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ORIGINAL RESEARCH

Coronavirus Disease 2019 Hospitalizations Attributable to Cardiometabolic Conditions in the United States: A Comparative Risk Assessment Analysis

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BACKGROUND: Risk of coronavirus disease 2019 (COVID-19) hospitalization is robustly linked to cardiometabolic health. We estimated the absolute and proportional COVID-19 hospitalizations in US adults attributable to 4 major US cardiometabolic conditions, separately and jointly, and by race/ethnicity, age, and sex.

METHODS AND RESULTS: We used the best available estimates of independent associations of cardiometabolic conditions with a risk of COVID-19 hospitalization; nationally representative data on cardiometabolic conditions from the National Health and Nutrition Examination Survey 2015 to 2018; and US COVID-19 hospitalizations stratified by age, sex, and race/ethnicity from the Centers for Disease Control and Prevention's Coronavirus Disease 2019–Associated Hospitalization Surveillance Network database and from the COVID Tracking Project to estimate the numbers and proportions of COVID-19 hospitalizations attributable to diabetes mellitus, obesity, hypertension, and heart failure. Inputs were combined in a comparative risk assessment framework, with probabilistic sensitivity analyses and 1000 Monte Carlo simulations to jointly incorporate stratum-specific uncertainties in data inputs. As of November 18, 2020, an estimated 906 849 COVID-19 hospitalizations occurred in US adults. Of these, an estimated 20.5% (95% uncertainty interval [UIs], 18.9–22.1) of COVID-19 hospitalizations were attributable to diabetes mellitus, 30.2% (UI, 28.2–32.3) to total obesity (body mass index ≥30 kg/m^2), 26.2% (UI, 24.3–28.3) to hypertension, and 11.7% (UI, 9.5–14.1) to heart failure. Considered jointly, 63.5% (UI, 61.6–65.4) or 575 419 (UI, 559 072–593 412) of COVID-19 hospitalizations were attributable to these 4 conditions. Large differences were seen in proportions of cardiometabolic risk–attributable COVID-19 hospitalizations by age and race/ethnicity, with smaller differences by sex.

CONCLUSIONS: A substantial proportion of US COVID-19 hospitalizations appear attributable to major cardiometabolic conditions. These results can help inform public health prevention strategies to reduce COVID-19 healthcare burdens.

Key Words: COVID-19 ■ diabetes mellitus ■ heart failure ■ hypertension ■ obesity

The coronavirus disease 2019 (COVID-19) pandemic is causing a tremendous public health, social, and economic crisis. The United States has the highest numbers of deaths globally, representing <5% of the world's population but ~25% of COVID-19 deaths.[1] Individuals diagnosed with COVID-19 experience a remarkable breadth of symptom severity, ranging from no symptoms to severe hypoxia and need for hospitalization. Multiple reports consistently demonstrate that poor cardiometabolic health is a major risk factor for increased COVID-19 severity, including higher risks of hospitalizations and in-hospital mortality.[2–4] A meta-analysis of patients with COVID-19 in China found that hypertension, cardiovascular diseases, and diabetes

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CLINICAL PERSPECTIVE

What Is New?

- Patients with cardiometabolic conditions, in particular obesity, hypertension, diabetes mellitus, and heart failure, have a high risk of poor outcomes from coronavirus disease 2019 infection.
- Among >900 000 US coronavirus disease 2019 hospitalizations through November 18, 2020, nearly two thirds (63.5%) were estimated to be attributable to these cardiometabolic conditions, that is, preventable if these conditions had not been present.
- Top risks were obesity (30.2%), hypertension (26.2%), and diabetes mellitus (20.5%). (Attributable proportions are multiplicative, not additive, when 2 or more exist.)

What Are the Clinical Implications?

- Clinicians should educate their patients who may be at risk and consider promoting preventive lifestyle measures, such as improved dietary quality and physical activity, to improve overall cardiometabolic health and potentially minimize the risk for coronavirus disease 2019 severity.

Nonstandard Abbreviations and Acronyms

CDC	Centers for Disease Control and Prevention
CMS	Center for Medicare & Medicaid Services
COVID-19	coronavirus disease 2019
COVID-NET	Coronavirus Disease 2019–Associated Hospitalization Surveillance Network
NHANES	National Health and Nutrition Examination Survey
NYC	New York City
PAF	population-attributable fraction
UI	uncertainty interval

mellitus were each 2-fold to 3-fold more prevalent among severe cases than nonsevere cases.[5] US reports similarly demonstrate a much higher prevalence of underlying cardiometabolic conditions among hospitalized cases and severe cases of COVID-19 compared with infected individuals who do not suffer hospitalization or severe illness.[2,6,7] In a multivariable-adjusted investigation of COVID-19 in New York City, obesity, diabetes mellitus, hypertension, and heart failure were independent predictors of hospitalization, with many of these conferring the highest risks after advanced age.[2] In the most recent Centers for Disease Control and Prevention (CDC) analysis of available national data among individuals diagnosed with COVID-19, a 35-year-old with diabetes mellitus, hypertension, cardiovascular disease, obesity, or other chronic conditions had a similar risk of COVID-19 related hospitalization as a 75-year-old with none of these conditions, and a similar risk of COVID-19–related death as a 65-year-old with none: a dramatic "biologic aging" effect of poor metabolic health on risk of severity of a viral infection such as COVID-19.[6]

These heightened risks for COVID-19 hospitalization are alarming given the ubiquity of cardiometabolic diseases. Nearly half of American adults are diabetic or prediabetic,[8] nearly half have hypertension,[9] and nearly 3 in 4 are overweight or obese.[10] In sum, diet-attributable chronic diseases are the leading cause of morbidity, mortality, and healthcare spending in the United States.[11] Tremendous disparities by race/ethnicity are also evident in both COVID-19 deaths and burdens of cardiometabolic conditions.[7,12–14] Cardiometabolic conditions could be contributing to a substantial proportion of COVID-19 hospitalizations in the United States as well as to associated health disparities, exacerbating strains on hospital bed utilization, personal protective equipment supplies, availability of mechanical ventilators, and the healthcare workforce.

Given the extant burdens of cardiometabolic conditions, consistent evidence for strong associations between cardiometabolic conditions and COVID-19 severity and the high rates of COVID-19 hospitalizations in the United States, there is a need to quantify and compare the extent to which cardiometabolic conditions may be contributing to national COVID-19 hospitalizations and associated health disparities. To address these questions, we used a comparative risk assessment modeling framework to estimate the proportions and numbers of COVID-19 hospitalizations attributable to 4 major cardiometabolic risk factors, individually and jointly, among US adults overall and according to age, sex, and race/ethnicity.

METHODS

Study Design

A comparative risk assessment model was used to estimate the numbers and proportions of COVID-19–related US hospitalizations attributable to key cardiometabolic conditions. The model incorporated separately derived input data and corresponding uncertainty on (1) nationally representative demographics and prevalence of cardiometabolic conditions by age, sex, and race/ethnicity; (2) independent relationships of cardiometabolic conditions with COVID-19 hospitalization from the largest multivariable analysis in the United States; (3) numbers of COVID-19 hospitalizations by age, sex, and race/ethnicity from the CDC from 14

states with reliable stratified data; and (4) national data on estimated total COVID-19 hospitalizations (Table 1). This modeling investigation based on published and nationally representative data sets that include no personally identifiable information was exempt from human subjects (institutional review board) review. As data are based on publicly available sources, no data are available directly from the researchers.

National Distributions of Cardiometabolic Conditions

The relevant study base for this investigation is the entire COVID-19–infected population in the United States, including both diagnosed and undiagnosed cases. Based on limited diagnostic testing as well as large numbers of minimally symptomatic or asymptomatic cases, current studies suggest that confirmed diagnoses represent a small fraction of the total infected population.[15] This widespread underdiagnosis prevents us from knowing the true distribution of cardiometabolic conditions among all adults who have been infected nationally. In the absence of this information, we used the distribution of cardiometabolic conditions among US adults based on nationally representative data from the 2 most recent cycles of the National Health and Nutrition Examination Survey (NHANES 2015–2016 and 2017–2018), accounting for the complex survey design and sampling weights to be representative of the US population.

Relevant cardiometabolic conditions were selected based on evidence for the strongest independent associations with COVID-19 hospitalization,[2] including diabetes mellitus, obesity (stratified by body mass index [BMI] 30–40 kg/m^2 and BMI >40 kg/m^2), hypertension, heart failure, and chronic kidney disease (see Independent Associations Between Cardiometabolic Conditions and COVID-19 Hospitalizations section

Table 1. Input Data for Comparative Risk Assessment Analysis of Cardiometabolic Risk Attributable COVID-19 Hospitalizations in the United States

Input	Data Source and Description	Assumption
Cardiometabolic risk prevalence distributions	NHANES (2015–2016 and 2017–2018 cycles) among adults aged >18 y, stratified by age, sex and race	Prevalence of cardiometabolic risk factors in the NHANES general population estimates the cardiometabolic risk prevalence in the COVID-19-infected US population.
Estimated RRs	Multivariable-adjusted predictors of COVID-19 hospitalization among 5279 patients testing positive for COVID-19 in New York City[2]	Reported multivariable-adjusted OR estimate the RR for COVID-19 hospitalization given each cardiometabolic risk in the COVID-19-infected source population given data that confirmed diagnosis cases of COVID-19 are a small fraction of total cases in the population[17–21] (ie, hospitalization represents a relatively rare event).
		Relative risks for the association between COVID-19 hospitalization and cardiometabolic risk factors are biologic, that is, consistent in different populations.
		The source population (all adults infected with COVID-19, whether diagnosed or not) is similar or healthier than the diagnosed COVID-19 population (Table 2), and thus the true RRs for cardiometabolic risk factors are similar or even greater than the observed RRs.
COVID-19 hospitalizations stratified by age, sex, and race/ethnicity	CDC COVID-NET laboratory-confirmed hospitalizations, stratified by age, sex, and race/ethnicity as of November 14, 2020[13]	
Total COVID-19 hospitalizations nationally	The COVID Tracking Project daily national hospitalization count, as of November 18, 2020[22]	The overall attributable fraction of hospitalizations, considering modest potential differences in each age, sex, and race/ethnicity stratum in relative proportions of total hospitalizations and total cardiometabolic risk factors, may be reasonable similar to the 14 COVID-NET states.
		Most (37) US states report the cumulative number of individual COVID-19 hospitalizations, whereas 13 states and Washington, D.C. only report daily hospitalization counts (total number of patients hospitalized with COVID-19 on each day). We used 2 methods to estimate total cumulative hospitalizations in the latter: the ratio of cumulative daily hospitalization counts to the cumulative number of individual COVID-19 hospitalizations in the 37 states reporting both and separate CMS data on COVID-19 hospitalization lengths of stay[23] (see Data S2). These 2 estimates provided broadly similar results, and we used the lower estimate to be more conversative.

CDC indicates Centers for Disease Control and Prevention; CMS, Center for Medicare & Medicaid Services; COVID-19, coronavirus disease 2019; COVID-NET, Coronavirus Disease 2019-Associated Hospitalization Surveillance Network; NHANES, National Health and Nutrition Examination Survey; OR, odds ratio; and RR, relative risk.

