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The association between household and neighborhood characteristics and COVID-19 related ICU admissions

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ABSTRACT

Introduction: Approaches to COVID-19 mitigation can be more efficiently delivered with a more detailed understanding of where the severe cases occur. Our objective was to assess which demographic, housing and neighborhood characteristics were independently and collectively associated with differing rates of severe COVID-19.

Methods: A cohort of patients with SARS-CoV-2 in a single health system from March 1, 2020 to February 15, 2021 was reviewed to determine whether demographic, housing, or neighborhood characteristics are associated with higher rates of severe COVID-19 infections and to create a novel scoring index. Characteristics included proportion of multifamily homes, essential workers, and ages of the homes within neighborhoods.

Results: There were 735 COVID-19 ICU admissions in the study interval which accounted for 61 percent of the state's ICU admissions for COVID-19. Compared to the general population of the state those admitted to the ICU with COVID-19 were disproportionately older, male sex, and were more often Black, Indigenous, People of Color. Patients disproportionately resided in neighborhoods with three plus unit multifamily homes, homes built before 1940, homes with more than one person to a room, homes of lower average value, and in neighborhoods with a greater proportion of essential workers. From this our COVID-19 Neighborhood Index value was comparatively higher for the ICU patients (61.1) relative to the population of Rhode Island (49.4).

Conclusion: COVID-19-related ICU admissions are highly related to demographic, housing and neighborhood-level factors. This may guide more nuanced and targeted vaccine distribution plans and public health measures for future pandemics.

1. Introduction

The Center for Disease Control defines severe COVID-19 as the need for hospitalization, admission to the intensive care unit (ICU), intubation or mechanical ventilation, or death (Centers for Disease Control and Prevention, 2020a). High rates of mortality, prolonged hospitalization, and complications from severe COVID-19 have had an enormous impact on families, health systems, and the economy. Awareness of this potential for SARS-CoV-2 infections to lead to severe disease led to unparalleled restrictions on commerce and mobility in an effort to protect limited healthcare resources. Such restrictions have been implemented for other respiratory viruses since the 1918 influenza pandemic. Many ICUs housed a number of patients beyond their pre-pandemic capacity throughout the multiple waves of the pandemic that has spurred discussions of ethical decision making surrounding care rationing and resource utilization (Bravata et al., 2021; 2020Wamsley).

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Racial, ethnic, and demographic disparities have been revealed among severe COVID-19 cases (Abrams & Szefler, 2020; Boserup et al., 2020; Centers for Disease Control and Prevention, 2020b). Twelve percent of the United States population is non-Hispanic Black; however, 34 percent of COVID deaths are among this group. (Centers for Disease Control and Prevention, 2020c). Prior studies have demonstrated racial and ethnic minorities to be at increased risk for severe COVID-19 and resultingly increased mortality (Florida Department of Health, 2021; Garg et al., 2020; Gibson et al., 2011). The cause of this elevated risk is likely multifactorial, related to social determinants of health including financial status, occupation, education, access to healthcare, and the physical environment in which they live, rooted in centuries of policies and structures that have shaped inequitable distributions of wealth, power, and opportunity (Bailey et al., 2017; Crighton et al., 2007).

Regarding the domestic physical environment, there is an association between severe COVID-19 cases and high population density (Upshaw et al., 2021) which may result from several possibilities: increased transmissibility in crowded settings, increased comorbidities and decreased access to care in urban settings for example. Household crowding, status as a renter, and employment as an essential worker are associated with increased risk of COVID-19 infection, but not necessarily severe COVID-19 [14]. Similarly, higher infection and hospitalization rates have been noted among those living in census tracts with higher percentage of multifamily homes (Cromer et al., 2020). However, there is scant literature regarding individual housing and neighborhood characteristics of those who have severe COVID-19.

The primary goal of vaccination is to reduce the burden of severe cases. Vaccine distribution plans in most states have been largely guided by age, comorbidities and occupation. We hypothesize that demographic, housing and neighborhood factors are collectively associated with more severe COVID-19 illness. These variables may be useful to incorporate into public health initiatives such as COVID-19 vaccine booster distribution plans in an effort to reduce cases of severe COVID-19 with subsequent variants and for any future pandemic respiratory illness (Marani et al., 2021). Thus, we assessed these characteristics among our COVID-19 ICU admissions.

