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ORIGINAL ARTICLE

A Geoprocessing Approach for Mortality and Social Vulnerability Analysis during the COVID-19 Pandemic

Andres Felipe Valencia Rendon,[1] Isabela Mendes Volschan,[1] Manoella Novais Pereira,[1] Wagner Lima Monteiro,[1] Alessandra de Freitas Pimentel,[1] Emilia Matos do Nascimento,[2] Basilio de Bragança Pereira,[1] Glaucia Maria Moraes de Oliveira[1]

Universidade Federal do Rio de Janeiro,[1] Rio de Janeiro, RJ – Brazil
Universidade do Estado do Rio de Janeiro,[2] Rio de Janeiro, RJ – Brazil

Abstract

Background: Brazil had high COVID-19 lethality/mortality with multiple social inequalities, where color/race was highly relevant, especially in Rio de Janeiro. Therefore, we hypothesize that COVID-19 hospitalized patients with a highly socially vulnerable background would have more significant in-hospital mortality.

Objective: To analyze the socioeconomic factors of social vulnerability and their association with COVID-19 mortality.

Methods: This work was a prospective study of 274 confirmed adult COVID-19 hospitalized patients in the University Hospital of Clementino Fraga Filho (HUCFF). The clinical features/blood chemistry information were collected from the clinical record. The ArcGIS Pro Software (Esri Gis mapping software, Redlands California-US) and a Python-based algorithm were used to determine in-app/in-map variable management relevance to the socioeconomic variables, inequity markers, and vulnerability. Our study also analyzed the transfers from other primary care institutions to our hospital in order to examine its potential delays in advanced medical care. Logistic regression and ROC curve were used to investigate in-hospital mortality for our statistical analysis. The significance level adopted in the statistical analysis was 5%

Results: Male sex, total days of hospitalization, age, having more than three comorbidities, intensive care unit (ICU) admission, hemodialysis, and transfer from other hospitals showed statistical significance. Patients living in low-adequate households ($p = 0.030$) with high in-house individual agglomeration markers ($p = 0.017$) and transfers from another Primary Health Care (PHC) institution ($p = 0.047$) were associated with increased in-hospital mortality, with high ICU admission and mechanical ventilation.

Conclusions: In-hospital mortality due to COVID-19 was influenced by social individual background characteristics of vulnerability. Among other clinical parameters, these markers should be considered to predict the likelihood of complications related to the COVID-19 pandemic.

Keywords: COVID-19; SARS-CoV-2; Social Vulnerability; Hospital Mortality; Socioeconomic Disparities in Health.

Introduction

In November 2019, an alarming disease in the Wuhan province, China, gained attention from the local authorities.[1,2] Its clinical features were related to a virus with very particular characteristics that no other pathogen had shown at that time.[3] Later, identified as a new Coronavirus disease (SARS-CoV-2), the illness became present throughout all continents, except Antarctica, in the first semester of the following year, as declared by the World Health Organization on March 11, 2020.[4]

Mailing Address: Glaucia Maria Moraes de Oliveira
Universidade Federal do Rio de Janeiro. Rua Visconde de Pirajá, 330, Sala 1114. Postal code: 22410-000. Rio de Janeiro, RJ – Brazil
E-mail: glauciamoraesoliveira@gmail.com
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Central Illustration: A Geoprocessing Approach for Mortality and Social Vulnerability Analysis during the COVID-19 Pandemic

