cluster analysis, the highest HMR occurred in FUs in the N/NE regions in both years, particularly among individuals who were 0-28-days and 29 days to less than 1 year. These findings corroborate the severity of the disease in the under-1 age group. Research in China[18] and Italy[19] observed greater vulnerability to the severe type of infection in children younger than 1 year and requiring more hospitalization and admission to intensive care compared to older children[19].

Table 1. Deaths and hospital mortality rate (HMR) by age group and Federal Unit, Influenza Epidemiological Surveillance Information System (SIVEP-Gripe). Brazil, March 2020-December 2021.

Federative Unit		0-28 days		29d-11 months		1-2 years		3-5 years		6-9 years		10-14 years		15-19 years		Total	
		2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Acre	cases	0	0	4	6	2	3	4	2	1	1	3	0	17	11	31	23
	deaths	0	0	2	1	1	0	1	0	0	0	1	0	3	2	8	3
	*HMR (%)		0	50	16,67	50	0	25	0	0	0	33,33		17,65	18,18	25,81	13,04
Alagoas	cases	11	27	36	78	49	65	55	32	28	23	30	11	55	40	264	276
	deaths	5	1	5	12	3	3	4	1	2	1	4	1	13	9	36	28
	HMR (%)		3,70	13,89	15,38	6,12	4,62	7,27	3,13	7,14	4,35	13,33	9,09	23,64	22,5	13,64	10,14
Amazonas	cases	36	19	210	109	224	94	179	67	141	52	144	38	322	131	1256	510
	deaths	6	0	14	8	4	6	5	1	1	3	4	3	24	6	58	27
	HMR (%)	16,67	0	6,67	7,34	1,79	6,38	2,79	1,49	0,71	5,77	2,78	7,89	7,45	4,58	4,62	5,29
Amapá	cases	7	5	73	31	65	34	32	16	25	9	26	11	27	23	255	129
	deaths	0	1	2	1	0	2	1	0	0	0	2	2	0	2	5	8
	HMR (%)	0	20	2,74	3,23	0	5,88	3,13	0	0	0	7,69	18,18	0	8,70	1,96	6,20
Bahia	cases	35	16	115	166	110	139	110	87	105	86	95	70	146	179	716	743
	deaths	7	0	22	9	4	8	3	5	4	5	8	7	18	23	66	57
	HMR (%)	20	0	19,13	5,42	3,64	5,76	2,73	5,75	3,81	5,81	8,42	10	12,33	12,85	9,22	7,67
Ceará	cases	34	41	119	141	97	98	70	76	66	72	94	61	193	141	673	630
	deaths	5	12	21	25	8	8	5	7	5	4	15	5	22	19	81	80
	HMR (%)	14,71	29,27	17,65	17,73	8,25	8,16	7,14	9,21	7,58	5,56	15,96	8,20	11,40	13,48	12,04	12,70
Distrito Federal	cases	11	5	73	46	39	48	30	24	32	20	39	24	61	71	285	238
	deaths	0	0	1	1	0	1	0	1	1	0	1	0	4	3	7	6
	HMR (%)	0	0	1,37	2,17	0	2,08	0	4,17	3,13	0	2,56	0	6,56	4,23	2,46	2,52
Espírito Santo	cases	12	1	22	9	9	9	11	1	14	12	10	9	37	13	115	54
	deaths	2	0	5	0	0	1	2	0	1	1	2	1	7	5	19	8
	HMR (%)	16,67	0	22,73	0	0	11,11	18,18	0	7,14	8,33	20	11,11	18,92	38,46	16,52	14,81
Goiás	cases	12	14	54	71	36	54	35	48	36	33	27	61	71	176	271	457
	deaths	1	3	6	5	1	6	0	4	1	4	3	8	11	15	23	45
	HMR (%)	8,33	21,43	11,11	7,04	2,78	11,11	0,00	8,33	2,78	12,12	11,11	13,11	15,49	8,52	8,49	9,85

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Table 1. Deaths and hospital mortality rate (HMR) by age group and Federal Unit, Influenza Epidemiological Surveillance Information System (SIVEP-Gripe). Brazil, March 2020-December 2021.