2. Materials and methods

Study Setting and Population: We sought to establish a level of validity of a comparison between severe COVID-19 cases in our hospital system relative to the state population. This was done by querying the Rhode Island Department of Health's (RIDOH) COVID-19 Joint Information Center to determine the proportion of the state's ICU COVID-19 patients admitted to our system.

After study approval was obtained from the Lifespan system Institutional Review Board (IRB# 1605870-6), we queried our electronic health record for any adult patients admitted to our hospital system (Rhode Island Hospital, The Miriam Hospital, and Newport Hospital) in Rhode Island March 1, 2020–February 15, 2021 with the ICD-10-CM diagnosis of COVID-19 (U07.1) as their principal or first-listed diagnosis in a given encounter (Centers for Disease Control and Prevention, 2019). From this set of patients, we filtered for those who had an admission event to one of the five ICUs in our system that cared for COVID-19 patients during that time. Individual electronic medical record (EMRs) were then manually reviewed to confirm that patients had recently obtained a positive RT-PCR test for SARS-CoV-2. The EMRs were also reviewed to ensure that patients met severe COVID-19 criteria (dyspnea, respiratory rate >30, blood oxygen saturation≤ 93%, partial pressure of arterial oxygen to fractional inspired oxygen ratio <300, or opacities in >50% of lung fields[15]. Since the focus of our study is on demographic, housing, and neighborhood level factors associated with severe disease, we further restricted our analytic sample to non-institutionalized patients for whom a Rhode Island address was indicated as place of residence (Fig. 1)

Variables Collected: The EMRs were reviewed for age, sex, race/ethnicity, primary language, and address. Outcomes reviewed included mortality, ICU and hospital length of stay, and discharge location.

Databases: Addresses were entered into a public online real-estate marketplace (Redfin®) to extract estimated home values (for the building), number of bedrooms and bathrooms, square footage, and year built. Patients were considered to live in a multi-family dwelling if their home address had an apartment or floor listing, or their address was a free-standing house with multiple units.

Measures of housing and neighborhood environment were extracted from the 2019 American Community Survey (ACS). We used address of residence reported in the EMR to identify each patient's 2010 assigned US census tract and then linked patient-level data to census tract-level neighborhood data. Census tract-level data on number of units, year of construction, number of rooms, household size, owner occupancy, housing value, rent, commute, occupation, and earnings were abstracted. Occupation data were used to determine percent in essential work as previously described by the National Conference of State Legislatures (National Conference of State Legislature, 2021). Essential workers are defined as those who provide operations and services to allow critical infrastructure to continue to function. When stay at home

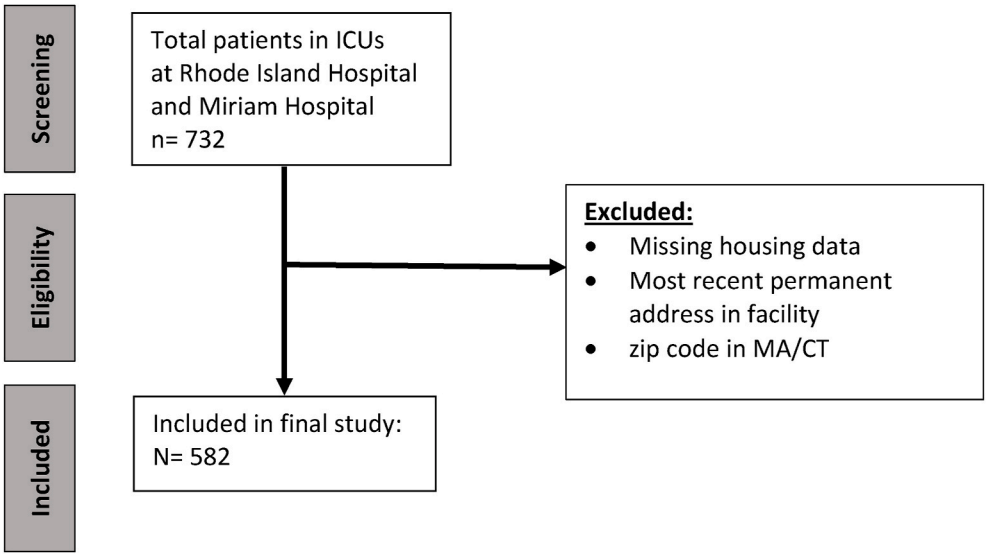

Fig. 1. Flow diagram for inclusion and exclusion of patients.

orders were instituted early in the pandemic, 23 states created categories of essential work in the fields of energy delivery, childcare, water and waste management, agriculture, critical retail, critical trades, transportation, and social service. For the purposes of these analyses, essential workers were those employed in 11 broad occupations including: Community and social services, Health practitioners and other technical occupations, Healthcare support, Protective service, Food preparation and service, Building and grounds cleaning and maintenance, Farming, fishing, and forestry, Construction and extraction, Installation, maintenance, and repair, Production, and Transportation and material moving.