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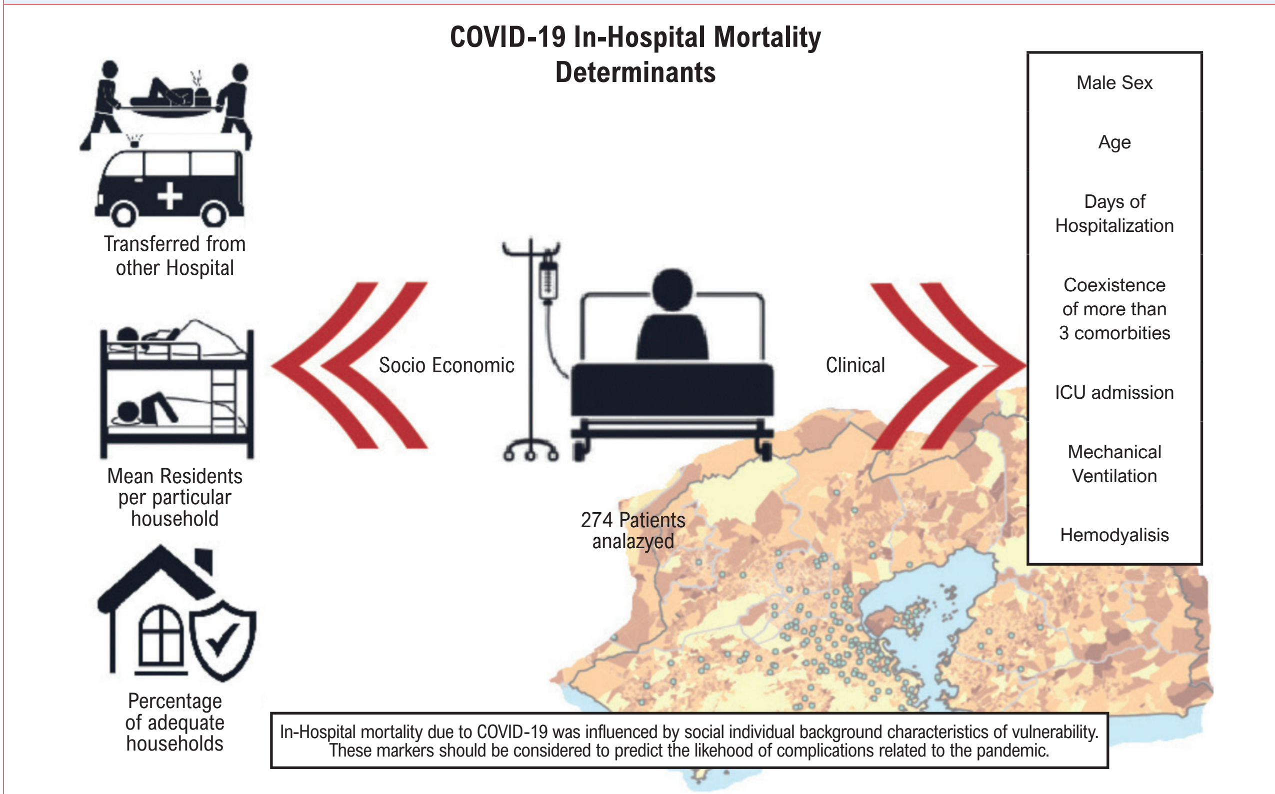

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ICU: intensive care unit

Initially thought to primarily affect pulmonary parenchyma, further research also demonstrated its pro-thrombotic characteristics and multi-organ disruption.[3,5-7] The clinical impact of the virus was heterogeneous among the general population, where older patients with baseline comorbidities, such as hypertension, diabetes, and obesity, had the worst outcomes. However, the impact on an individual's health depended on biological factors, and individuals from low-resource communities with higher rates of social vulnerability showed higher rates of the incidence of disease and death during the COVID-19 pandemic as regards individuals from more affluent areas.[8-10]

In addition, patients with low socioeconomic status and high individual concentration households were also important prognostic variables to influence the pandemic's outcomes. When speaking of the socially vulnerable population, Latin America is one of the most relevant latitudes, where countries like Brazil show highly heterogeneous incomes per person, where slums are known not only for the low-income status, but also for a high concentration of individuals per household,[11–15] where essential resources, including electricity, fresh water, and sewers, are scarce.[16–18]

Moreover, in this context, access to health care is especially difficult for this population, where local gangs determine who can access the streets and when not to mention the locations of the Primary Health Care (PHC) hospitals. Considering this relatively long distance, access to public transportation is cumbersome.[16,19]

Better understanding these complex social dynamics is paramount, since essential daily individual life factors can determine the individual and the collective outcome of the new disease. Therefore, the objective of the present study was to analyze these socioeconomic factors and their association with COVID-19 mortality.