Federative Unit		0-28 days		29d-11 months		1-2 years		3-5 years		6-9 years		10-14 years		15-19 years		Total	
		2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Maranhão	cases	8	3	34	41	30	22	17	19	33	12	28	27	65	61	215	185
	deaths	2	1	13	7	2	1	2	1	3	2	2	3	14	6	38	21
	HMR %)	25	33,33	38,24	17,07	6,67	4,55	11,76	5,26	9,09	16,67	7,14	11,11	21,54	9,84	17,67	11,35
Minas Gerais	cases	27	70	113	250	87	195	89	126	75	99	71	115	143	275	605	1130
	deaths	2	9	6	10	4	7	2	6	4	6	4	9	10	23	32	70
	HMR (%)	7,41	12,86	5,31	4	4,60	3,59	2,25	4,76	5,33	6,06	5,63	7,83	6,99	8,36	5,29	6,19
Mato Grosso do Sul	cases	4	8	29	34	19	32	12	13	22	16	13	22	33	63	132	188
	deaths	0	0	0	2	0	0	0	1	3	2	0	0	1	5	4	10
	HMR %)	0	0	0	5,88	0	0	0	7,69	13,64	12,5	0	0	3,03	7,94	3,03	5,32
Mato Grosso	cases	11	12	84	69	84	61	88	42	102	44	190	79	517	177	1076	484
	deaths	1	0	13	3	2	1	3	2	1	0	1	0	10	7	31	13
	HMR (%)	9,09	0	15,48	4,35	2,38	1,64	3,41	4,76	0,98	0	0,53	0	1,93	3,95	2,88	2,69
Pará	cases	26	19	193	127	191	99	120	65	88	45	98	65	207	146	923	566
	deaths	7	2	22	8	14	5	8	1	3	0	10	7	25	16	89	39
	HMR (%)	26,92	10,53	11,40	6,30	7,33	5,05	6,67	1,54	3,41	0	10,20	10,77	12,08	10,96	9,64	6,89
Paraíba	cases	40	9	60	54	30	20	35	20	33	16	40	24	103	81	341	224
	deaths	1	1	13	5	2	1	2	1	1	0	0	0	3	5	22	13
	HMR (%)	2,5	11,11	21,67	9,26	6,67	5	5,71	5	3,03	0	0	0	2,91	6,17	6,45	5,80
Pernambuco	cases	122	11	186	90	127	57	110	42	126	35	119	31	192	54	982	320
	deaths	27	5	26	12	8	2	9	1	8	3	9	7	21	12	108	42
	HMR (%)	22,13	45,45	13,98	13,33	6,30	3,51	8,18	2,38	6,35	8,57	7,56	22,58	10,94	22,22	11,00	13,13
Piauí	cases	3	5	38	23	38	19	24	13	32	9	31	28	68	34	234	131
	deaths	2	1	3	3	2	0	0	0	1	0	5	2	9	2	22	8
	HMR (%)	66,67	20	7,89	13,04	5,26	0	0	0	3,13	0	16,13	7,14	13,24	5,88	9,40	6,11
Paraná	cases	16	33	73	147	62	110	47	83	39	89	59	165	108	330	404	957
	deaths	1	1	1	8	2	3	1	7	2	3	3	14	13	27	23	63
	HMR (%)	6,25	3,03	1,37	5,44	3,23	2,73	2,13	8,43	5,13	3,37	5,08	8,48	12,04	8,18	5,69	6,58

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Table 1. Deaths and hospital mortality rate (HMR) by age group and Federal Unit, Influenza Epidemiological Surveillance Information System (SIVEP-Gripe). Brazil, March 2020-December 2021.