Statistical Analysis: All analyses were conducted in Stata version 14.2 (StataCorp LP, College Station, Texas). We first assessed the distribution of individual-level and neighborhood-level characteristics for patients admitted to the ICU with COVID-19, as well as for Rhode Island residents overall. Second, we used principal components analysis (PCA) to construct the COVID-19 Neighborhood Index. As with factor analysis, PCA is a data reduction technique used in index development. However, the goal of PCA is to construct a linear combination of variables, not model the measurement of a latent variable (Widaman, 2007). PCA enabled us to obtain an index that incorporated multiple neighborhood items – with some items and contributing more weight to the index than others – while also minimizing bias from highly correlated neighborhood characteristics. We retained the first principal component, the unique linear combination that accounted for the largest possible proportion of total variability in the component measures. Individual neighborhood variables with loadings $\geq$0.25 were retained in the index; the index was subsequently rescaled to have a range of 0–100. Finally, we examined the association between quartiles of the COVID-19 Neighborhood Index and ICU admissions in a Poisson model with robust standard errors. Since our aim was to *describe* the total magnitude of inequities in ICU admissions by levels of our multidimensional neighborhood index irrespective of underlying cause, we did not adjust for confounding variables because adjustment could needlessly distort the observed associations within the cohort (Conroy & Murray, 2020).

3. Results

The RIDOH COVID-19 Joint Information Center reported that from March 1, 2020 to February 15, 2021, our hospital system cared for 61% (N = 735) of the state's COVID-19 ICU admissions.

Most patients with COVID-19 related ICU admission were in the Providence area (Fig. 2) as evidence by the fact that the rate of ICU admissions among residents whose address was in the city of Providence was 2.5 times greater than that of other Rhode Island cities and towns (95% CI: 2.10,3.00), though not all neighborhoods within Providence were equally impacted (eFigure 2) (see Figs. 3-5).

Relative to the overall Rhode Island population, the 539 patients with a Rhode Island address who were admitted to the ICU with COVID-19 were disproportionately older (median age 66 years), male sex (59%), and were more often Black, Indigenous, People of Color (BIPOC; 47%, Table 1). Overall, ICU patients with COVID-19 had a median and median length of stay of 13.9 days (IQR: 7.0,23.9) and 4.8 days, respectively in the ICU (IQR:1.6,12.7).

Fifty-six percent of ICU patients with COVID-19 infection lived in multifamily housing (Table 2). Additional real estate data were available for 388 of the 539 ICU patients, revealing 48% lived in homes built before 1940, with a median of 2.8 bedrooms, 1.4 baths, and 1382 square