Methods

With previous approval from our hospital's ethics committee, individual Electronic Medical Records (EMR) from the University Hospital of Clementino

Fraga Filho (HUCFF) were accessed. The HUCFF from the Federal University of Rio de Janeiro (UFRJ) is a high-complexity public hospital in Rio de Janeiro, Brazil. Being the principal university hospital in the city, it attends to the most vulnerable low-income population. With 350 hospital beds,[20,21] it offers its patients high-quality multidisciplinary medical attention. Since the beginning of the COVID-19 pandemic in 2020, HUCFF has provided medical care to more than 30,00 patients affected by the vírus.[21,22]

Adult patients, aged 18 years or over, who required medical care related to COVID-19, with a positive RT-PCR SARS-CoV-2 result on a nasal swab, who required hospitalization (defined as in-patient care for at least 24 hours) were included in our study, conducted from March to October 2020 at the HUCFF. Age, sex, base comorbidities (Hypertension, Diabetes, Heart Failure, Pulmonary Disease, and Chronic Kidney Failure), total days of hospitalization, Intensive Care Unit (ICU)/ Mechanical Ventilation, Hemodialysis, and initial blood analysis (Hemoglobin, Leukocytes, Platelets, and Creatinine) where obtained directly from the EMR. The sum of total comorbidities for each patient were also analyzed.

Examining an individual's background, targeting the sociodemographic variable markers for vulnerability, our study conducted a detailed geoprocessing analysis to evaluate the sociodemographic vulnerabilities of individuals in Rio de Janeiro. This involved a multi-step methodology:

- **Geolocation of Patient Households**: This study began by accurately pinpointing the geographic location of each patient's household within the municipality of Rio de Janeiro. This process used computational geoprocessing techniques to assign specific coordinates to each address.
- **Census Map Integration**: The next step involved integrating these household locations with the state's divisional census map. The divisional structure of this map is based on the 2010 Brazilian Census from the Brazilian Institute of Statistics and Geography (IBGE).
- **Software and Algorithm Use**: This analysis employed ArcGIS Pro Software (Esri in Redlands, California, USA), a GIS mapping tool, while a Python-based algorithm was used for efficient management of in-app and in-map variables. This combination allowed the researchers to accurately associate each patient's location with the corresponding census area.
- **Socioeconomic Variables Selection**: Specific socioeconomic variables were selected from the IBGE databank, which best represents local social vulnerability, as identified in previous studies.[23] These variables included mean residents per household, the percentage of families earning below a minimum wage, the average monthly income of inhabitants, the percentage of adequate households, areas of abnormally high population concentration, and the Human Development Index (HDI). Each patient's household was then correlated with these variables in their respective census area.[24]

The definition used by the IBGE for household adequation is shown in the Supplementary material. This socioeconomic information was added to our data set, obtaining the socioeconomically variable information for each given census division area. For each socioeconomic variable, a visual municipal map with the exact location of the individual household was generated.

It is important to note that not all patients sought medical care directly at our institution. Therefore, for those initially treated in a PHC or other institution and were then referred to our hospital, the total distance in kilometers to the HUCFF was computed within our geoprocessing methodology.

Statistical analysis

Study data were collected and managed using R computing language through R studio statistical package version 4.0.0. "Categorical variables were expressed as percentages. The data presented a normal distribution using the Kolmogorov-Smirnov test, with continuous variables presented as mean and standard deviation (SD). Those individuals with any missing variable information were excluded, and no assumptions were made for any missing value.

Multiple Logistic regression, initially including all variables, was performed, with mortality as the dependent variable, and using the Wald test to assess the degree of significance of each coefficient of the logistic equation.

For the predictability assessment of our study, when our data was gathered and analyzed, we performed a

ROC (Receiver operating characteristic) curve analysis with sensitivity vs. 1-specificity, with in-hospital mortality as the outcome, intending to asociate it with the studied variables. A p-value less than 0.05 was considered statistically significant.