Federative Unit		0-28 days		29d-11 months		1-2 years		3-5 years		6-9 years		10-14 years		15-19 years		Total	
		2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Rio de Janeiro	cases	52	47	324	277	194	227	163	197	154	152	188	161	277	267	1352	1328
	deaths	4	4	33	20	6	3	3	3	7	3	15	10	31	28	99	71
	HMR (%)	7,69	8,51	10,19	7,22	3,09	1,32	1,84	1,52	4,55	1,97	7,98	6,21	11,19	10,49	7,32	5,35
Rio Grande do Norte	cases	5	3	19	23	24	27	26	11	25	18	22	12	38	34	159	128
	deaths	0	0	1	1	4	0	4	0	1	3	1	1	6	5	17	10
	HMR (%)	0	0	5,26	4,35	16,67	0	15,38	0	4	16,67	4,55	8,33	15,79	14,71	10,69	7,81
Rondônia	cases	5	2	25	12	14	19	13	14	30	14	14	24	39	41	140	126
	deaths	1	0	4	1	3	0	1	0	1	0	2	1	7	6	19	8
	HMR (%)	20	0	16	8,33	21,43	0	7,69	0	3,33	0	14,29	4,17	17,95	14,63	13,57	6,35
Roraima	cases	1	1	9	7	4	0	2	1	4	0	2	0	15	14	37	23
	deaths	1	0	5	6	3	0	1	1	1	0	1	0	5	2	17	9
	HMR (%)	100	0	55,56	85,71	75		50	100	25		50		33,33	14,29	45,95	39,13
Rio Grande do Sul	cases	18	19	59	106	57	60	41	45	52	38	35	53	118	189	380	510
	deaths	1	2	3	3	2	5	1	1	1	1	2	3	13	23	23	38
	HMR (%)	5,56	10,53	5,08	2,83	3,51	8,33	2,44	2,22	1,92	2,63	5,71	5,66	11,02	12,17	6,05	7,45
Santa Catarina	cases	11	29	57	91	26	62	23	36	31	33	43	56	61	156	252	463
	deaths	2	6	2	7	1	2	4	0	1	0	4	3	8	13	22	31
	HMR (%)	18,18	20,69	3,51	7,69	3,85	3,23	17,39	0	3,23	0	9,30	5,36	13,11	8,33	8,73	6,70
Sergipe	cases	70	28	180	122	115	74	81	45	77	35	58	29	83	46	664	379
	deaths	5	1	17	8	8	3	0	3	7	3	6	5	8	8	51	31
	HMR (%)	7,14	3,57	9,44	6,56	6,96	4,05	0	6,67	9,09	8,57	10,34	17,24	9,64	17,39	7,68	8,18
São Paulo	cases	101	114	542	671	381	537	346	371	332	298	387	381	686	830	2775	3202
	deaths	7	17	20	20	11	10	6	17	10	12	27	23	56	68	137	167
	HMR (%)	6,93	14,91	3,69	2,98	2,89	1,86	1,73	4,58	3,01	4,03	6,98	6,04	8,16	8,19	4,94	5,22
Tocantins	cases	9	8	37	23	26	17	26	13	29	15	22	10	27	31	176	117
	deaths	0	0	0	3	1	0	0	1	0	1	1	1	4	4	6	10
	HMR (%)	0	0	0	13,04	3,85	0	0	7,69	0	6,67	4,55	10	14,81	12,90	3,41	8,55
Total	cases	687	549	2768	2824	2140	2182	1789	1509	1732	1276	1888	1567	3709	3614	14713	13521
	deaths	90	67	260	189	96	78	68	65	70	57	133	116	346	344	1063	916
	HMR (%)	13,10	12,20	9,39	6,69	4,49	3,57	3,80	4,31	4,04	4,47	7,04	7,40	9,33	9,52	7,22	6,77

*HMR: Hospital Mortality Rate (HMR). Data extracted from opendatasus.saude.gov.br/dataset.

Source: Authors.

Table 2. Mean hospital mortality rate (HMR) or clusters of Federal Units by age group. Brazil, March 2020-December 2021.