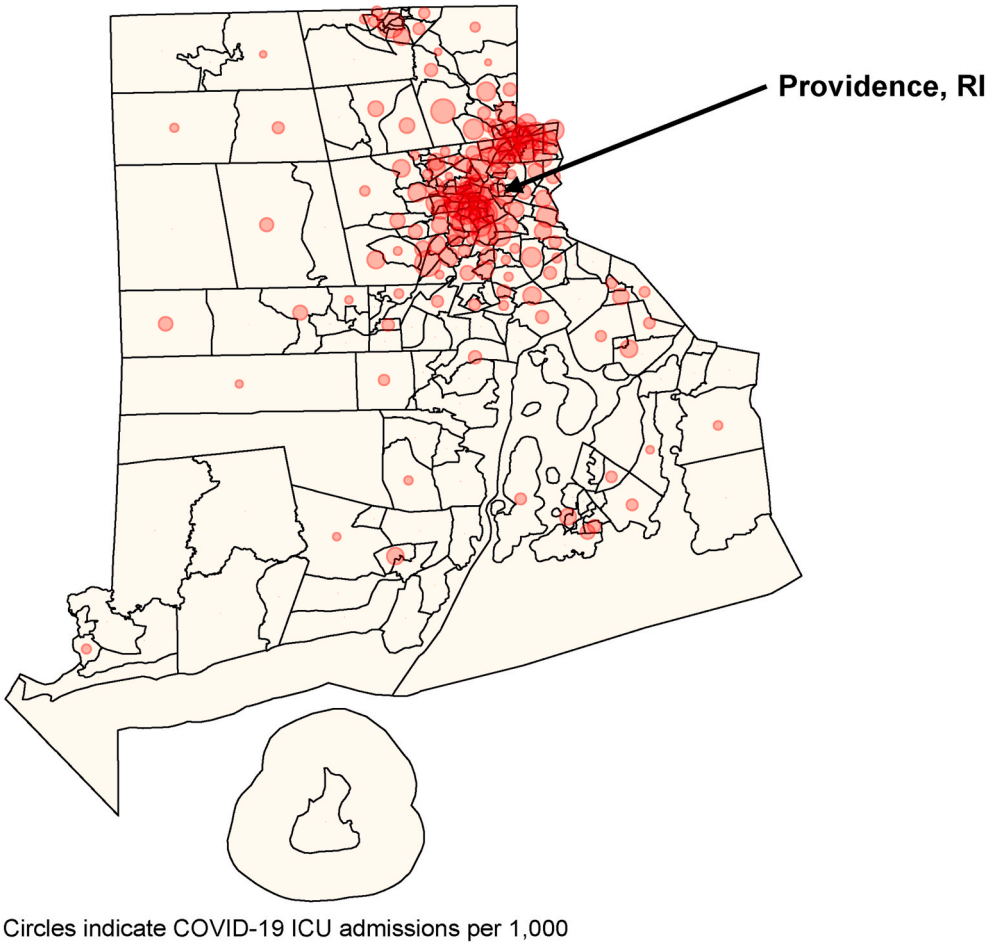

Fig. 2. Geographic distribution of COVID-19 related ICU incidence per 1000 from March 1, 2020 to February 15, 2021 in Rhode Island.

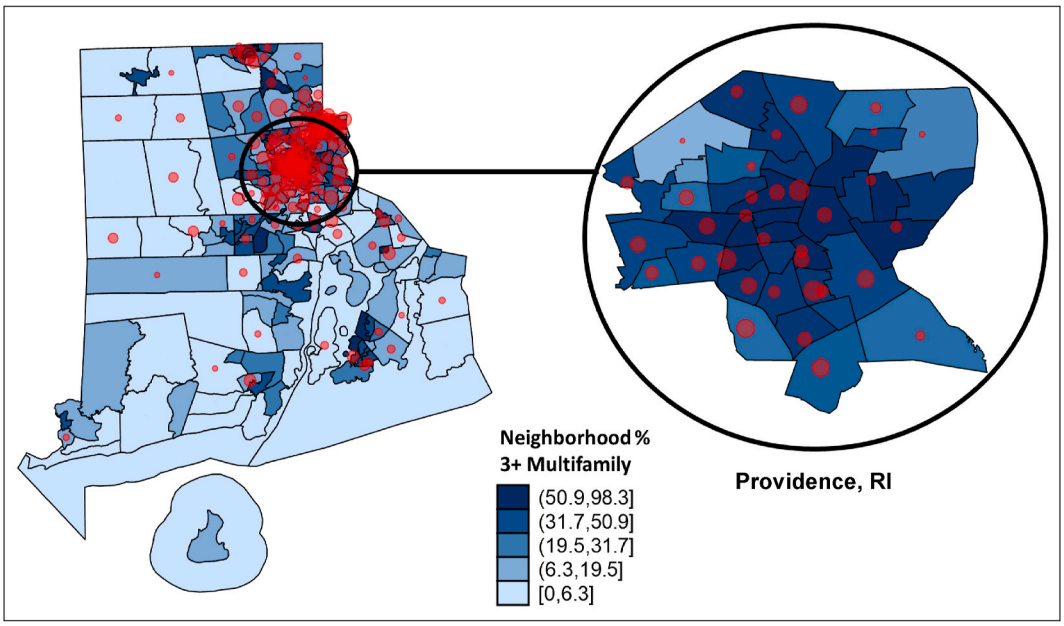

Fig. 3. Census-tract level proportion in multifamily housing and geographic distribution of COVID-19 related ICU incidence per 1000 from March 1, 2020 to February 15, 2021 in Rhode Island.