Results

Within the study period from March to October 2020, 274 patients met the inclusion criteria, with complete variable information at the EMR. A total of 310 individuals were excluded due to incomplete information in the EMR.

The baseline characteristics of the cohort are summarized in Table 1, where the meantime of the hospitalization period was 19.81 (SD 19.24) days. Males accounted for 52.18% of the cohort, with a mean age of 60.97 (SD15.03) years. Regarding the most common baseline comorbidities, 71% had Hypertension and 43.06% had Diabetes Mellitus. In addition, 48.17% needed admission to the ICU, with 38.68% requiring endotracheal intubation and mechanical ventilation.

The multivariate analyses are summarized in Table 2. Demographic and clinical variables, including male sex, total days of hospitalization, age, having more than three comorbidities, ICU admission, hemodialysis, and transfer from other hospitals, had statistical significance. Regarding the socioeconomic background variables, mean residents per household, percentage of adequate households, and percentage of abnormally high concentration of population showed statistical significance with its association to in-hospital mortality. In addition, transfers from other institutions was also statistically significant.

Using the statistically significant variables, in context within our primary outcome, predicting in-hospital mortality for individuals with the already cited characteristics, an ROC analysis was developed, with a result for sensitivity of 93.3%, specificity of 88.5%, positive predictive value (PPV) of 3.6%, negative predictive value (NPV) of 20.2% (Figure 1).

Using our geoprocessing methodology, we generated a state map with its divisional census area for each sociodemographic variable, after having located the individual´s address. Figure 2 shows an example of the Rio de Janeiro map. In this case, the average nominal income per household, in light green, represents the household location on the map. The other maps can be found in the supplementary material.

Table 1 – Clinical characteristics of patients with COVID-19 who were admitted to the hospital.

VARIABLE	NUMBER, PERCENTAGE (%)
MEN	143 (52.18%)
WOMEN	131 (47.81%)
AGE, MEAN, SD	60.97 (15.03)
IN HOSPITAL TIME, MEAN, SD	19.81 (19.24)
NUMBER OF DISEASED PATIENTS	92 (33.57%)
HEMOGLOBIN, MEAN, SD	12.04 (3.40)
LEUCOCYTES, MEAN, SD	9052.97 (4926.87)
PLATELETS, MEAN, SD	242.93 (116.43)
CREATININE, MEAN, SD	2.43 (5.34)
HEMODYALISE	70 (25.54%)
HYPERTENSION	197 (71%)
DIABETES MELLITUS	118 (43.06%)
HEART FAILURE	35 (12.77%)
PULMONARY DISEASE	35 (12.77%)
CHRONIC RENAL DISEASE	54 (19.70%)
ICU ADMISSION	132 (48.17%)
MECHANICAL VENTILATION	106 (38.68%)
PATIENTS WITH 0 COMORBIDITIES	51 (18.61%)
1 COMORBIDITY	74 (27%)
2 COMORBIDITIES	100 (36.49%)
3 COMORBIDITIES	39 (14.23%)
4 COMORBIDITIES	6 (2.18%)
5 COMORBIDITIES	4 (1.45%)

SD: standard deviation.

Discussion

Extensive research has been performed since the beginning of the pandemic, trying to elucidate its clinical characteristics, viral spread dynamics, human cellular and molecular interactions, and, most importantly, the potential treatments and social policies to control the total number of infected individuals and the number of casualties caused by COVID-19.[19,25-27]

Social vulnerability status has played an almost forgotten role in mortality during the COVID-19

Table 2 – Variables that presented statistical significance after the Logistic Regression analysis with Intra-hospital Mortality as the primary outcome.

VARIABLE	ESTIMATION	ODDS RATIO	SE	PR(>|Z|)
INTERCEPTION	-2.537		2.639	0.337
MALE SEX	1.114	3.045	0.533	0.037
AGE	0.041	1.041	0.017	0.016
DAYS OF HOSPITALIZATION	-0.035	1.036	0.013	0.009
MORE THAN 3 COMORBIDITIES	3.326	27.835	1.372	0.015
ICU ADMISSION	2.279	9.769	0.696	0.001
MECHANICAL VENTILATION	3.93	50.887	0.674	0
HEMODIALYSIS	1.296	3.654	0.539	0.016
TRANSFERRED FROM ANOTHER HOSPITAL	-1.385	4	0.698	0.047
MEAN RESIDENTS PER PARTICULAR HOUSEHOLD	-2.107	8.264	0.88	0.017
PERCENTAGE OF ADEQUATE HOUSEHOLDS	0.027	1.027	0.012	0.03

PR: probabiliy; SE: p-value associated with Z statistics.