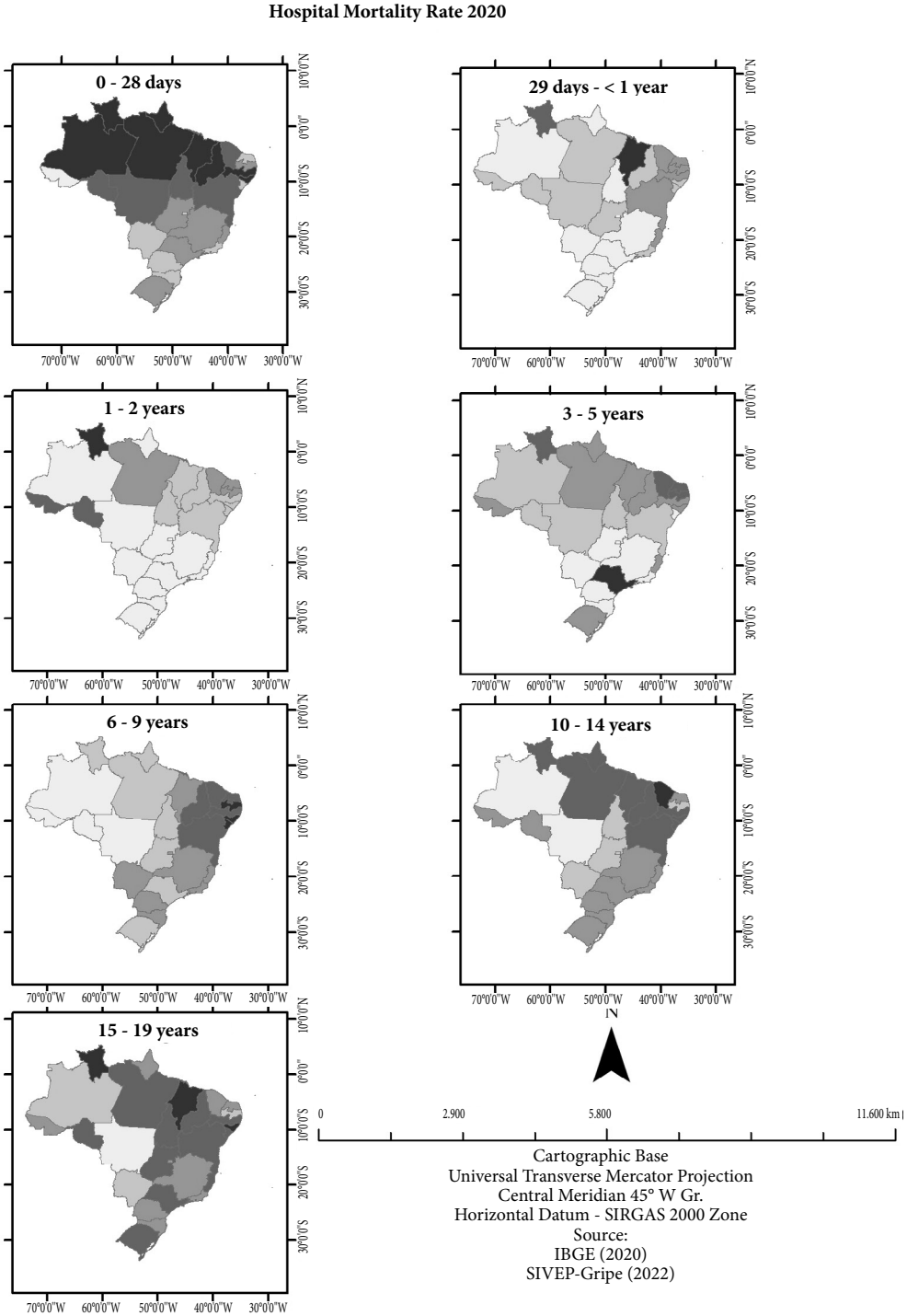
Age group	Cluster	2020 *FU	Average *HMR	Cluster	2021 FU	Average HMR
0-28 days	C1	1	0	C1	3	1
	C2	7	7	C2	7	6
	C3	6	10	C3	12	12
	C4	5	17	C4	2	23
	C5	8	22	C5	3	28
29 days to <1 year	C1	10	5	C1	11	5
	C2	9	12	C2	8	7
	C3	6	16	C3	5	11
	C4	1	23	C4	2	13
	C5	1	30	C5	1	52
1-2 years	C1	13	3	C1	1	0
	C2	7	6	C2	4	2
	C3	4	8	C3	8	4
	C4	2	12	C4	8	5
	C5	1	25	C5	6	6
3-5 years	C1	8	2	C1	6	2
	C2	5	3	C2	7	4
	C3	9	5	C3	12	5
	C4	4	7	C4	1	7
	C5	1	11	C5	1	25
6-9 yeas	C1	4	1	C1	2	0
	C2	6	3	C2	6	2
	C3	8	4	C3	9	5
	C4	6	5	C4	8	7
	C5	3	6	C5	2	8
10-14 years	C1	2	2	C1	2	0
	C2	5	5	C2	2	3
	C3	10	7	C3	11	6
	C4	9	9	C4	6	9
	C5	1	13	C5	6	12
15-19 years	C1	1	2	C1	2	6
	C2	3	7	C2	12	9
	C3	9	9	C3	6	10
	C4	11	12	C4	4	13
	C5	3	14	C5	3	16