Table 2. Demographic and Cardiometabolic Risk Characteristics of the General US Population and the New York City COVID-19 Report

Characteristic	US Adult Population, NHANES 2015 to 2018, N=11 268*	New York City Report†	
		Total Infected Patients, N=5279	Hospitalized Patients, N=2741
Age, y (IQR)	47 (32–61)	54 (38–66)	63 (51–74)
Sex, N (%)			
Female	5837 (51.8%)	3114 (50.5%)	1063 (38.8%)
Male	5431 (48.2%)	2615 (49.5%)	1678 (61.2%)
Race/ethnicity, N (%)			
White	3737 (62.7%)	2003 (37.9%)	1094 (39.9%)
Black	2510 (11.4%)	835 (15.8%)	392 (14.3%)
Hispanic	3039 (15.8%)	1330 (25.2%)	731 (26.7%)
Asian	1476 (5.9%)	383 (7.3%)	187 (6.8%)
Other/multiracial/unknown	506 (4.2%)	728 (13.8%)	337 (12.3%)
Cardiometabolic risk factor characteristics,‡ N (%)			
Diabetes mellitus	2065 (14.2%)	1195 (22.6%)	950 (34.7%)
Obesity: 30–40 kg/m^2	3562 (32.1%)	1554 (29.4%)	899 (32.8%)
Obesity: >40 kg/m^2	1092 (9.3%)	311 (5.9%)	185 (6.7%)
Hypertension	4085 (32.6%)	2256 (42.7%)	1699 (62.0%)
Heart failure	385 (2.4%)	367 (7.0%)	350 (12.8%)
Chronic kidney disease	821 (6.1%)	647 (12.3%)	581 (21.2%)

COVID-19 indicates coronavirus disease 2019; IQR, interquartile range; and NHANES, National Health and Nutrition Examination Survey.

*Best estimate of potential characteristics among all infected adults nationally, especially as several reports suggest that undiagnosed cases may be approximately 10-fold larger than diagnosed cases.[15]

†Based on patients with laboratory-confirmed severe acute respiratory syndrome coronavirus 2 infection from March 1, 2020 to April 8, 2020 at New York University Langone Health in New York City. The cross-sectional analysis of all laboratory-confirmed positive cases assessed predictors of hospitalization and critical illness using multivariable logistic regression.[2]

‡The following definitions were used in NHANES for risk factors: Diabetes mellitus was defined as self-reported physician diagnosis of diabetes mellitus or any of the following 4 criteria: fasting plasma glucose level ≥126 mg/dL, 2-hour plasma glucose level ≥200 mg/dL; hemoglobin A1c level ≥6.5%; or on diabetes mellitus medications (chlorpropamide, diazoxide, glipizide, glyburide, insulin, tolazamide, metformin, acarbose, glimepiride, miglitol, troglitazone, repaglinide, rosiglitazone maleate, pioglitazone, and nateglinide). Obesity was defined based on BMI between 30 and 40 kg/m^2 or >40 kg/m^2. Hypertension was defined as having measured systolic pressure of at least 140 mm Hg or diastolic pressure of at least 90 mm Hg based on the average of up to 4 measurements or taking prescription medication for hypertension. Heart failure was defined based on self-reported physician diagnosis. Chronic kidney disease was defined based on estimated glomerular filtration rate at stage 3 (30–59 mL/min per 1.73 m^2), stage 4 (15–29 mL/min per 1.73 m^2), or stage 5 (<15 mL/min per 1.73 m^2).

for association estimates. Each condition was defined in the NHANES based on a combination of self-reported physician diagnosis, biomarker results, and medication use (see Table 2 and Data S1 for complete definitions). The prevalence of each condition and its uncertainty (standard error) was estimated in 24 population subgroups jointly stratified by age (18–49 years, 50–64 years, ≥65 years), sex (male, female), and race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, Asian/other; Table 3).

Independent Associations Between Cardiometabolic Conditions and COVID-19 Hospitalizations

We identified and used multivariable-adjusted risk estimates that had assessed collinearity and used multivariable logistic regression to account for the correlation and potential confounding or mediating effects of each of the other risk factors based on 5279 patients with a laboratory-confirmed COVID-19 diagnosis at a major health center in New York City (NYC).[2] Collinearity was assessed using the variance inflation factor and ensuring all were <2, followed by testing for overall multicollinearity among all variables simultaneously using the determinant of correlation matrix implemented in R's (https://www.r-project.org/about.html) McTest library (https://cran.r-project.org/web/packages/mctest/mctest.pdf). The model evaluated age, sex, race, ethnicity, tobacco use, hypertension, hyperlipidemia, coronary artery disease, heart failure, chronic obstructive pulmonary disease or asthma, malignancy (excluding nonmelanoma skin cancer), diabetes mellitus, chronic kidney disease, obesity (BMI 30–40 kg/m^2), and severe obesity (BMI >40 kg/m^2).[2] Risks (odds ratios [ORs]) for hospitalization were calculated using multivariable logistic regression, including all factors together in the model. For the present analysis, we evaluated cardiometabolic factors with significant independent

Table 3. Prevalence of COVID-19–Related Cardiometabolic Risk Factors* in the General US Adult Population, Overall and Stratified by Age, Sex, and Race/Ethnicity and Based on NHANES 2015 to 2018

	Diabetes Mellitus	Obesity		Hypertension	Heart Failure	Chronic Kidney Failure	At Least 2 Risk Factors	At Least 3 Risk Factors	At Least 4 Risk Factors	No Risk Factors
		30 to 40 kg/m^2	>40 kg/m^2							
Overall, n=11 268	2065 (14.2)	3562 (32.1)	1092 (9.3)	4085 (32.6)	385 (2.4)	821 (6.1)	3091 (26.9)	1168 (9.1)	285 (2.1)	3341 (39.5)
Age										
18–49 years	393 (6.0)	1680 (29.8)	588 (9.8)	741 (12.6)	36 (0.4)	32 (0.5)	634 (12.3)	140 (2.40)	14 (0.1)	2358 (53.4)
50–64 years	725 (19.6)	993 (34.9)	300 (10.2)	1479 (47.5)	91 (2.5)	144 (4.1)	1047 (35.1)	386 (12.1)	68 (2.2)	680 (29.9)
≥65 y	947 (29.5)	889 (34.9)	204 (6.5)	1865 (67.2)	258 (7.2)	645 (24.0)	1410 (53.3)	642 (22.5)	203 (6.9)	303 (16.7)
Sex										
Male	1080 (15.3)	1654 (33.4)	411(7.3)	2028 (33.2)	228 (2.8)	402 (5.3)	1502 (27.4)	596 (9.5)	153 (2.3)	1636 (39.5)
Female	985 (13.1)	1908 (31.0)	681(11.1)	2057 (32.0)	157 (2.0)	419 (6.8)	1589 (26.4)	572 (8.8)	132 (1.9)	1705 (39.4)
Race/ethnicity										
White	628 (13.7)	1183 (31.9)	372(9.0)	1406 (33.7)	167 (2.5)	424 (7.3)	1109 (27.6)	429 (9.4)	128 (2.4)	1124 (39.4)
Black	475 (15.6)	882 (34.9)	334(13.5)	1150 (41.0)	104 (3.4)	184 (6.1)	816 (33.8)	333 (13.1)	78 (2.8)	558 (31.6)
Hispanic	636 (14.3)	1124 (36.2)	295 (9.6)	945 (23.6)	74 (1.5)	138 (2.7)	806 (21.9)	301 (7.2)	61 (1.2)	866 (40.1)
Asian/other	326 (15.4)	373 (24.1)	91 (5.6)	584 (30.1)	40 (1.9)	75 (3.7)	360 (22.7)	105 (6.1)	17 (0.8)	793 (47.4)

Data are provided as number (percentage). COVID-19 indicates coronavirus disease 2019; and NHANES, National Health and Nutrition Examination Survey.
*See the Table 2 footnote for definitions of each cardiometabolic risk factor.

associations including diabetes mellitus (OR, 2.24; 95% CI, 1.84–2.73), obesity with BMI 30 to 40 kg/m^2 (OR, 1.80; 95% CI, 1.47–2.20), severe obesity with BMI >40 kg/m^2 (OR, 2.45; 95% CI, 1.78–3.36), heart failure (OR, 4.43; 95% CI, 2.59–8.04), and hypertension (OR, 1.78; 95% CI, 1.49–2.12). The multivariable model would adjust for confounding or mediation between the risk factors: thus, the estimated risk for diabetes mellitus would be the estimated risk above and beyond its impact through obesity, hypertension, or heart failure; for obesity, the estimated risk above and beyond its impact through diabetes mellitus, hypertension, or heart failure; and so on. In sensitivity analysis, we evaluated chronic kidney disease (OR, 2.60; 95% CI, 1.89–3.61), which can be attributed to cardiometabolic causes but also other factors (eg, glomerulonephritis, polycystic kidney disease).[16]

These ORs were assumed to approximate relative risks (RRs) in the full study base based on 2 considerations. First, confirmed diagnoses of COVID-19 appear to represent only a fraction (~10%) of total infected cases in the United States.[17–21] Thus, hospitalization represents a reasonably rare event among the full population of infected cases, such that ORs can approximate RRs. Second, we assumed that any asymptomatic or undiagnosed patients who would otherwise have been seen at this NYC health center were of similar or better health than those who came to the center and were diagnosed. Thus, the observed ORs for hospitalization associated with these cardiometabolic conditions could have been even larger if these healthier, undiagnosed patients had also been identified. A comparison of cardiometabolic conditions in the general US adult population versus all diagnosed patients with COVID-19 in the NYC study was consistent with these assumptions, with the exception of obesity, which was somewhat less prevalent in NYC compared with national data (Table 2).

COVID-19 Hospitalizations by Age, Sex, and Race/Ethnicity

COVID-19 hospitalizations stratified by age, sex, and race/ethnicity were obtained from the CDC's Coronavirus Disease 2019–Associated Hospitalization Surveillance Network (COVID-NET) as of November 14, 2020.[13] COVID-NET conducts population-based surveillance for laboratory-confirmed COVID-19–associated hospitalizations in 10 Emerging Infection Program states (California, Colorado, Connecticut, Georgia, Maryland, Minnesota, New Mexico, New York, Oregon, Tennessee) and 4 states in the Influenza Hospitalization Surveillance Project (Iowa, Michigan, Ohio, Utah), representing about 10% of the US population.[13] Data are considered preliminary, updated weekly, and require laboratory confirmation based on clinician-ordered COVID-19 testing. Thus, this data set may underestimate total COVID-19 hospitalizations because of limited testing availability. Although these data are not national, they provide the highest quality age, sex, and race/ethnicity-stratified estimates of COVID-19–associated US hospitalizations.

National hospitalizations from COVID-19 were obtained from the COVID Tracking Project updated as of November 18, 2020.[22] All data compiled and updated daily come from state/district/territory public health authorities or, in the absence of public health authority data, other reporting tools (trusted news sources, directly asking state officials, etc.). Most (37) US states report the cumulative number of individual COVID-19 hospitalizations, whereas 13 states and Washington, D.C. only report daily hospitalization counts (total number of patients hospitalized with COVID-19 on each day). We used 2 methods to estimate total cumulative hospitalizations in the latter: the ratio of cumulative daily hospitalization counts to the cumulative number of individual COVID-19 hospitalizations in the 37 states reporting both and separate Center for Medicare & Medicaid Services data on COVID-19 hospitalization lengths of stay[23] (see Data S2). These 2 estimates provided broadly similar results, and we used the lower estimate to be more conversative.