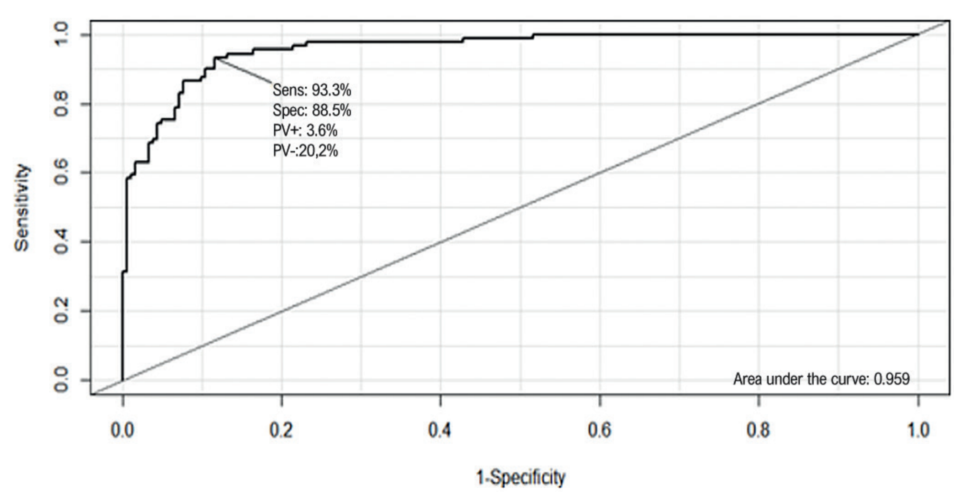

Figure 1 – ROC analysis based on statistically significant variables. With a sensitivity of 93.3%, specificity of 88.5%, positive predictive value of 3.6%, and negative predictive value of 20.2%.

pandemic. However, it was clear that those vulnerability markers were in fact essential to the recent phenomenon. Agglomeration was important for our primary outcome (in-hospital mortality) within our studied sociodemographic variables. This condition is often seen in Brazilian slums regions, with a higher degree in Rio de Janeiro, where the virus finds ideal conditions for its spread throughout the community. Other poverty markers in our study, such as the adequacy of the household, where poor hygiene conditions, garbage management, sanitation conditions, and access to clean water, not only within the property, but also in the surrounding area, have shown an major influence on the individual outcome.

Represented on the municipal map used for our geoprocessing methodology, we can also elucidate that most of our patients lived in census division areas, with mild to low monthly incomes, highlighting the vulnerable conditions of these individuals (**Figure 2).** This methodology potentially offers a better contextualization of the local areas, where the patient's household interacts with their particular regional social characteristics, more accurately demonstrating the living conditions of the participants than using only the HDI tool. When analyzing the statistically significant results, HDI did not show a significant value, potentially showing its low accuracy when analyzing locally driven comparatives in social characteristics.

The HDI is based on a summary of 3 dimensions: life expectancy, access to knowledge, and a decent standard of living.[28] It is precisely here that the HDI could offer us a potentially false measure of the living conditions of the individuals due to the fact that this "summary" is calculated based on relatively large areas.[12,28] The index often fails to reflect the significant regional disparities within the country, as conditions vary greatly among states, cities, and rural areas. One critical aspect overlooked by the HDI is income inequality within communities, leading to a scenario in which two regions with the same HDI score might have vastly different wealth distribution levels.[12,28] Additionally, the HDI does not account for cultural, environmental, and social factors unique to particular communities, which can significantly impact their development. It also fails to consider specific local issues, such as crime rates, local governance, environmental degradation, or access to essential services, like clean water or sanitation. Moreover, the reliability of the HDI is further compromised in many communities, especially in remote or less developed areas, due to the lack of accurate and reliable data, leading to potentially misleading or inaccurate HDI assessments.