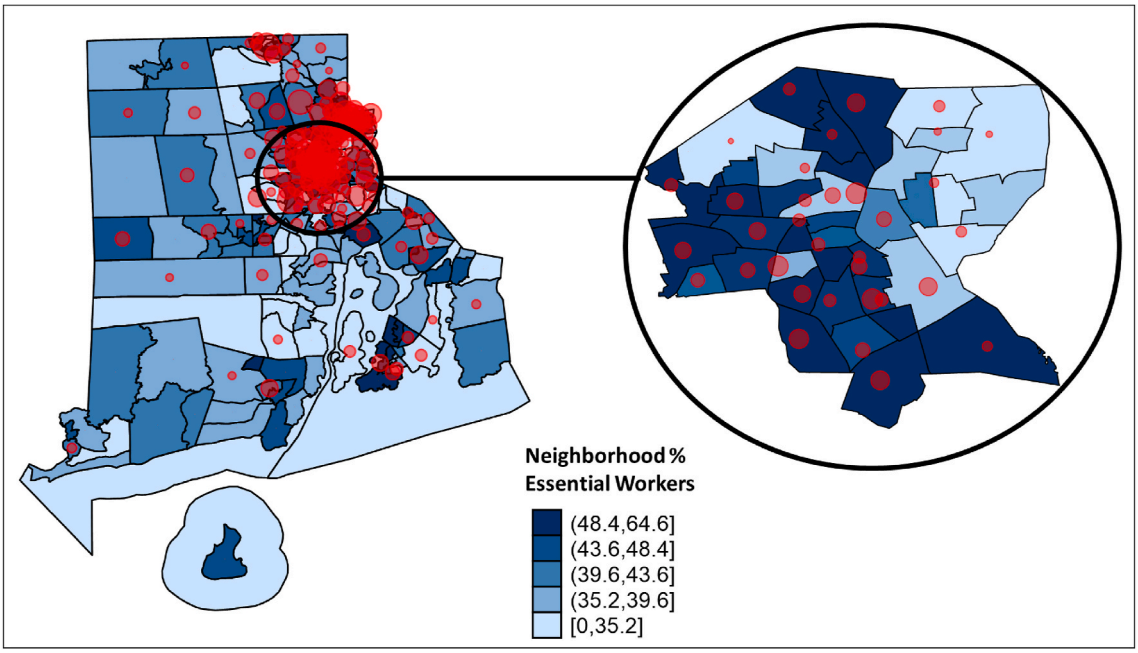

Fig. 4. Census-tract level proportion in employed in essential work and geographic distribution of COVID-19 related ICU incidence per 1000 from March 1, 2020 to February 15, 2021 in Rhode Island.
Red circles denote incident ICU admissions with circle size proportional to ICU admissions per 1000 residents in a given census tract.

footage.

3.1. COVID-19 neighborhood index

Relative to the overall Rhode Island population, the patients admitted to the ICU with COVID-19 disproportionately resided in neighborhoods with more: three plus unit multifamily homes; homes built before 1940; homes with more than 1 person to a room; homes of lower average value, and in neighborhoods with a greater proportion of essential workers (Table 3). These items all loaded highly onto our COVID-19 Neighborhood Index ($\geq$0.25) along with percent built on or after 1980, median number of rooms, percent owner occupied, and median earnings. As such, the average COVID-19 Neighborhood Index value was comparatively higher for the ICU patients (median: 61.1) relative to the general population of Rhode Island (median: 49.4).