Comparative Risk Assessment Framework

Data inputs were combined in a comparative risk assessment framework to estimate the proportion and absolute number of COVID-19 hospitalizations attributable to each cardiometabolic condition individually. This framework incorporated each stratum-specific input and its uncertainty, jointly stratified into 24 population subgroups by age (18–49 years, 50–64 years, ≥65 years), sex (male, female), and race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, Asian/other). In each stratum, the distributions of the different metabolic risk factors, including their clustering, were separately assessed. Findings of stratum-specific versus individual-level simulation modeling are similar in these settings.[24] Metabolic risks were modeled as binary exposures using Bernoulli distributions. For each stratum, the model estimated the percentage of COVID-19 hospitalizations attributable to each cardiometabolic condition by comparing the present prevalence of the cardiometabolic condition with the counterfactual case of no cardiometabolic condition (0% prevalence) using the following population-attributable fraction (PAF) formula:[25,26]

$$PAF = \frac{\sum_{i=1}^{n} P_i(RR_i - 1)}{\sum_{i=1}^{n} P_i(RR_i - 1) + 1}$$

where RR_i indicates the RR of COVID-19 hospitalization for the cardiometabolic condition, P_i indicates the

fraction of the population with that cardiometabolic condition, and n is number of exposure categories (binary: present, absent).

The numbers of attributable hospitalizations in each stratum were calculated by multiplying the stratum-specific PAF by the number of hospitalizations in the corresponding COVID-NET population stratum. Cases were summed across strata to determine overall proportions of COVID-NET hospitalizations attributable to each cardiometabolic condition. These proportions were applied to the COVID Tracking Project data on national COVID-19 hospitalizations to estimate the national hospitalizations attributable to each cardiometabolic condition. To determine joint effects of different combinations of cardiometabolic conditions, the stratum-specific PAFs for each risk factor were combined by proportional multiplication as done in other established studies (and which avoids overestimation from crude summing of PAFs).[27,28] For example, the joint PAF for 3 risk factors each with a PAF of 20% would be 1–(0.8*0.8*0.8)=48.8% (rather than 60% from crude summing). The PAF for total obesity (BMI ≥30 kg/m^2) was assessed by jointly modeling obesity (BMI 30–40 kg/m^2) and severe obesity (BMI >40 kg/m^2). To explore the potential effect of a theoretically achievable reduction in prevalence of these cardiometabolic conditions among US adults, we also calculated the proportional and absolute number of cardiometabolic risk-attributable COVID-19 hospitalizations that might be prevented for a 10% reduction in prevalence of each of these cardiometabolic conditions. Analyses were performed using R statistical software, version 3.6.1 (2019-07-05).

Uncertainty and Sensitivity Analyses

Uncertainty was quantified using probabilistic sensitivity analyses, jointly incorporating stratum-specific uncertainties in inputs including the prevalence of each cardiometabolic condition and the association (RR) of each cardiometabolic condition with COVID-19 hospitalization. Corresponding 95% uncertainty intervals (UIs) were derived from the 2.5th and 97.5th percentiles from 1000 Monte Carlo simulation models. In 1-way sensitivity analysis, the proportions and numbers of COVID-19–associated hospitalizations attributable to chronic kidney disease were further estimated.

RESULTS

Cardiometabolic Risk Distribution

The characteristics of the US adult population and NYC patient cohort are shown in Table 2. Compared with all diagnosed patients, hospitalized patients were more likely to be male, older, and have a higher prevalence of cardiometabolic risk factors. Compared with the general US population, the NYC patient cohort was generally older; more likely to be of non-Hispanic Black, Hispanic, Asian, or other race/ethnicity; have higher prevalence of diabetes mellitus, hypertension, heart failure, and chronic kidney disease; and have a lower prevalence of obesity (Table 2).

In evaluating joint distributions of major cardiometabolic risk factors in the United States based on NHANES data (Figure 1), ~2 in 5 obese adults and 1 in 2 adults with hypertension had both conditions; and ~2 in 5 adults with diabetes mellitus also had obesity and hypertension. Among individuals with heart failure, 1.1% also had obesity, 1.2% had diabetes mellitus, and 1.9% had hypertension (with 2.1% having any 1 or more of these conditions). These small joint distributions with heart failure were accounted for when assessing joint attributable risk.

Estimated COVID-19 Hospitalizations Attributable to Cardiometabolic Risks

As of November 18, 2020, a total of 69 669 adult COVID-19 hospitalizations were documented in COVID-NET states, and a total of 906 849 adult COVID-19 hospitalizations were documented nationally. Among individual cardiometabolic conditions, the largest estimated proportion of COVID-19 hospitalizations was attributable to total obesity (BMI ≥30 kg/m^2; 30.2%; 95% UI, 28.2–32.3) followed by hypertension (25.5%; 95% UI, 23.6–27.4) and diabetes mellitus (20.5%; 95% UI, 18.9–22.1; Table 4). Heart failure and chronic kidney disease had smaller estimated attributable proportions at 11.7% (95% UI, 9.5–14.1) and 12.9% (95% UI, 11.0–14.7), respectively.

Considering cardiometabolic conditions jointly, 40.7% (95% UI, 38.7–42.7) of COVID-19 hospitalizations were estimated to be attributable to the combination of diabetes mellitus and hypertension; 44.5% (95% UI, 42.5–46.5) to the combination of diabetes mellitus and total obesity (BMI ≥30 kg/m^2), and 58.7% (95% UI, 56.9–60.4) to the combination of diabetes mellitus, hypertension, and total obesity (BMI ≥30 kg/m^2; Table 4). Adding heart failure, the estimated joint attributable fraction was 63.5% (95% UI, 61.6–65.4).

In terms of numbers of COVID-19 hospitalizations, total obesity (BMI ≥30 kg/m^2) was estimated to account for 274 322 (95% UI, 255 779–293 070) hospitalizations nationally, hypertension accounted for 237 738 (95% UI, 219 952–256 390) hospitalizations, and diabetes mellitus accounted for 185 678 (95% UI, 171 112–200 350) hospitalizations (Table 4). An estimated 575 419 (95% UI, 559 072–593 412) COVID-19 hospitalizations were attributable to all 4 cardiometabolic risk factors jointly, that is, attributable to the

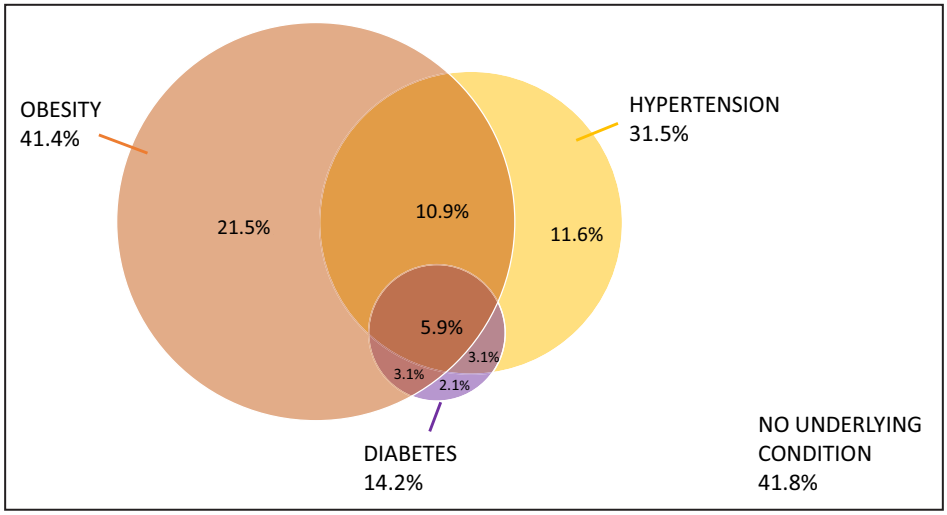

Figure 1. Joint distributions of total obesity, hypertension, and diabetes mellitus in the US adult population, National Health and Nutrition Examination Survey 2015 to 2018.
Heart failure (2.4% prevalence in the adult US population) was omitted for visual clarity (see text and Table 3).

presence of 1 or more of these conditions among US adults.

Findings by Age, Sex, and Race/Ethnicity

The estimated proportion of COVID-19 hospitalizations attributable to several cardiometabolic risk factors increased with age, except for hospitalizations attributable to various categories of obesity (Figures 2–4, Figure S1, Tables S1 and S2). For example, diabetes mellitus was estimated to account for only 7.8% (95% UI, 6.7–9.1) of hospitalizations among adults aged 18 to 49 years versus 28.9% (95% UI, 25.6–32.1) among those aged ≥65 years. These differences were similarly large for heart failure (2.4 versus 20.9%) and hypertension (10.2 versus 34.8%). In contrast, the proportion of COVID-19 hospitalizations attributable to obesity (30–40 kg/m^2) was similar in the youngest and oldest age groups (20.0% versus 21.4%), whereas the proportion attributable to severe obesity was higher in the youngest age groups (13.5% versus 9.3%). Based on these partly offsetting attributable fractions, the proportion of COVID-19 hospitalizations attributable to all 4 cardiometabolic conditions jointly was 44.2% (95% UI, 41.2–47.0) among those aged 18 to 49 years (representing 119.781 [95% UI, 111 745–127 395] national hospitalizations), 64.5% (95% UI, 61.7–67.2) among those aged 50 to 64 years (167 343 [95% UI, 160 016–174 414]), and 73.9% (95% UI, 70.8–76.9) among those aged ≥65 years (278 280 [95% UI, 266 550–289 408]). For all ages, total obesity (BMI ≥30 kg/m^2) was the top cardiometabolic risk factor for COVID-19 hospitalizations, with hypertension the second leading cardiometabolic risk factor.

Differences were modest by sex, with largest differences in attributable risk for severe obesity, estimated to be responsible for 9.2% (95% UI, 7.4–11.0) of COVID-19 hospitalizations in men versus 13.8% (95% UI, 11.5–16.4) in women (Figure 3, Table S1).

At any age group, the proportion of COVID-19 hospitalizations attributable to each cardiometabolic condition was higher in Black compared with White adults (Figure 2–4). The proportion of COVID-19 hospitalizations, by age, attributable to both diabetes mellitus and obesity (30–40 kg/m^2) was nominally higher in Hispanic compared with White adults, except for the attributable risk to obesity among those aged ≥65 years, which appeared more similar in Hispanic versus White adults. Among adults of Asian/other race/ethnicity, the proportion attributable to diabetes mellitus and hypertension was higher, and to total obesity lower, compared with White adults. Considering the 4 cardiometabolic risks jointly, the proportion of attributable COVID-19 hospitalizations was highest in Black adults across all age groups followed by Hispanic, White, and Asian/other adults (Table S2).