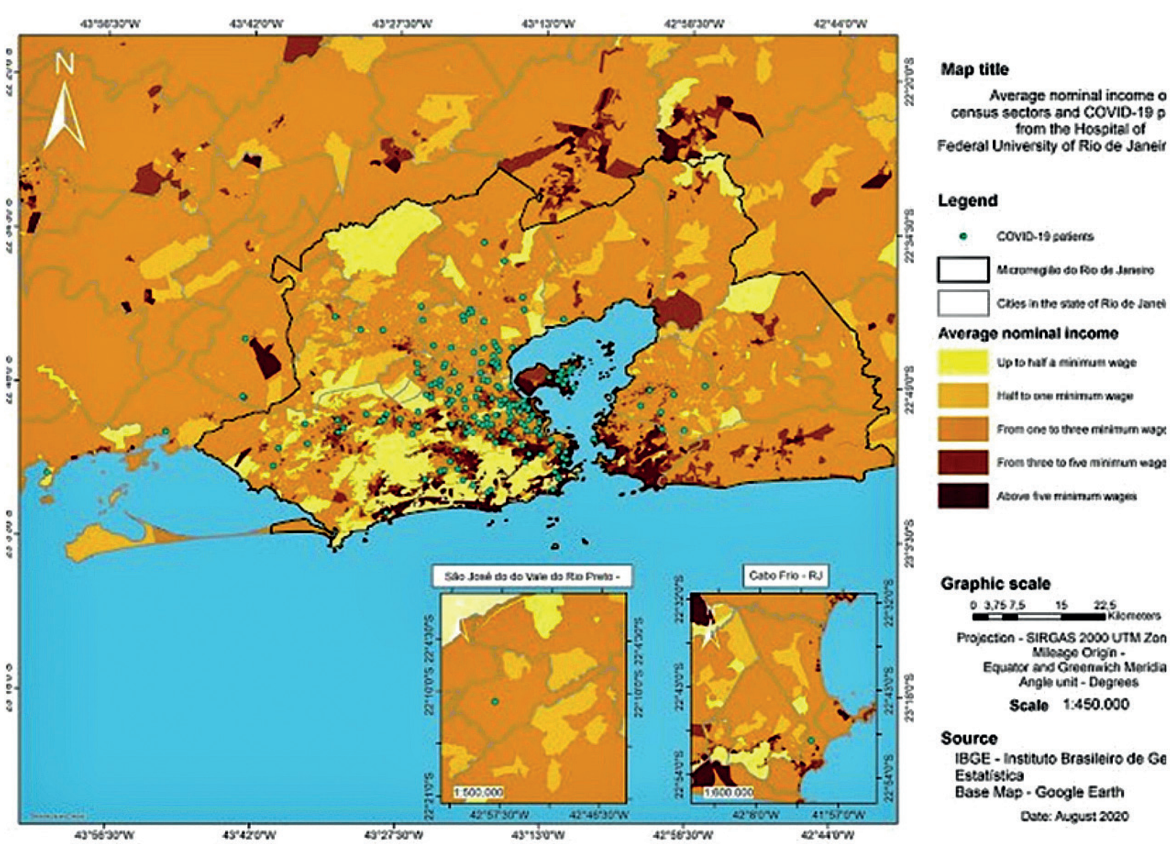

Figure 2 – The map shows the average nominal income of each census tract in Rio de Janeiro. Patients' home locations are shown in light green.

In addition, because of its characteristics, this tool could potentially overvalue specific communities in our city because of virtual juxtapositions between impoverished areas, like Rocinha slums and São Conrado (with one with the highest incomes in America). Our geoprocessing approach gives more locally individualized information, given that the census division area better represents the actual living conditions, with more precise boundaries of the studied sector. In accordance with previously published studies, base comorbidities are determinant for COVID-19 survival.[5,8,29]

It is also important to note that our patients had a relatively long hospital stay; this in part could be explained by the late access to proper medical attention. Hence, patients arrived at our hospital with more severe/ critical conditions, highlighting that almost half of them needed ICU admission, a significant portion of whom (38.68%) required mechanical ventilation, with referred acute decompensated base comorbidities.