Each of the items that loaded highly on our COVID-19 Neighborhood

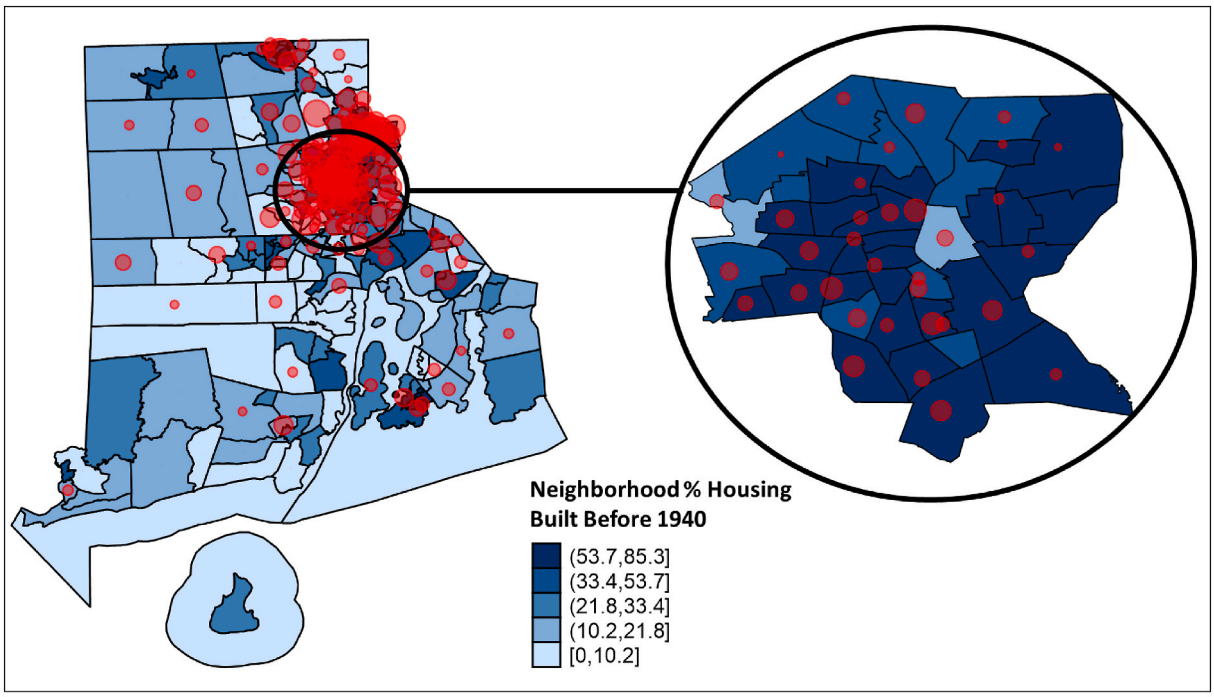

Fig. 5. Census-tract level proportion in housing built before 1940 and geographic distribution of COVID-19 related ICU incidence per 1000 from March 1, 2020 to February 15, 2021 in Rhode Island.
Red circles denote incident ICU admissions with circle size proportional to ICU admissions per 1000 residents in a given census tract.

Index were moderately to strongly associated with COVID-19 ICU admissions in separate crude Poisson models (Table A1). **Figure,3,4,5** display geographic distribution of COVID-19 related ICU incidence per 1000 from February 2020 to February 2021 overlayed on key census tract-level characteristics – proportion of three plus unit multifamily homes, proportion employed in essential occupations, and proportion of homes built before 1940. These figures show that there is substantial – but not complete – overlap in census tract-level characteristics; that is, many but not all tracts with a high percentage of multifamily homes also have a high percentage of homes built before 1940 and a high proportion of residents employed in essential work. This overlap further substantiates our primary focus on a multidimensional neighborhood index.

When we examined the association between our multidimensional neighborhood index and ICU admission, we observed that the incidence of ICU admission in neighborhoods in the highest quartile for the COVID-19 Neighborhood Index (score range 76–100) was 5.16 times the incidence in neighborhoods in the bottom quartile for COVID-19 Neighborhood Index (95% CI: 3.06,8.70; Table 4)

4. Discussion

Identification of those who are at higher risk for having severe COVID-19 infection and targeting interventions in these cohorts could assist in mitigating morbidity and mortality and reduce the ICU burden during the ongoing staffing crisis. We demonstrate that supplementing demographic data with housing and neighborhood characteristics could improve the risk assessment of an individual to develop severe COVID-19 within the larger schema of social determinants of health. Similar findings have been noted with influenza (Otero & Mermel, 2020). Putting these factors together allowed us to create a novel COVID-19 Neighborhood Index that may be useful in other parts of the country to guide vaccine triage and other public health measures.