COVID-19 Hospitalizations Potentially Preventable by a 10% Reduction in Cardiometabolic Conditions

Considering cardiometabolic conditions individually, a 10% reduction in diabetes mellitus nationally was estimated to potentially prevent 2.7% (95% UI, 2.40–3.0) of COVID-19 hospitalizations (Table 5). A 10% reduction in hypertension was estimated to potentially prevent 3.5% (95% UI, 3.1–4.0) of COVID-19 hospitalizations; a 10% reduction in total obesity was estimated to potentially prevent 3.9% (95% UI, 3.6–4.3) of COVID-19 hospitalizations; and a 10% reduction in heart failure was estimated to potentially prevent 1.4% (95% UI,

Table 4. COVID-19 Hospitalizations Attributable to Cardiometabolic Risk Factors in the COVID-NET States and the Overall US Adult Population

Cardiometabolic Risk Factor	Attributable Percent of Adult COVID-19 Hospitalizations (95% UI)	Attributable Adult Hospitalizations, COVID-NET States* (95% UI)	Attributable Adult Hospitalizations, Nationally† (95% UI)
Total adult hospitalizations		69 669	906 849‡
Risk factors considered individually			
Diabetes mellitus	20.5 (18.9–22.1)	14 262 (13 144–−15 389)	185 678 (171 112–200 350)
Obesity (30–40 kg/m^2)	21.3 (19.3–23.2)	14 817 (13 406–16 144)	192 915 (174 706–210 180)
Severe obesity (>40 kg/m^2)	11.5 (10.1–13.1)	7980 (7011–9098)	103 892 (91 270–118 447)
Hypertension	26.2 (24.3–28.3)	17 740 (16 413–19 105)	237 738 (219 952–256 390)
Heart failure	11.7 (9.5–14.1)	8153 (6589–9829)	106 139 (85 772–127 965)
Chronic kidney disease	12.9 (11–14.7)	8965 (7696–10 267)	116 721 (100 193–133 665)
Risk factors considered jointly§			
Total obesity¶	30.2 (28.2–32.3)	21 071 (19 647–22 511)	274 322 (255 779–293 070)
Diabetes+hypertension	40.7 (38.7–42.7)	28 358 (26 956–29 708)	369 201 (350 938–386 772)
Diabetes+total obesity	44.5 (42.5–46.5)	31 022 (29 623–32 422)	403 880 (385 664–422 100)
Diabetes+hypertension+total obesity	58.7 (56.9–60.4)	40 854 (39 644–42 105)	531 879 (516 129–548 159)
Diabetes+hypertension+total obesity+heart failure	63.5 (61.6–65.4)	44 198 (42 943–45 580)	575 419 (559 072–593 412)

COVID-19 indicates coronavirus disease 2019; COVID-NET, Coronavirus Disease 2019–Associated Hospitalization Surveillance Network; and UI, uncertainty interval.

*The Centers for Disease Control and Prevention's COVID-NET conducts population-based surveillance for laboratory-confirmed COVID-19–associated hospitalizations in 10 Emerging Infection Program states (California, Colorado, Connecticut, Georgia, Maryland, Minnesota, New Mexico, New York, Oregon, Tennessee) and 4 states in the Influenza Hospitalization Surveillance Project (Iowa, Michigan, Ohio, Utah), representing about 10% of the US population. Data are considered preliminary, updated weekly, and require laboratory confirmation based on clinician-ordered COVID-19 testing. These data (latest available as of November 14, 2020) provide the highest quality age-stratified, sex-stratified, and race/ethnicity-stratified estimates of COVID-19–associated hospitalization in the United States and were used as inputs for determining stratum-specific rates.

†In the absence of age, sex, and race-stratified national data on COVID-19 hospitalizations, we sourced total national hospitalization data from the COVID Tracking Project for November 18, 2020. The COVID Tracking Project compiles data (updated on a daily basis) from state/district/territory public health authorities or other reporting tools (trusted news sources, directly asking state officials, etc.) in the absence of public health authority data. Most (37) US states report the cumulative number of individual COVID-19 hospitalizations, whereas 13 states and Washington, D.C. only report daily hospitalization counts (total number of patients hospitalized with COVID-19 on each day). We used 2 methods to estimate total cumulative hospitalizations in the latter: the ratio of cumulative daily hospitalization counts to the cumulative number of individual COVID-19 hospitalizations in the 37 states reporting both and separate Center for Medicare & Medicaid Services data on COVID-19 hospitalization lengths of stay[23] (see Data S2). These 2 estimates provided broadly similar results, and we used the lower estimate to be more conversative. To extrapolate our hospitalization outcome data from COVID-NET states to the entire US population, we calculated the age-stratified, sex-stratified, race/ethnicity-stratified proportions of COVID-NET hospitalizations and applied these calculated proportions to the national adult US hospitalizations. Estimated population attributable fractions and corresponding UIs were then multiplied by the extrapolated number of national hospitalizations in each stratum for each cardiometabolic risk factor to obtain the attributable adult hospitalizations and corresponding 95% CI.

‡As of November 18, 2020, there were 921 896 national COVID-19 hospitalizations. Based on age-stratified hospitalization data from COVID-NET, we estimated 98.4% of national COVID-19 hospitalizations (N=906 849) to be in adults (≥18 years).

§To determine joint associations of different combinations of cardiometabolic conditions, the stratum-specific population attributable fraction for each condition were combined by proportional multiplication, which avoids overestimation for jointly distributed risk factors when crudely summing each stratum-specific population attributable fraction.

¶Total obesity (body mass index ≥30 kg/m^2) is defined as obesity (body mass index 30–40 kg/m^2) and severe obesity (body mass index >40 kg/m^2), modeled jointly.

1.1–1.8) of COVID-19 hospitalizations. Considering all 4 cardiometabolic conditions jointly, a 10% reduction in the prevalence of each was estimated to potentially prevent 11.1% (95% UI, 10.5–11.9) of COVID-19 hospitalizations.

DISCUSSION

Based on nationally representative data on demographics and cardiometabolic conditions, stratified and national data on COVID-19 hospitalizations, and multivariable-adjusted estimates of associations of cardiometabolic conditions with risks of COVID-19 hospitalization, our comparative risk assessment model estimated that nearly 2 in 3 (63.5%) COVID-19 hospitalizations among US adults are attributable to the following 4 cardiometabolic conditions: total obesity (BMI ≥30 kg/m^2), diabetes mellitus, hypertension, and heart failure. Among individual cardiometabolic conditions, the largest proportions of COVID-19 hospitalizations were attributable to total obesity (30.2%) and hypertension (26.2%), and lowest for heart failure (11.7%). Diabetes mellitus, heart failure, hypertension, and chronic kidney disease were estimated contributors to

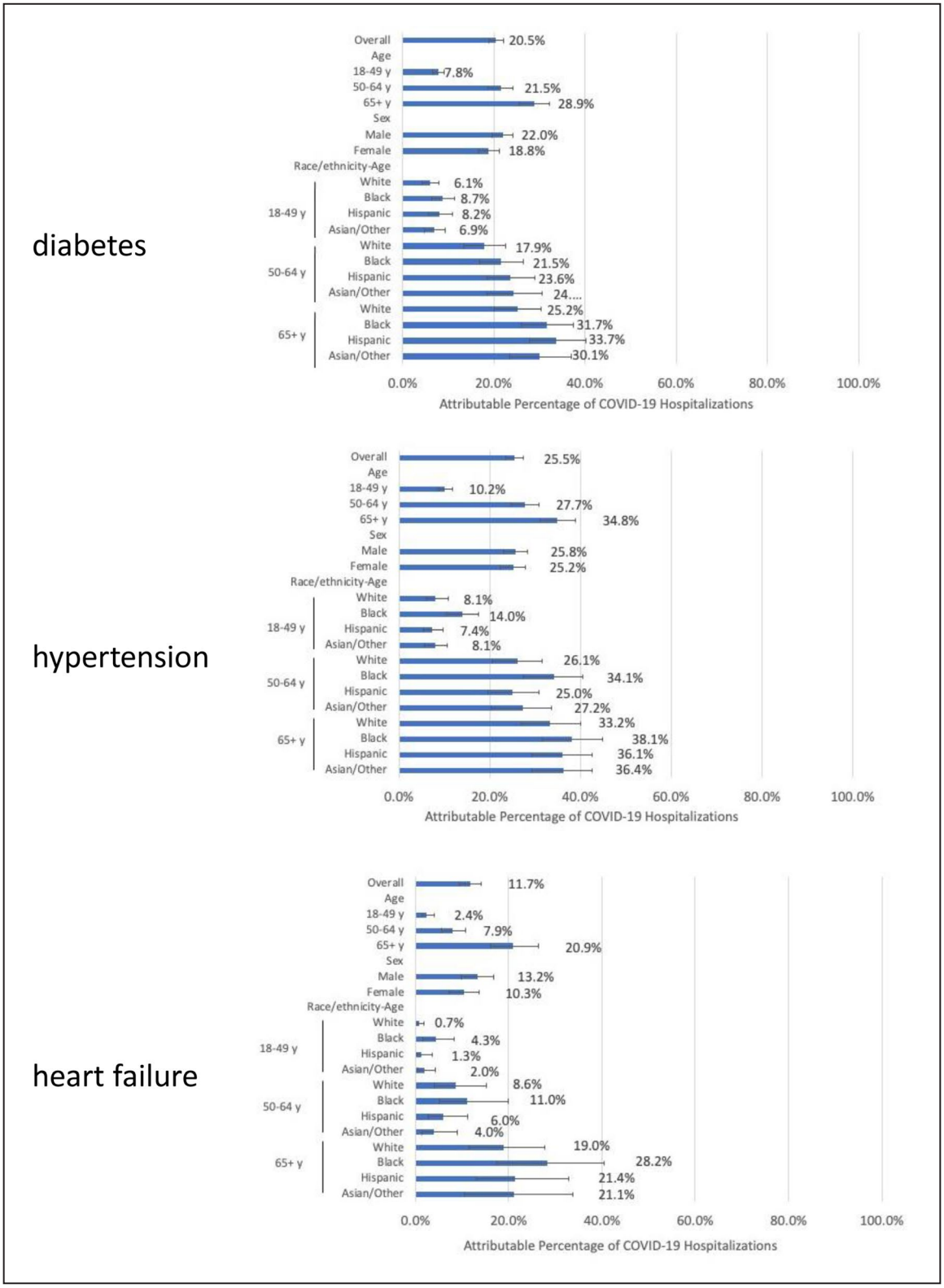

Figure 2. Proportion of COVID-19 hospitalizations among US adults attributable to diabetes mellitus (top panel), hypertension (middle panel), and heart failure (bottom panel), overall and stratified by age, sex, and age–race/ethnicity.
COVID-19 indicates coronavirus disease 2019.