Among other highly relevant biological factors, like hypertension and diabetes in association with COVID-19-related morbidity and mortality, social factors and vulnerability markers also determine the survival rate and complications within the COVID-19 pandemic. The question still remains: Can these types of studies help to better elucidate impacts and guide local health policies and authorities in the process of distributing the available resources to the virus contingency, thus prioritizing health care and vaccination? With this highly relevant finding, these characteristics of socioeconomic vulnerability can positively influence the patient's outcome during the pandemic. Unlike biological risk factors, healthcare policies can modify outcomes considerably, potentially saving lives and resources (Central Illustration).

To the best of our knowledge, this is one of the few studies developed to comprehend the influence of the markers of social vulnerability in Latin American latitudes like Brazil, using a novel, specific geoprocessing division census approach. These harsh conditions, virtually unique in Rio de Janeiro, directly impact minorities, as African descendants and mixed-race people mainly inhabit those slums. Violence, poverty, low public transportation quality, and relatively long distances to quality medical care all influence the outcomes of the individuals who face this pandemic with already critical baseline conditions. Morevoer these individuals need effective medical care and are most likely the last populations to receive the needed help.[14,25,30]

With the ongoing effort of global vaccination, now facing new virus variants, the most vulnerable communities suffer the most, and these impacts accentuate these factors. Furthermore, a portion of the population that had not previously come into contact with those circumstances was pushed into an environment in which unemployment and multifactorial economical struggle skyrocketed due to mandatory lockdowns.[31,32] Those who must face this significant disadvantage are generally the last to have access to vaccinations. However, with a better comprehension of those in the worst living conditions, healthcare professionals can potentially put an end to COVID-19.

Limitations

Our study used data from the 2010 Brazilian national census; currently, the national census committee was analyzed. Thus, the baseline characteristics of the households could vary from the current conditions. Our methodology used the determined census area for each household, where different living conditions could co-exist. Consequently, for a better individualized approach, questionnaire-based research should be implemented in order to better understand each individual's particular environment.

In addition, when working with the EMR, our research group found a lack of data consistency regarding blood tests and basic patient information due to an absence of hospital protocosl when admitting the patient to in-hospital treatment. Not only was there a lack of information concerning total leukocyte creatinine, but the data, including patient addresses, was also incomplete or confusing with reference to the patient's past medical history, which forced us to exclude a significant number of patients.

To achieve a more comprehensive social view of the current social dynamics within the COVID-19 pandemic, multicenter studies should also be implemented by the scientific community, together with the inclusion of the private healthcare sector, where COVID-19 patients treated in private hospital institutions with prioritized care and better household conditions could possibly show higher rates of survival. Further research is therefore warranted.

Conclusion

Social individual background characteristics of vulnerability influenced in-hospital mortality due to

COVID-19. Therefore, these social markers, among other well-known clinical parameters, should be considered so as to predict the particular likelihood of complications related to the COVID-19 pandemic. This study depicts the frequently forgotten complexity of social dynamics and the vulnerability of markers that influence mortality caused by COVID-19.

Author Contributions

Conception and design of the research, acquisition of data, analysis and interpretation of the data and critical revision of the manuscript for intellectual content: Rendon AFV, Volschan IM, Pereira MN, Monteiro WL, Pimentel AF, Matos E, Pereira BB, Oliveira GMM; statistical analysis: Rendon AFV, Volschan IM, Matos E, Pereira BB, Oliveira GMM; writing of the manuscript: Rendon AFV, Volschan IM, Oliveira GMM.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

This article is part of the thesis of master submitted by Andres Felipe Valencia Rendon, from UFRJ.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of the Hospital Clementino Fraga Filho under the protocol number 34020720.2.0000.5257. All the procedures in this study were in accordance with the 1975 Helsinki Declaration, updated in 2013.

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