BIPOC individuals have suffered far greater rates of ICU admission, mortality, and morbidity from COVID-19 [5–7]. We noted similar findings with higher rates of ICU admission among non-White individuals relative to our state's population. Long standing structural racism has led to disproportionate exposures to environmental pollutants that exacerbate asthma and chronic lung disease (Bailey et al., 2021; Thakur et al., 2017). Consequently, BIPOC individuals are at increased risk of hypertension, obesity, and chronic kidney disease, with more frequent exacerbations of chronic pulmonary disease among non-Hispanic Black race (Federico et al., 2020; Judd & Calhoun, 2016; Norton et al., 2016). These comorbidities have been clearly linked to worse outcomes with COVID-19 infections and have led other investigators to consider this a syndemic rather than just a pandemic (Horton, 2020). Relating racial and socioeconomic factors to the presence and management of non-communicable diseases, and in turn COVID-19 outcomes, is critical to guide interventions at the individual and community level.

We found that COVID-19 patients admitted to our ICUs commonly lived in multi-family homes and more often came from neighborhoods with a higher percentage of three-plus unit housing reaffirming the association between crowding and respiratory infections (Shannon, 2018). Zip code and state level data have shown increased COVID-19 related deaths in areas with increased crowding and household transmission has been shown to be more common compared with transmission among non-household contacts (Chen et al., 2020; Chen & Krieger, 2021). There is scant literature regarding individual housing type as a risk for COVID-19 infection. While it is unclear whether multi-family homes increase transmissibility due to increased personal contact, it is very likely that multi-family housing is a surrogate for other, more important variables that contribute to increased rates of severe COVID-19 infection beyond population density or inability to socially distance. As such, the linkages between race, socioeconomic status, living situation, comorbidities, and this current pandemic are numerous and complex.

We also found COVID-19 patients requiring ICU admission lived in neighborhoods with more essential workers and lower median earnings

Table 1
Characteristics of patients hospitalized in the ICU within the Lifespan Healthcare System for COVID-19-related illness, March 2020–February 2021.

	RI Residents[a] (N = 1,059,361)	RI Resident ICU Patients Complete Address Data N = 539
	Col % or Median (Interquartile Range)	
Age (years) [b]	40	66 (56,74)
Gender		
Men	49	59
Women	51	40
Race/Ethnicity		
NH White	79	50
Hispanic/Latinx	16	26
NH Black	7.4	11
NH Asian	3.5	2.6
Multiracial	4.2	6.7
NH NHoPI	0.0	0.6
Unknown		3.7
Language		
English	77	66
Spanish	13	26
Other	9.9	7.8
Marital Status		
Married/Partnered	43	48.4
Divorced/Separated	13	15
Single	39	28
Widowed	5.9	8.7
Disposition		
Home	–	35
Facility	–	18
Hospice	–	6.3
Death	–	42
ICU LOS (days) [b]	–	4.8 (1.6,12.7)
Overall LOS (days) [b]	–	13.9 (7.0,23.9)
ICU LOS, Survivors (days) [b]	–	3.1 (1.3,8.3)
Overall LOS, Survivors (days) [b]	–	13.5 (7.0,26.2)

[a] 2019 5-year estimates from the American Community Survey.
[b] Median (Interquartile Range); Abbreviations: NH, Non-Hispanic/Latinx; NHoPI, Native Hawaiian or Pacific Islander; ICU, Intensive Care Unit; LOS, Length of Stay.

Table 2
Household characteristics (Centers for Disease Control and Prevention, 2020a) of RI residents admitted with COVID-19.

	RI Residents with COVID-19 related ICU admission
Number of Units (N=539)	
% Single Family	44
% Multifamily	56
Year of Construction (N=388)	
% Built on or after 1980	20
% Built 1940–1979	32
% Built before 1940	482
Household Size (N=388)	
Median number of bedrooms	2.8
Median number of bathrooms	1.4
Median Square Footage	1382
Median Housing Value (N=388)	$252,385

[1] Data abstracted from Redfin.

Table 3
Census tract-level characteristics of Rhode Island houses and household members, 2019 American Community Survey.