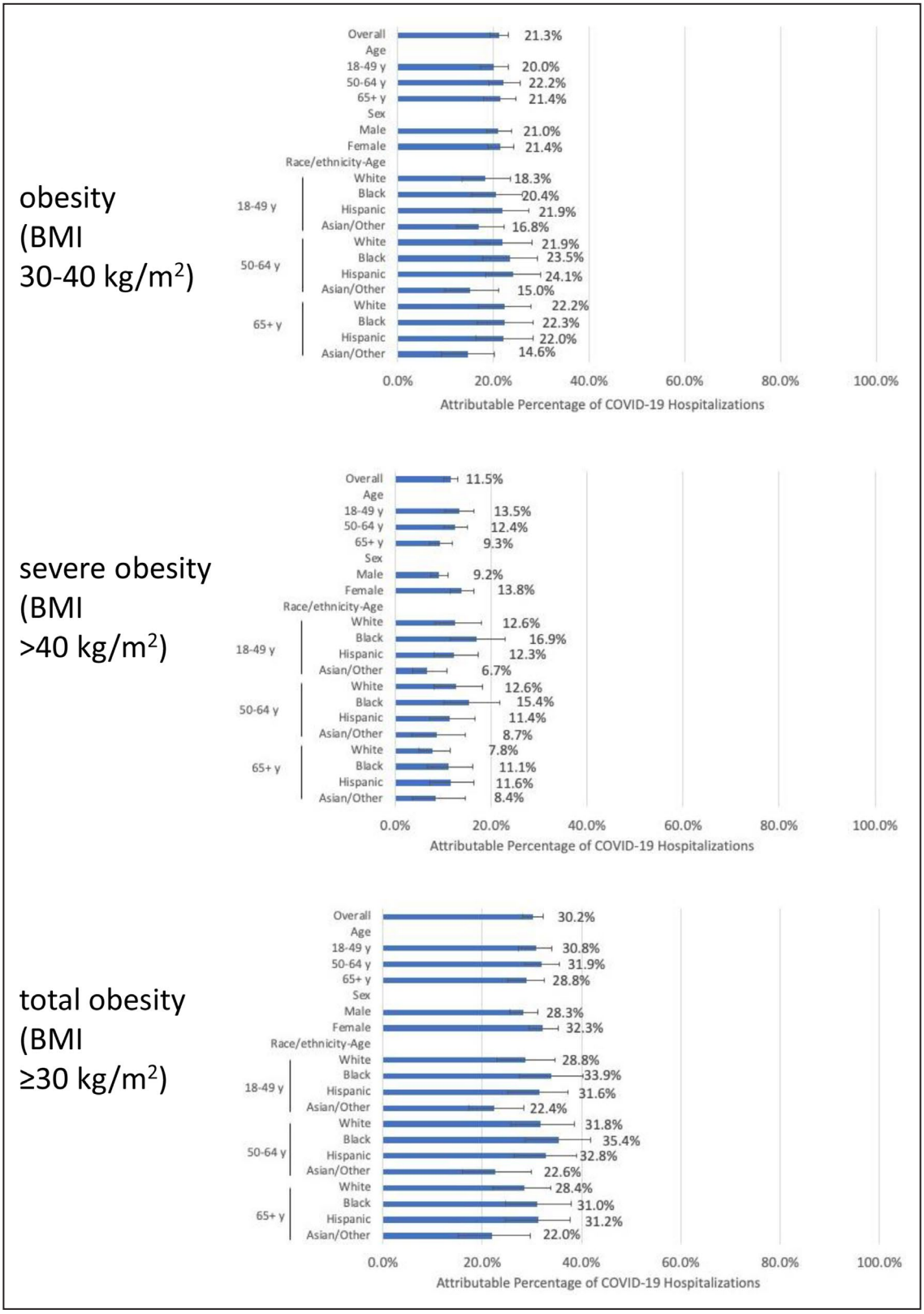

Figure 3. Proportion of COVID-19 hospitalizations among US adults attributable to obesity (BMI 30–40 kg/m²; top panel), severe obesity (BMI >40 kg/m²; middle panel), and total obesity (BMI ≥30 kg/m²; bottom panel), overall and stratified by age, sex, and age–race/ethnicity.
BMI indicates body mass index; and COVID-19, coronavirus disease 2019.

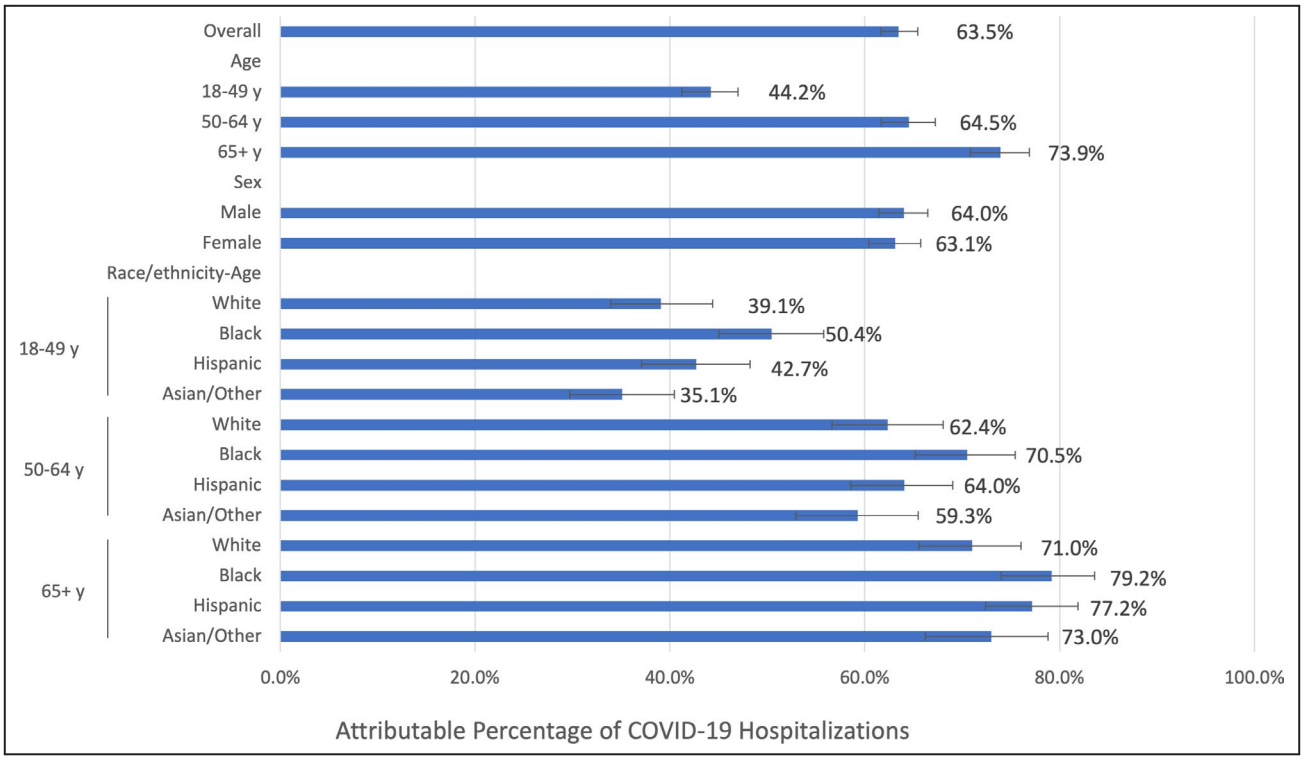

Figure 4. Proportion of COVID-19 hospitalizations among US adults attributable to 4 cardiometabolic risk factors—total obesity (body mass index ≥30 kg/m2), diabetes mellitus, hypertension, and heart failure—jointly, overall, and stratified by age, sex, and age–race/ethnicity.
COVID-19 indicates coronavirus disease 2019.

a much higher proportion of COVID-19 hospitalizations among older adults (aged ≥65 years) compared with younger ages, whereas the proportion attributable to severe obesity (BMI >40 kg/m^2) was similar or higher among younger versus older adults. Disparities were evident by race/ethnicity, with Black adults generally having the highest proportion of COVID-19 hospitalizations attributable to cardiometabolic conditions across all age groups, with the exception of diabetes mellitus for which the proportion of attributable COVID-19 hospitalizations was highest among Hispanics aged 50 to 64 years and ≥65 years. A 10% reduction in these 4 cardiometabolic conditions was estimated to potentially prevent 11.1% of COVID-19 hospitalizations.

Attributable risk estimates are reliant on causality of the association. The consistency of international evidence on relationships between poor cardiometabolic health and severity of COVID-19 infection and the magnitude of these associations are supportive. Studies of clinical characteristics of patients with COVID-19 in Wuhan, China, and Italy first suggested that diabetes mellitus, hypertension, and ischemic heart disease were the most distinctive and/or frequent comorbidities associated with severe infection.[5,29–32] Similarly, a high prevalence of cardiometabolic comorbidities were found among patients hospitalized with COVID-19 in NYC and Washington state.[33,34] Cardiometabolic comorbidities including obesity, chronic cardiac disease, hypertension, diabetes mellitus, and chronic kidney disease have been further identified as strong predictors of COVID-19 hospitalization among infected patients in NYC and of in-hospital mortality in China and the United Kingdom.[2–4] A CDC analysis of the COVID-NET states from March 1, 2020, to March 30, 2020, suggests that 89% of all COVID-19 hospitalizations had at least 1 underlying medical condition, with hypertension (49.7%) the most common comorbidity and a high prevalence of total obesity (BMI ≥30 kg/m^2; 48.3%), diabetes mellitus (28.3%), and cardiovascular disease (27.8%) among COVID-19 hospitalizations.[7]

Biologic plausibility is supported by several lines of evidence. Cardiometabolic diseases, including diabetes mellitus, heart failure, hypertension, and obesity, are associated with diminished innate and adaptive immune responses.[35–38] Obesity reduces baseline pulmonary function and ventilatory reserve,[39] which could predispose to worse COVID-19 outcomes as seen with influenza.[40] Biologic plausibility is further supported by the unusual harms of COVID-19 related to vascular endothelial cells, in the lungs and throughout the body, and excessive proinflammatory responses. Each of the cardiometabolic conditions

Table 5. Estimated COVID-19 Hospitalizations Prevented With a 10% Reduction in RR* for Each Cardiometabolic Condition in the COVID-NET States and the Overall US Adult Population

Cardiometabolic Risk Factor	Attributable Percent of Adult COVID-19 Hospitalizations Prevented (95% UI)	Attributable Adult Hospitalizations Prevented, COVID-NET States† (95% UI)	Attributable Adult Hospitalizations Prevented, Nationally‡ (95% UI)
Total adult hospitalizations		69 669	906 849§
Risk factors considered individually			
Diabetes mellitus	2.7 (2.4–3)	1869 (1677–2077)	24 316 (21 824–27 029)
Obesity (30–40 kg/m^2)	2.7 (2.4–3)	1860 (1646–2075)	24 215 (21 429–27 015)
Severe obesity (>40 kg/m^2)	1.3 (1.1–1.5)	916 (790–1070)	11 911 (10 279–13 919)
Hypertension	3.5 (3.1–4)	2480 (2228–2768)	32 100 (28 524–35 821)
Heart failure	1.4 (1.1–1.8)	1004 (776–1272)	13 055 (10 093–16 550)
Chronic kidney disease	1.7 (1.4–2)	1160 (953–1408)	15 103 (12 404–18 319)
Risk factors considered jointly¶			
Total obesity**	3.9 (3.6–4.3)	2747 (2509–3006)	35 758 (32 655–39 133)
Diabetes mellitus+hypertension	6.1 (5.7–6.6)	4281 (3963–4623)	55 734 (51 595–60 179)
Diabetes mellitus+total obesity	6.5 (6.1–7)	4542 (4242–4870)	59 127 (55 217–63 393)
Diabetes mellitus+hypertension+total obesity	9.8 (9.3–10.4)	6855 (6487–7270)	89 240 (84 444–94 647)
Diabetes+hypertension+total obesity+heart failure	11.1 (10.5–11.9)	7760 (7348–8269)	101 021 (95 653–107 647)

COVID-19 indicates coronavirus disease 2019; COVID-NET, Coronavirus Disease 2019–Associated Hospitalization Surveillance Network; and UI, uncertainty interval.

*To estimate the effect of a 10% reduction in risk among US adults, we calculated the proportionate and absolute number of cardiometabolic condition–attributable COVID-19 hospitalizations that might be prevented for a 10% reduction in prevalence of each of these cardiometabolic conditions in the NHANES population.

†The Centers for Disease Control and Prevention's COVID-NET conducts population-based surveillance for laboratory-confirmed COVID-19–associated hospitalizations in 10 Emerging Infection Program states (California, Colorado, Connecticut, Georgia, Maryland, Minnesota, New Mexico, New York, Oregon, Tennessee) and 4 states in the Influenza Hospitalization Surveillance Project (Iowa, Michigan, Ohio, Utah), representing about 10% of the US population. Data are considered preliminary, updated weekly, and require laboratory confirmation based on clinician-ordered COVID-19 testing. These data (latest available as of November 14, 2020) provide the highest quality age-stratified, sex-stratified, and race/ethnicity-stratified estimates of COVID-19–associated hospitalization in the United States and were used as inputs for determining stratum-specific rates.