*HMR: Hospital Mortality Rate (HMR); *FU: Federative Unit.

Source: Authors.

COVID-19 in children and adolescents presents unevenly among countries[20]. Study on the impact of COVID-19 in children with data from different countries showed that most pediatric fatalities were reported in low- and middle-income countries. In these countries, adverse circumstances as precarious sanitation conditions, food insecurity, lower application of resources in health have contributed to disproportionate risk of deaths as well as social impacts[21].

Horton[22] suggested applying the term "syndemic" to COVID-19 because of its clustering and interactions with pre-existing conditions and the influence of broader political, economic, and social factors, additionally obesity can also be considered a syndemic condition, so are important for prognosis, treatment, and health policy. Marked weight gain among children aged 8-12 years[23] and 6-11 years[24] has been pointed out in the literature, probably related to a more signif-



it continues

Figure 1. Hospital mortality rate clusters by age group. Brazil, 2020 and 2022.

Source: IBGE (2020), SIVEP-Gripe (2022).

icant increase in sedentary behavior, electronic games and screen time, especially in younger children, in addition a significant increase in the risk of severe illness by COVID-19 and conse-

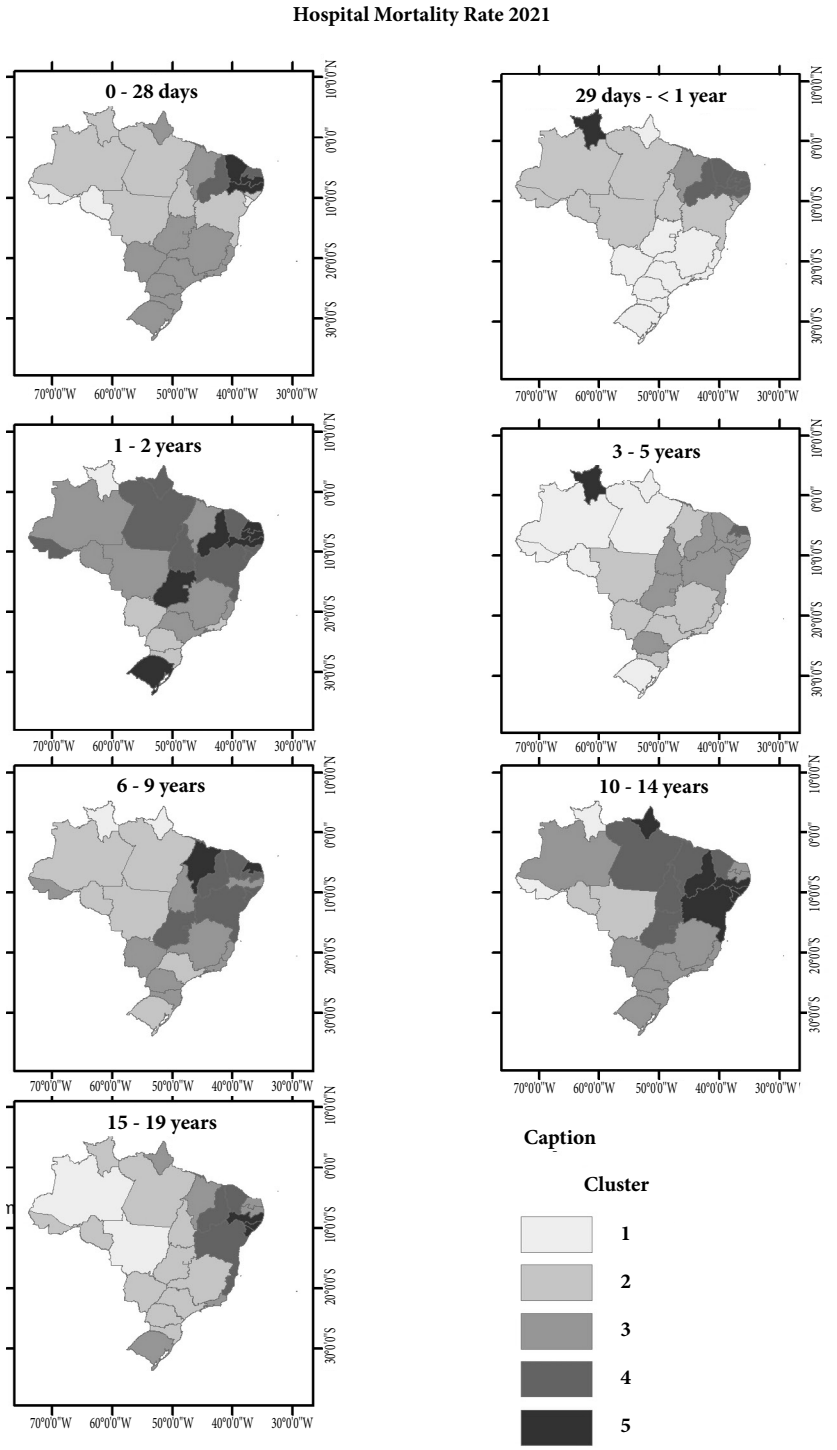


Figure 1. Hospital mortality rate clusters by age group. Brazil, 2020 and 2022.

Source: IBGE (2020), SIVEP-Gripe (2022).

quently hospital/ICU admission in overweight/obese youth has been observed[25]. It is possible that this aspect also interfered with our results.

In the Brazilian context, the difficulty of access to health services and ICU beds is uneven among the states[26]. HMR in FUs may be related