Neighborhood-Level Characteristics	Neighborhood Index Factor Loadings	RI Residents (N = 1,059,361)	RI Residents with COVID-19 related ICU admission (N = 539)
Number of Units			
% Single Family, Detached	–	55	41
% Multifamily, 3 or more	0.3835	29	40
% Multifamily, 5 or more	–	17	20
% Mobile home or van	–	0.9	0.4
Year of Construction			
% Built on or after 1980	−0.2818	26	20
% Built 1940–1979	–	43	40
% Built before 1940	0.3206	31	39
Household Size			
Median number of rooms	−0.3739	5.4	5.1
Average HH size (owner occupied)	–	2.7	2.8
Average HH size (renter occupied)	–	2.2	2.4
% >1 person per room	0.3039	1.9	2.9
Housing Value			
% Owner occupied	−0.4140	61	50
Median Housing Value (owner occupied)	−0.2601	$272,992	$226,913
Median Rent	–	$1090	$992
Commute, Occupation, & Earnings			
% Carpool	–	5.2	6.3
% Public transit	–	1.5	2.2
% Work from home	–	2.7	2.8
% Essential Work	0.2894	43	46
Median Earnings for Workers	−0.3449	$39,629	$35,524
Median COVID-19 Neighborhood Index (Range:0–100)		49	61

Table 4
Association between COVID-19 Neighborhood Index quantiles and COVID-19-related ICU admissions, Rhode Island March 1, 2020–February 15, 2021.

COVID-19 Neighborhood Index	Incidence Rate Ratio (95% Confidence Interval)[a] (Centers for Disease Control and Prevention, 2020a)
Q1: 0 to 27	Referent
Q2: 28 to 42	1.57 (0.85,2.88)
Q3: 43 to 54	2.16 (1.25,3.73)
Q4: 55 to 75	2.20 (1.21,3.99)
Q5: 76 to 100	5.16 (3.06,8.70)

[a] Estimated with Poisson regression and robust standard errors.

compared to the state population. These two variables were important components of our COVID-19 Neighborhood Index and contribute to the differences observed between our patient sample and the state population. Essential workers are more often non-white, earn lower wages, are more frequently in close contact with the public and their co-workers, and less likely to work remotely [31] [32]. At various stages of the pandemic, they have also lacked personal protective equipment and other workplace protections to reduce exposure to SARS-CoV-2 [33]. It is then unsurprising that higher rates of infection, severe COVID-19 cases and mortality have been observed among workers in meat processing plants, mass transit, large department stores, warehouses, factories, and restaurants (Billingsley et al., 2020; Chen et al., 2021; Hawkins et al., 2021). In the first few months of the pandemic 120 Metropolitan Transportation Authority employees died from COVID-19 complications (Lancet null, 2020). Neighborhoods with greater proportions of essential workers should be considered for prioritization of COVID-19 vaccination, especially as the booster vaccine programs have now begun. This

could reduce rates of severe COVID-19 cases among the workers themselves, their families and neighbors. It may also allow commerce that depends on their work to continue with less interruptions, important during this time of critical supply chain shortages.

Our study has important limitations. Our analytic sample is restricted to ICU patients admitted within a single healthcare system in Rhode Island. However, our healthcare system includes the only tertiary medical center where the majority of severe COVID-19 cases were managed. Census tract-level data on households cannot be used to infer the specific conditions of patients' households within those tracts and census tract boundaries may be inconsistent with one's own definition of their neighborhood. However, we bolster neighborhood-level housing data with individual-level housing data from Redfin. Redfin data were missing for approximately 28% of ICU patients. Additionally, while the proportion of owner-occupied homes in a given census tract was the highest loading attribute in PCA – and thus weighted the highest in our index – we were unable to infer from Redfin data whether or not the patient rented or owned a home. Finally, in this study we leveraged data on multiple indicators to construct an index to identify areas where a greater proportion of people may be at increased risk of severe COVID-19, however, we can not infer from the present study specific causes. This study's approach can be applied to future pandemics. Further investigation into specific neighborhood traits that portend a worse prognosis in respiratory illness will be helpful to elucidate social determinants of health that are modifiable.

5. Conclusion

COVID-19-related ICU admissions are highly patterned by both individual factors (race, gender, and age) and neighborhood-level factors like proportion of homes that are multifamily and proportion of residents that are essential workers. It is paramount that efforts to mitigate risk of severe COVID-19 illness, as well as illnesses from similarly communicable respiratory infections, take into account the way exposures are shared within households and neighborhoods. Given the ongoing pandemic and future such challenges, it is imperative that we study the most vulnerable populations and better describe the barriers to overcome and achieve health equity.

Ethical statement

This material is the authors' own work, it is original and has not been previously published elsewhere and it is not currently submitted to any other journals. The manuscript and data is the authors' own research and analysis. All authors have contributed substantially to the carrying out of the research, and the writing and editing of the manuscript.

Financial disclosures

None to disclose.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2022.101133.

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