‡In the absence of age, sex, and race-stratified national data on COVID-19 hospitalizations, we sourced total national hospitalization data from the COVID Tracking Project for November 18, 2020. The COVID Tracking Project compiles data (updated on a daily basis) from state/district/territory public health authorities or other reporting tools (trusted news sources, directly asking state officials, etc.) in the absence of public health authority data. Most (37) US states report the cumulative number of individual COVID-19 hospitalizations, whereas 13 states and Washington, D.C. only report daily hospitalization counts (total number of patients hospitalized with COVID-19 on each day). We used 2 methods to estimate total cumulative hospitalizations in the latter: the ratio of cumulative daily hospitalization counts to the cumulative number of individual COVID-19 hospitalizations in the 37 states reporting both and separate Center for Medicare & Medicaid Services data on COVID-19 hospitalization lengths of stay[23] (see Data S2). These 2 estimates provided broadly similar results, and we used the lower estimate to be more conversative. To extrapolate our hospitalization outcome data from COVID-NET states to the entire US population, we calculated the age-stratified, sex-stratified, race/ethnicity-stratified proportions of COVID-NET hospitalizations and applied these calculated proportions to the national adult US hospitalizations. Estimated population attributable fractions and corresponding UIs were then multiplied by the extrapolated number of national hospitalizations in each stratum for each cardiometabolic risk factor to obtain the attributable adult hospitalizations and corresponding 95% CI.

§As of November 18, 2020, there were 921 896 national COVID-19 hospitalizations. Based on age-stratified hospitalization data from COVID-NET states, we estimated 98.4% of national COVID-19 hospitalizations (N=906 849) to be in adults aged ≥18 years.

¶To determine joint associations of different combinations of cardiometabolic conditions, the stratum-specific population attributable fractions or each condition were combined by proportional multiplication, which avoids overestimation for jointly distributed risk factors.

**Total obesity (body mass index ≥30 kg/m^2) is defined as obesity (body mass index 30–40 kg/m^2) and severe obesity (body mass index >40 kg/m^2), modeled jointly.

in our analysis share, as a foundation of underlying pathophysiology, endothelial dysfunction and chronic systemic inflammation. COVID-19 avidly infects vascular endothelial cells, and the resulting vasculitis, intravascular microthrombi, inflammatory cascades, and disrupted vascular architecture appear to contribute to 'happy hypoxemia' (greater hypoxemia than expected from patient symptoms or lung imaging) as well as extra-respiratory manifestations including acute kidney injury, stroke, and cardiac, cutaneous, and systemic vasculitis.[41,42] The common thread of chronic systemic inflammation also likely predisposes individuals with cardiometabolic conditions to higher risks of lung injury, cytokine storm, and respiratory failure from COVID-19 infection.[43–46] As confounders, underlying drivers of poor cardiometabolic health may also predispose individuals to insufficient or dysregulated inflammatory responses. Individuals with cardiometabolic risks have generally poorer quality diets,[28,47,48] which could be lower in potentially immune-relevant nutrients such as zinc; selenium; iron; quercetin; epigallocatechin gallate; and vitamins

A, C, D, E, B-6 and folate. Physical inactivity is a driver of both cardiometabolic and immune health, increasing inflammation and illness risk and reducing overall immune regulation.[43,49] Our findings suggest that, in the absence of these cardiometabolic conditions and/or their underlying drivers, such individuals could be still infected but experience significantly less severity of illness requiring hospitalization.

This research further highlights the societal burdens of cardiometabolic diseases.[11,28] The strong links between these conditions and poor outcomes in COVID-19 provide a compelling signal to clinicians and policymakers on additional approaches to improve population resilience for COVID-19 as well as future pandemics. Public health messaging on effective strategies such as social distancing, face masks, and hand washing should additionally consider highlighting the critical risk for Americans with underlying cardiometabolic conditions. As states and communities reopen shuttered economies, prevention campaigns and activities should focus on and target these individuals to minimize the burden of severe infection and hospital case load. The newly authorized COVID-19 vaccines will decrease the number of COVID-19 infections overall. However, rates will be unlikely to drop to zero any time soon, in the United States or globally. Among infected (nonvaccinated) cases, proportions of cases that are severe and require hospitalization will continue to be influenced by preexisting cardiometabolic conditions. Our findings lend further support to the need for prioritizing vaccine distribution to individuals with cardiometabolic conditions, particularly among demographic subpopulations at higher risk such as the elderly, Blacks, and Hispanics.

Our findings highlight the urgent need for trials to understand whether improving cardiometabolic health will reduce hospitalizations, morbidity, and healthcare strains from COVID-19. Controlled trials demonstrate rapid improvements in cardiometabolic health from lifestyle changes. In randomized controlled feeding trials, changes in diet quality alone, without weight loss, led to improvements in just 6 to 8 weeks, including reducing blood pressure by 12 to 16 mm Hg among hypertensives, low-density lipoprotein cholesterol by 12 to 14 mg/dL among hypercholesterolemics, apolipoprotein B by 6% to 10%, and the very-low-density lipoprotein apolipoprotein C-III to apolipoprotein E ratio by 18%; and if changes in diet quality included healthy dietary fats, insulin sensitivity also improved.[50–54] In 1 trial, dietary guidance emphasizing healthful minimally processed foods, without any focus on energy restriction, resulted in an average ~6.0 kg weight loss and 4 cm waist reduction in 12 months, with corresponding improvements in multiple cardiometabolic risk parameters.[55] Increases in physical activity also significantly improve cardiometabolic health in controlled trials, even without weight loss.[56] Given the estimated burdens of COVID-19 hospitalizations attributable to cardiometabolic conditions, our results indicate a need to test whether even modest improvements in cardiometabolic health in individuals and populations, through clinical efforts, public guidance, or other public health actions, could have an impact.

Our model assumes that the prevalence of cardiometabolic conditions from the full, national NHANES population approximates the prevalence of cardiometabolic conditions of the infected US population given the widespread underdiagnosis of COVID-19 infection nationally. If infected (diagnosed and undiagnosed) adults are somewhat less healthy than the full national population (unknown but plausible), cardiometabolic risk prevalence would be underestimated, causing underestimation of attributable risk. If infected adults are somewhat healthier than the full national population, cardiometabolic risk prevalence would be overestimated, causing overestimation of attributable risk. Without nationally representative random testing of US individuals, our analysis cannot distinguish between these possibilities.

Our investigation has several strengths. The modeling design permitted incorporation of best available measures of demographics, cardiometabolic conditions, COVID-19 hospitalizations, and estimated cardiometabolic–hospitalization relationships, including uncertainty in these data. This approach, which estimates COVID-19 hospitalization attributable to cardiometabolic conditions based on independent lines of evidence, differs from an ecologic analysis. The RRs of cardiometabolic risks and COVID-19 hospitalization were derived from the largest multivariable-adjusted US study to date. In addition, this cohort was assembled early in the COVID-19 pandemic (laboratory-confirmed infection between March 1, 2020, and April 8, 2020), when the proposed association between cardiometabolic conditions and COVID-19 severity was preliminary, so that individuals with such underlying conditions would have been unlikely to substantially alter their behaviors to reduce infection risk (and thus potentially bias results). The modeling framework incorporated stratum-specific data by sex, age, and race/ethnicity, allowing us to assess disparities. Uncertainties were incorporated and quantified using probabilistic sensitivity analyses, allowing estimation of the bounds of plausible effects. Use of nationally representative data sets on demographics, cardiometabolic risks, and COVID-19 hospitalizations increases generalizability to the US population.

Potential limitations should be considered. Association does not equal causation, and our modeling approach does not prove that improvements in cardiometabolic health will reduce the risk of COVID-19 hospitalization.

However, the magnitude of our simulated findings support the need for interventional studies to test this possibility. Although the multivariable-adjusted ORs from the NYC study represent the best available evidence on the independent associations between cardiometabolic comorbidities and COVID-19 hospitalization in the United States, their use may bias the findings if confounded by other unmeasured factors (eg, dietary habits, physical activity) that also influence risk of COVID-19 hospitalization or significantly underestimate effects if the (potentially large) number of undiagnosed individuals in the underlying source population were on average healthier than diagnosed individuals. In addition, because all of these risk factors would be expected to have more monotonic, rather than binary, relationships with COVID-19 outcomes, a comparative risk assessment using continuous variables for our metabolic risk factors could likely provide even larger effect estimates. Given limited data to the contrary, our modeling assumed consistent effects of these risk factors across age, sex, and race/ethnicity. Further research is necessary to elucidate potential etiologic differences in subpopulations. Complete national data on COVID-19 hospitalizations by age, sex, and race/ethnicity are not available. Thus, we took advantage of national counts of COVID-19 hospitalizations from the COVID Tracking Project, leveraging the relative proportions by age, sex, and race/ethnicity in the COVID-NET data set only to estimate relative proportions of COVID-19 hospitalization within each national subgroup. Although confirmed COVID-19–positive hospitalizations are likely categorized correctly to a large extent, missed cases may be present, causing underestimation of the total number of attributable cases. We limited our investigation to cardiometabolic conditions with the strongest evidence, which could thereby underestimate the full proportion of COVID-19 hospitalizations attributable to other cardiometabolic conditions, such as coronary heart disease. Further research is required to elucidate the underlying mechanisms of association as well as interventions that might reduce COVID-19 hospitalization among individuals with underlying cardiometabolic conditions.

In summary, our modeling study estimates that a substantial proportion of COVID-19 hospitalizations in the United States may be attributable to cardiometabolic conditions. These results can help inform public health planning and prevention strategies to reduce COVID-19 healthcare burdens in the United States.

ARTICLE INFORMATION

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All authors had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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Supplementary Material

Data S1
Data S2
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SUPPLEMENTAL MATERIAL

Data S1. Definitions of cardiometabolic risk factors

Sourced from NHANES 2015-2016 and 2017-2018 survey cycle

DIABETES: defined as self-reported, physician-diagnosed diabetes or any of the following 4 criteria: fasting plasma glucose (FPG) level ≥ 126 mg/dl, 2-hour plasma glucose (PG) level ≥ 200 mg/dl; Hemoglobin A1c level ≥ 6.5%; or on diabetes medications (chlorpropamide, diazoxide, glipizide, glyburide, insulin, tolazamide, metformin, acarbose, glimepiride, miglitol, troglitazone, repaglinide, rosiglitazone maleate, pioglitazone, and nateglinide).

OBESITY: defined based on BMI >=30 kg/m^2.

HYPERTENSION: defined as having measured systolic pressure of at least 140 mm Hg or diastolic pressure of at least 90 mm Hg based on the average of up to 4 measurements; or taking prescription for hypertension.

HEART FAILURE: defined based on the subject's response to the question: 'Have you ever been told by a physician that you had heart failure?'.

CHRONIC KIDNEY DISEASE: was defined as stage 3-5 based on the estimated glomerular filtration rate (eGFR): Stage 3, eGFR 30-59 ml/min/1.73 m^2; Stage 4, 15-29 ml/min/1.73 m^2; Stage 5, <15 mL/min/1.73 m2).[56]

Data S2. Methodology for calculating U.S. adult COVID-19 hospitalization in the 13 U.S. states and District of Columbia without reported cumulative COVID-19 hospitalizations

From 37 U.S states reporting both the daily COVID-19 hospitalization counts and cumulative number of individual COVID-19 hospitalizations, we summed the total hospital days during the time period of analysis (Mar 18-Nov 18, 2020), and divided this by number of individual COVID-19 hospitalizations during this time period to calculate a mean 10.90 days per hospitalization. Using separate data from the Center for Medicare & Medicaid Services (CMS),[23] which reported proportions of patients with COVID-19 hospitals stays in different categories (<=7 days, 8-10 days, 11-15 days, etc.), median values were used to estimate a mean 9.17 days per hospitalization. We used these two separate estimates of mean hospital stay to convert the cumulative total hospital days in the 13 states and D.C. (n=5,765,619 days) into estimated numbers of individual COVID-19 hospitalizations. Results were reasonably similar (466,632 vs. 392,728 total COVID-19 hospitalizations); we used the lower (more conservative) estimate in our analyses.