to factors such as socioeconomic development level, diagnostic conditions, assistance to symptomatic patients, and prevention and control capacity through nonpharmacological measures[27].

There was a disparity in the availability of human and hospital resources between the S/SE and N/NE regions, revealing an unequal capacity to cope with the crisis, which probably impacted the COVID-19 mortality rates[28]. In 2020, in Brazil, 31% of children/adolescents with SARS who died were not admitted to the ICU, probably due to the absence of these facilities, reinforcing regional socioeconomic inequalities[29].

Some states in the Northeast stand out from other FUs in the same region when composing high HMR clusters. The heterogeneity among the Northeastern states indicates the need for resources and a focus on the precariousness of timely diagnoses[30], which enables the isolation of patients and surveillance of their contacts to reduce transmission.

The North region has high poverty indicators, a low human development index, and insufficient resources for public health, resulting in difficulties facing the pandemic[31]. Roraima stood out in the clusters with the largest HMR. The weaknesses in the health system and the presence of illegal mining near villages may have contributed to the spread of this disease in Roraima[32]. Another important aspect in Roraima is the vulnerability, in the midst of the pandemic, of indigenous immigrants originating from groups in Venezuela, with no command of the language and limited access to the health network, and also the situation of unaccompanied Venezuelan children and adolescents[33], may have converged to a difficult control of COVID-19 in this state.