Table S1. COVID-19 hospitalizations attributable to cardiometabolic risk factors, in the COVID-NET states and the overall US adult population by age, sex, and race/ethnicity by age.

Characteristic	Cardiometabolic Risk Factor	Attributable percent of adult COVID-19 hospitalizations (95% UI)	Attributable adult hospitalizations, COVID-NET states* (95% UI)	Attributable adult hospitalizations, nationally† (95% CI)
Total national adult hospitalizations (N=906,849)‡				
Age				
18-49 years	Diabetes	7.8 (6.7, 9.1)	1635 (1389, 1891)	21277 (18079, 24605)
50-64 years		21.5 (18.8, 24.2)	4294 (3749, 4824)	55856 (48755, 62741)
65+ years		28.9 (25.6, 32.1)	8334 (7386, 9280)	108598 (96257, 120937)
18-49 years	Obesity (30-40 kg/m^2)	20 (17.3, 23.1)	4169 (3612, 4809)	54234 (47001, 62583)
50-64 years		22.2 (19, 25.5)	4421 (3788, 5080)	57502 (49262, 66070)
65+ years		21.4 (18, 24.8)	6183 (5175, 7156)	80623 (67731, 93263)
18-49 years	Severe Obesity (>40 kg/m^2)	13.5 (10.4, 16.4)	2804 (2175, 3421)	36474 (28307, 44511)
50-64 years		12.4 (10, 15.1)	2467 (1994, 3013)	32086 (25935, 39195)
65+ years		9.3 (7.1, 11.8)	2694 (2060, 3405)	35105 (26844, 44381)
18-49 years	Hypertension	10.2 (8.5, 11.8)	2121 (1771, 2458)	27599 (23040, 31984)
50-64 years		27.7 (24.6, 30.8)	5532 (4915, 6133)	71965 (63918, 79776)
65+ years		34.8 (31.1, 38.9)	10060 (8979, 11238)	131113 (117015, 146465)
18-49 years	Heart Failure	2.4 (1.3, 4.1)	510 (279, 847)	6639 (3623, 11020)
50-64 years		7.9 (5.5, 10.8)	1580 (1103, 2183)	20546 (14345, 28059)
65+ years		20.9 (16.2, 26.3)	6048 (4678, 7597)	78825 (60957, 99019)
18-49 years	Chronic Kidney Disease	0.9 (0.6, 1.3)	191 (125, 274)	2486 (1631, 3564)
50-64 years		6.2 (4.7, 7.9)	1244 (933, 1575)	16184 (12136, 20489)
65+ years		26.1 (21.8, 30.5)	7530 (6293, 8811)	98170 (82005, 114843)
Sex				
Male	Diabetes	22 (19.7, 24.2)	7763 (6949, 8538)	101124 (90517, 111226)
Female		18.8 (16.7, 21.2)	6483 (5750, 7283)	84352 (74816, 94770)
Male	Obesity (30-40 kg/m^2)	21 (18.6, 23.7)	7402 (6553, 8343)	96429 (85442, 108675)
Female		21.4 (18.7, 24.1)	7361 (6446, 8307)	95792 (83872, 108085)
Male	Severe Obesity (>40 kg/m^2)	9.2 (7.4, 11)	3230 (2613, 3889)	42081 (34037, 50659)
Female		13.8 (11.5, 16.4)	4757 (3964, 5636)	61891 (51573, 73345)
Male	Hypertension	25.8 (23.2, 28.4)	9071 (8157, 10005)	118168 (106246, 130331)
Female		25.2 (22.4, 27.8)	8661 (7721, 9561)	112691 (100460, 124401)
Male	Heart Failure	13.2 (9.9, 16.7)	4648 (3497, 5890)	60541 (45550, 76731)
Female		10.3 (7.2, 13.7)	3558 (2494, 4728)	46299 (32440, 61529)

Male	Chronic Kidney Disease	12.3 (10, 15)	4337 (3529, 5267)	56504 (45962, 68620)
Female		13.4 (10.6, 16.1)	4606 (3654, 5534)	59943 (47549, 72013)

Characteristic	**Cardiometabolic risk factor**	**Attributable percent of adult COVID-19 hospitalizations (95% UI)**	**Attributable adult hospitalizations, COVID-NET states* (95% UI)**	**Attributable adult hospitalizations, nationally† (95% CI)**
Race/ethnicity - Age				
18-49 y, White	Diabetes	6.1 (4.3, 8.1)	234 (166, 312)	3050 (2165, 4068)
18-49 y, Black		8.7 (6.4, 11.4)	684 (500, 894)	7250 (5300, 9480)
18-49 y, Hispanic		8.2 (5.7, 10.9)	525 (366, 699)	8394 (5847, 11175)
18-49 y, Asian/Other		6.9 (4.8, 9.4)	187 (130, 256)	2436 (1697, 3338)
50-64 y, White		17.9 (13.4, 22.7)	1095 (819, 1385)	14259 (10658, 18029)
50-64 y, Black		21.5 (17.0, 26.6)	991 (783, 1224)	19102 (15095, 23598)
50-64 y, Hispanic		23.6 (18.5, 28.9)	1611 (1262, 1972)	14164 (11099, 17340)
50-64 y, Asian/Other		24.4 (18.5, 30.7)	589 (448, 740)	7661 (5827, 9635)
65+ y, White		25.2 (20.2, 30.5)	3673 (2946, 4442)	47822 (38360, 57835)
65+ y, Black		31.7 (26.0, 37.6)	1007 (822, 1193)	33606 (27601, 39827)
65+ y, Hispanic		33.7 (27.8, 40.3)	2748 (2267, 3278)	13955 (11513, 16648)
65+ y, Asian/Other		30.1 (23.6, 36.9)	896 (703, 1099)	11665 (9151, 14310)
18-49 y, White	Obesity (30-40 kg/m^2)	18.3 (13.4, 23.5)	705 (517, 905)	9183 (6729, 11786)
18-49 y, Black		20.4 (15.5, 26.0)	1604 (1217, 2039)	17005 (12903, 21616)
18-49 y, Hispanic		21.9 (15.9, 27.3)	1399 (1017, 1746)	22352 (16252, 27913)
18-49 y, Asian/Other		16.8 (12.4, 22.3)	459 (338, 608)	5985 (4401, 7914)
50-64 y, White		21.9 (16.0, 28.0)	1337 (979, 1710)	17410 (12744, 22262)
50-64 y, Black		23.5 (17.6, 29.2)	1084 (811, 1345)	20898 (15637, 25937)
50-64 y, Hispanic		24.1 (18.4, 29.8)	1645 (1256, 2033)	14466 (11042, 17880)
50-64 y, Asian/Other		15.0 (9.9, 21.2)	362 (240, 511)	4714 (3120, 6649)
65+ y, White		22.2 (16.7, 27.8)	3238 (2434, 4054)	42167 (31718, 52789)
65+ y, Black		22.3 (16.6, 28.2)	709 (529, 897)	23651 (17653, 29949)
65+ y, Hispanic		22.0 (16.4, 28.2)	1794 (1336, 2298)	9114 (6787, 11670)
65+ y, Asian/Other		14.6 (9.1, 20.3)	435 (272, 603)	5669 (3539, 7849)
18-49 y, White	Severe Obesity (>40 kg/m^2)	12.6 (8.4, 17.9)	484 (322, 691)	6305 (4194, 9002)
18-49 y, Black		16.9 (11.5, 23)	1331 (906, 1804)	14103 (9607, 19124)
18-49 y, Hispanic		12.3 (8, 17.3)	788 (512, 1105)	12593 (8181, 17666)
18-49 y, Asian/Other		6.7 (3.6, 10.8)	182 (99, 294)	2365 (1288, 3833)
50-64 y, White		12.6 (8.2, 18.1)	770 (500, 1104)	10029 (6504, 14377)
50-64 y, Black		15.4 (10.1, 21.8)	708 (466, 1004)	13653 (8990, 19359)

50-64 y, Hispanic		11.4 (7.2, 16.5)	776 (489, 1126)	6822 (4303, 9906)
50-64 y, Asian/Other		8.7 (3.5, 14.6)	209 (84, 353)	2725 (1089, 4593)
65+ y, White		7.8 (4.9, 11.5)	1131 (716, 1676)	14727 (9328, 21830)
65+ y, Black		11.1 (6.8, 16.2)	353 (215, 515)	11777 (7183, 17198)
65+ y, Hispanic		11.6 (7.3, 16.4)	947 (592, 1335)	4816 (3008, 6779)
65+ y, Asian/Other		8.4 (3.5, 14.6)	249 (105, 435)	3237 (1373, 5661)
Characteristic	**Cardiometabolic risk factor**	**Attributable percent of adult COVID-19 hospitalizations (95% UI)**	**Attributable adult hospitalizations, COVID-NET states* (95% UI)**	**Attributable adult hospitalizations, nationally† (95% CI)**
18-49 y, White	Hypertension	8.1 (6.0, 10.9)	312 (230, 418)	4062 (2996, 5446)
18-49 y, Black		14.0 (10.4, 17.6)	1099 (820, 1385)	11657 (8690, 14688)
18-49 y, Hispanic		7.4 (5.3, 9.8)	475 (341, 627)	7596 (5452, 10024)
18-49 y, Asian/Other		8.1 (5.6, 10.8)	220 (153, 294)	2871 (1987, 3824)
50-64 y, White		26.1 (20.6, 31.5)	1595 (1260, 1920)	20759 (16397, 25001)
50-64 y, Black		34.1 (27.5, 40.6)	1572 (1268, 1870)	30313 (24434, 36044)
50-64 y, Hispanic		25.0 (19.7, 30.9)	1707 (1345, 2108)	15010 (11823, 18538)
50-64 y, Asian/Other		27.2 (20.2, 33.6)	657 (487, 810)	8557 (6343, 10549)
65+ y, White		33.2 (26.9, 40.0)	4846 (3918, 5837)	63092 (51017, 76000)
65+ y, Black		38.1 (31.4, 44.8)	1212 (999, 1423)	40440 (33343, 47500)
65+ y, Hispanic		36.1 (29.3, 42.5)	2941 (2389, 3462)	14936 (12137, 17585)
65+ y, Asian/Other		36.4 (29.2, 42.6)	1082 (870, 1266)	14084 (11323, 16486)
18-49 y, White	Heart Failure	0.7 (0.1, 1.7)	26 (5, 66)	342 (69, 854)
18-49 y, Black		4.3 (1.6, 8.2)	335 (125, 648)	3556 (1325, 6867)
18-49 y, Hispanic		1.3 (0.1, 3.5)	84 (8, 225)	1347 (126, 3604)
18-49 y, Asian/Other		2.0 (0.4, 4.3)	54 (12, 116)	702 (157, 1511)
50-64 y, White		8.6 (4.1, 15.1)	528 (250, 923)	6868 (3253, 12017)
50-64 y, Black		11.0 (5.1, 19.8)	509 (234, 916)	9803 (4519, 17610)
50-64 y, Hispanic		6.0 (2.6, 11.2)	408 (176, 765)	3591 (1549, 6733)
50-64 y, Asian/Other		4.0 (1.3, 8.9)	97 (30, 214)	1258 (397, 2787)
65+ y, White		19 (11.4, 27.7)	2767 (1656, 4034)	36073 (21564, 52532)
65+ y, Black		28.2 (17.4, 40.4)	896 (552, 1283)	29911 (18430, 42831)
65+ y, Hispanic		21.4 (13.0, 32.8)	1743 (1058, 2667)	8851 (5372, 13548)
65+ y, Asian/Other		21.1 (10.6, 33.7)	627 (315, 1003)	8168 (4095, 13068)
18-49 y, White	Chronic Kidney Disease	0.6 (0.2, 1.3)	24 (7, 51)	315 (88, 660)
18-49 y, Black		1.3 (0.6, 2.2)	103 (51, 176)	1097 (539, 1862)
18-49 y, Hispanic		0.7 (0.4, 1.2)	47 (24, 78)	749 (384, 1252)
18-49 y, Asian/Other		0.4 (0.0, 1.1)	12 (0, 30)	155 (0, 386)
50-64 y, White		6.2 (3.7, 9.6)	377 (225, 587)	4913 (2925, 7649)
50-64 y, Black		9.3 (5.5, 14.5)	430 (254, 670)	8295 (4898, 12917)