To address the pandemic, it is necessary to consider social vulnerabilities related to sanitary, structural, and organizational conditions and the quality of health services in each territory[34]. High mortality rates may lead to serious failures in the health care and surveillance system in a state[27]. The mortality rate may be influenced by the lack of diagnosis of the disease, including among patients hospitalized with SARS, owing to difficulties in testing and performing imaging tests. The high number of deaths without a confirmed cause compromises the quality of the records[35].

Among the limitations of this study is the use of secondary data with possible inconsistencies, possibility of under/recording, especially in localities where deaths without hospital care may occur and level of aggregation used (FU), which does not allow for more detailed analyses. The strengths of the study include the amount of data analyzed, national coverage, and spatial analysis of HMR among individuals 0-19 years of age and with subdivisions of the age groups and most recent period that have not been analyzed in similar studies so far[36,37].

Regional differences were observed in the HMR. States were grouped with others from different regions, showing the importance of the spatial issue by revealing the heterogeneity in the behavior of rates within each region and among regions. These findings may reflect social and access inequalities among the Brazilian population regarding hospital care and structural weaknesses in the health surveillance system. It is essential to acknowledge the vulnerabilities of each region, particularly the N/NE region.

The findings show a worsening of the mortality rate picture for COVID-19 in the study age group from 2020 to 2021, which follows the general increase in deaths in Brazil, probably due to issues related to the relaxation of preventive measures to SARS-CoV-2[38], presence of variants with high transmissibility[39], vaccine hesitancy[40] and in particular for children, the late introduction of vaccines[41].

The number of notifications of cases and deaths by COVID-19 in children is lower when compared to adults, probably due to previous immunity from contacts with similar and common viruses in early childhood generating a faster and more efficient immune response, and immunity acquired from recent vaccinations, since the childhood vaccination calendar is broad[42]. In addition, they present fewer risk factors for severe cases, such as the presence of comorbidities and age itself, thus being protective factors for children[42]. On the other hand, the pandemic brought negative impacts on the vaccination schedule for children in 2020, because there was a reduction in vaccination coverage throughout the Brazilian territory[43] especially in the North and Northeast regions, and may be one of the reasons for morbidity and mortality of this population[44].

According to Müller *et al.*[45], vaccination at the maximum rate could have prevented, between January and April 2022, about 5,400 hospitalizations and 410 deaths in children aged 5 to 11 years. On the other hand, a national survey of 15,297 respondents found that the vaccination hesitancy rate against COVID-19 of caregivers of children aged 0 to 4 years, 5 to 11 years, and adolescents was 16%, 13%, 15%, respectively, an aspect considered adverse to increasing vaccination coverage[46].

Children/adolescents represent a relevant age group in the transmission dynamics, but they also present factors of disease aggravation, especially among younger age groups. Immunization against COVID-19 in children older than 5 years was started in Brazil in January 2022. In Brazil, a study with different age groups, when comparing COVID-19 mortality, identified higher mortality rates in 2022 in the age groups 0 to 11 years compared to the previous year and lower rates in the 12-to-17-year age groups[47]. They found opposite patterns in mortality among children and individuals included in the national vaccination campaign, which likely contributed to the reduction in mortality in adolescents older than 11 years that started the vaccine in July 2021 and progressed in the following months[47]. The importance of vaccination especially in children under 5 years of age is reinforced to reduce severe forms and deaths from COVID-19 in this age group.

Collaborations

SSB Costa: conception of the research, data analysis and participated in all stages until the final writing of the article. MRFC Branco: research conception, data analysis, conception and writing of the article, coordination of all stages of the research until the final writing of the article. BLCA Oliveira: research conception, data analysis, conception and writing of the article. MES Rangel and AS Tonello: data analysis and article writing. MSM Araújo, EM Costa, AR Pereira, DAM Lopes, VV Pinheiro, and APB Câmara: data collection and article writing. DC Oliveira and VV Vasconcelos: data analysis, article conception and writing. AM Santos: research design, data analysis, article design and writing. All authors read and approved the final version.

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