50-64 y, Hispanic	4.3 (2.3, 6.9)	292 (157, 471)	2571 (1384, 4143)
50-64 y, Asian/Other	5.1 (1.9, 9.2)	122 (45, 222)	1593 (588, 2897)
65+ y, White	28 (20.4, 35.3)	4076 (2978, 5149)	53073 (38772, 67049)
65+ y, Black	30.2 (22.0, 38.9)	959 (698, 1234)	32010 (23303, 41193)
65+ y, Hispanic	22.3 (15.9, 29.8)	1819 (1291, 2424)	9241 (6559, 12315)
65+ y, Asian/Other	21.8 (14.6, 30.0)	647 (433, 893)	8434 (5643, 11633)

COVID-19, coronavirus disease 2019; COVID-NET, Coronavirus Disease 2019-Associated Hospitalization Surveillance Network; UI, uncertainty interval

*The CDC's *Coronavirus Disease 2019 (COVID-19)-Associated Hospitalization Surveillance Network* (COVID-NET) conducts population-based surveillance for laboratory confirmed COVID-19 associated hospitalizations in ten Emerging Infection Program states (CA, CO, CT, GA, MD, MN, NM, NY, OR, TN) and 4 states in the Influenza Hospitalization Surveillance Project (IA, MI, OH, UT), representing about 10% of the U.S. population. Data are considered preliminary, updated weekly, and requires laboratory confirmation based on clinician-ordered COVID-19 testing. While these data are limited, they provide the highest quality available stratified (age, sex, and race/ethnicity) estimates of COVID-19-associated hospitalization in the U.S. and were used as inputs for this comparative risk assessment model. COVID-NET's stratified adult hospitalization counts as of November 14, 2020 were used in these analyses.
† In the absence of age, sex, and race-stratified national data on COVID-19 hospitalizations, we sourced total national hospitalization data from The COVID Tracking Project for November 18, 2020. The COVID Tracking Project compiles data (updated on a daily basis) from state/district/territory public health authorities or other reporting tools (trusted news sources, directly asking state officials, etc.) in the absence of public health authority data. Most (37) U.S states report the cumulative number of individual COVID-19 hospitalizations, while 13 states and D.C. only report daily hospitalization counts (total number of patients hospitalized with COVID-19 on each day). We used two methods to estimate total cumulative hospitalizations in the latter: the ratio of cumulative daily hospitalization counts to the cumulative number of individual COVID-19 hospitalizations in the 37 states reporting both; and separate Center for Medicare & Medicaid Services (CMS) data on COVID-19 hospitalization lengths of stay[23] (see **Data S2**). These two estimates provided broadly similar results, and we used the lower estimate to be more conversative. To extrapolate our hospitalization outcome data from COVID-NET states to the entire U.S. population, we calculated the age-, sex-, race/ethnicity-stratified proportions of COVID-NET hospitalizations and applied these calculated proportions to the national adult U.S hospitalizations. Estimated Population Attributable Fractions (PAFs) and corresponding UIs were then multiplied by the extrapolated number of national hospitalizations in each stratum for each cardiometabolic risk factor to obtain the attributable adult hospitalizations and corresponding 95% CI.
‡ As of November 18, 2020 there were 921,896 national COVID-19 hospitalizations. Based on age-stratified hospitalization data from COVID-NET states, we expect 98.4% of all COVID-19 hospitalizations nationally to be in adults 18 years and older. As such, we estimate there were 906,849 adult COVID-19 hospitalizations and use this as a total in our analyses.

Table S2. COVID-19 hospitalizations attributable to all four major cardiometabolic conditions (total obesity, diabetes, hypertension and heart failure) jointly, in the COVID-NET states and the overall US adult population by age, sex, and race/ethnicity by age.

Characteristic	Attributable percent of adult COVID-19 hospitalizations (95% UI)	Attributable adult hospitalizations, COVID-NET states* (95% UI)	Attributable adult hospitalizations, nationally† (95% CI)
Age			
18-49 years	44.2 (41.2, 4.07)	9205 (8588, 9790)	119781 (111746, 127396)
50-64 years	64.5 (61.7, 67.2)	12866 (12303, 13410)	167343 (160017, 174415)
65+ years	73.9 (70.8, 76.9)	21352 (20452, 22206)	278280 (266550, 289408)
Sex			
Male	64.0 (61.5, 66.5)	22548 (21648, 23412)	293716 (281995, 304971)
Female	63.1 (60.4, 65.7)	21735 (20804, 22633)	282817 (270697, 294497)
Race/ethnicity - Age			
18-49 y, White	39.1 (33.9, 44.4)	1507 (1308, 1711)	19614 (17026, 22275)
18-49 y, Black	50.4 (45.0, 55.8)	3962 (3536, 4382)	41993 (37484, 46452)
18-49 y, Hispanic	42.7 (37.1, 48.2)	2733 (2371, 3087)	43685 (37895, 49337)
18-49 y, Asian/Other	35.1 (29.7, 40.4)	957 (812, 1103)	12467 (10570, 14368)
50-64 y, White	62.4 (56.7, 68.0)	3805 (3457, 4152)	49538 (45006, 54058)
50-64 y, Black	70.5 (65.2, 75.4)	3248 (3003, 3474)	62617 (57887, 66969)
50-64 y, Hispanic	64.0 (58.5, 69.0)	4368 (3993, 4708)	38408 (35112, 41401)
50-64 y, Asian/Other	59.3 (52.9, 65.5)	1430 (1277, 1580)	18616 (16629, 20565)
65+ y, White	71.0 (65.6, 76.0)	10355 (9559, 11089)	134828 (124467, 144395)
65+ y, Black	79.2 (74.0, 83.6)	2516 (2351, 2656)	83969 (78463, 88636)
65+ y, Hispanic	77.2 (72.4, 81.9)	6284 (5898, 6668)	31917 (29955, 33865)
65+ y, Asian/Other	73.0 (66.2, 78.8)	2171 (1970, 2344)	28265 (25647, 30517)

COVID-19, coronavirus disease 2019; COVID-NET, Coronavirus Disease 2019-Associated Hospitalization Surveillance Network; UI, uncertainty interval

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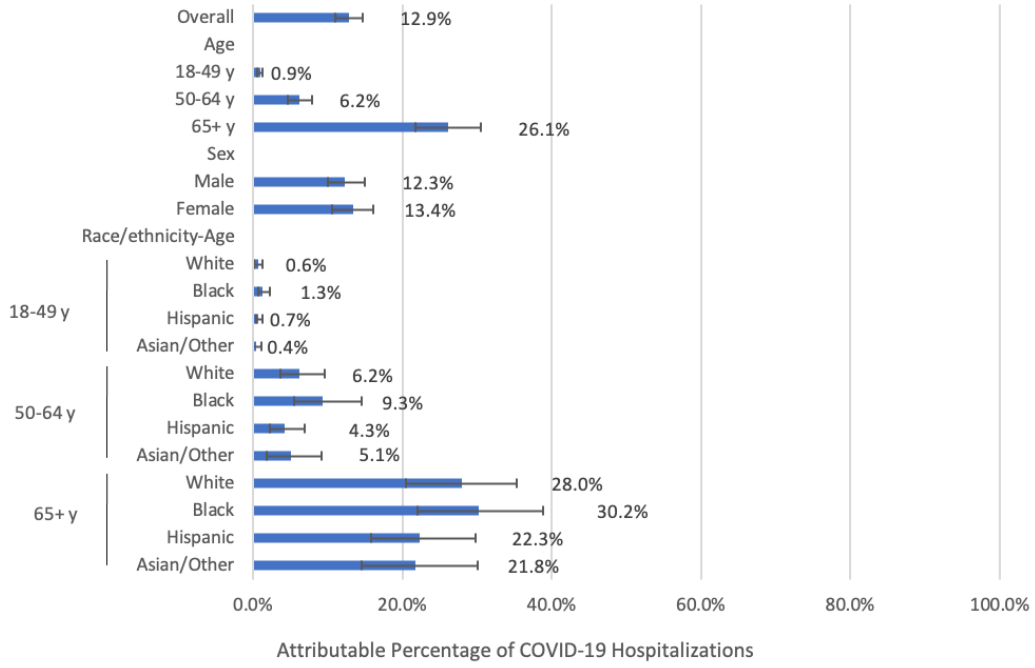
state/district/territory public health authorities or other reporting tools (trusted news sources, directly asking state officials, etc.) in the absence of public health authority data. Most (37) U.S states report the cumulative number of individual COVID-19 hospitalizations, while 13 states and D.C. only report daily hospitalization counts (total number of patients hospitalized with COVID-19 on each day). We used two methods to estimate total cumulative hospitalizations in the latter: the ratio of cumulative daily hospitalization counts to the cumulative number of individual COVID-19 hospitalizations in the 37 states reporting both; and separate Center for Medicare & Medicaid Services (CMS) data on COVID-19 hospitalization lengths of stay[23] (see **Data S2**). These two estimates provided broadly similar results, and we used the lower estimate to be more conversative. To extrapolate our hospitalization outcome data from COVID-NET states to the entire U.S. population, we calculated the age-, sex-, race/ethnicity-stratified proportions of COVID-NET hospitalizations and applied these calculated proportions to the national adult U.S hospitalizations. Estimated Population Attributable Fractions (PAFs) and corresponding UIs were then multiplied by the extrapolated number of national hospitalizations in each stratum for each cardiometabolic risk factor to obtain the attributable adult hospitalizations and corresponding 95% CI.

‡ As of November 18, 2020 there were 921,896 national COVID-19 hospitalizations. Based on age-stratified hospitalization data from COVID-NET states, we expect 98.4% of all COVID-19 hospitalizations nationally to be in adults 18 years and older. As such, we estimate there were 906,849 adult COVID-19 hospitalizations and use this as a total in our analyses.

Figure S1. Proportion of COVID-19 hospitalizations among U.S. adults attributable to chronic kidney disease overall and stratified by age, sex, and race/ethnicity by age.

Chronic Kidney Disease



COVID-19, Coronavirus Disease-2019