Is COVID-19 another case of the obesity paradox? Results from an international ecological study on behalf of the REPROGRAM Consortium Obesity study group

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Abstract

Introduction: Obesity has emerged as one of the major risk factors of severe morbidity and cause-specific mortality among severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) infected individuals. Patients with obesity also have overlapping cardiovascular diseases and diabetes, which make them increasingly vulnerable. This novel ecological study examines the impact of obesity and/or body mass index (BMI) on rates of population-adjusted cases and deaths due to coronavirus disease 2019 (COVID-19).

Material and methods: Publicly available datasets were used to obtain relevant data on COVID-19, obesity and ecological variables. Group-wise comparisons and multivariate logistic regression analyses were performed. The receiver operating characteristic curve (ROC) was plotted to compute the area under the curve.

Results: We found that male BMI is an independent predictor of cause-specific (COVID-19) mortality, and not of the caseload per million population. Countries with obesity rates of 20–30% had a significantly higher (approximately double) number of deaths per million population to both those in < 20% and > 30% slabs. We postulate that there may be a U-shaped paradoxical relationship between obesity and COVID-19 with the cause-specific mortality burden more pronounced in the countries with 20–30% obesity rates. These findings are novel along with the methodological approach of doing ecological analyses on country-wide data from publicly available sources.
Introduction

The ongoing coronavirus diseases 2019 (COVID-19) pandemic, caused by the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) viral infection, is a global health crisis of a scale reminiscent of the Spanish flu pandemic almost a century ago [1]. Studies have shown that elderly patients and those with pre-existing comorbidities such as cardiovascular disease, hypertension, obesity and diabetes are at increased risk of COVID-19 associated hospitalization, critical illness and mortality [2–7]. Several studies have demonstrated that obesity is associated with an increased risk of COVID-19 associated hospitalization and/or critical illness [4, 6, 8–17]. A recent meta-analysis found a strong association between obesity and adverse outcomes in COVID-19 patients [18], indicating the role of higher body mass index (BMI) in prognostication [19, 20]. A study from a French hospital on 124 intensive care patients found an association between the need for invasive mechanical ventilation and severe obesity [16]. Another recent study on 393 cases from New York found higher rates of obesity in patients receiving mechanical ventilation [9]. It was also found that obese individuals younger than 50 are more likely to die due to COVID-19 than those who are not obese [21].

Studies have also demonstrated the association of visceral adiposity with COVID-19 severity or critical illness [22–24]. Obesity, and especially diabetes, might also be predictors of long-COVID complications, including myocarditis, arrhythmias, thromboembolism, and heart failure, as indicated in the preliminary results of the Late-COVID study [5, 25]. The impact of obesity on population demography during COVID-19 and their link to reported COVID-19 case and death rates have not been reported so far.

The current study aims to assess the association between the gender stratified average BMI, life expectancy and gross domestic product (GDP) per capita with the population-adjusted COVID-19 case rate and death rate.

Material and methods

Data sources

We used data from the Worldometer, a real-time tracking website (www.worldinfometers.info), to extract data on country-wise COVID-19 confirmed cases including population-adjusted cases and mortality rates (data accessed on 29th June 2020). Our World in Data was used to acquire data on GDP per capita, life expectancy data, average male – and female – BMI, and nationwide obesity rates. The data on Our World in Data is sourced from the official government websites or social media accounts. Based on the unanimous expert decision, only countries with a minimum of 15,000 total COVID-19 cases, as of 29th June 2020, were included in our analysis [26]. This was done to ensure that a minimum sample size within each country was reached to improve the reliability of the results and minimize any crowding due to a disproportionate number of countries with relatively lower case counts. All data procured and analyzed were sourced from publicly available databases and are available in Supplementary Table SI.

Statistical analysis

All statistical analyses were performed using STATA software (Version 11, 2001; College Station, TX, USA). The data used in this study are publicly available. The curated dataset used in this study is provided in the Supplementary Table SI. COVID-19 confirmed cases and deaths per million population (total number of COVID-19 associated deaths divided by each respective region’s population) and 95% confidence intervals (CIs) were calculated. Groupwise comparison was performed using STATA version 13 to demonstrate the distribution of baseline characteristics between countries based on the nationwide obesity rates (subgroups: < 20% vs. 20–30% vs. ≥ 30%) and between average BMI subgroups of < 25 kg/m^2 vs. ≥ 25 kg/m^2 for males and females. Subsequently, univariate and multivariate logistic regression analyses were performed to determine the association between average male and female BMI, life expectancy and GDP per capita with the population-adjusted COVID-19 case rates (for cases: ≥ 3000, ≥ 4000, ≥ 5000 per 1 million population) and death rates (for deaths: ≥ 100, ≥ 150 and ≥ 200 per 1 million population). The thresholds for various groups of caseloads per million were used based on the closest approximation of median cases/million for the 20–30% nationwide obesity rate group. This translates to 3000 cases per million. Given that

Conclusions: We anticipate, in light of our findings, that appropriate targeted public health approaches or campaigns could be developed to minimize the risk and cause-specific morbidity burden due to COVID-19 in countries with nationwide obesity rates of 20–30%.

Key words: coronavirus 2019 (COVID-19), obesity, metabolic disease, non-communicable diseases (NCDs), demographics.
the majority of countries belong to the 20–30% obese group (n = 33), the threshold was chosen to reflect the overall spread. We also selected the caseloads of 4000 and 5000 to investigate any putative linear relationship. For deaths per million population, we chose the mortality threshold based on the nearest median for the 20–30% obesity rate group – which translated to 100 deaths per million. We also chose two more points, 150 and 200, to investigate linear trends in mortality. The receiver operating characteristic curve (ROC) for the final multivariate regression model (obtained by backwards regression with variables \( p < 0.1 \)) was plotted and the area under the curve computed to evaluate the predictive ability of the regression model.

**Results**

A correlation matrix of the investigated variables is shown in Figure 1. Male BMI shows a strong correlation with the female BMI (0.6274; \( p \leq 0.0001 \)), obesity rate (0.72; \( p < 0.00001 \)), GDP per capita (0.486; \( p = 0.0001 \)), and life expectancy (0.49; \( p = 0.0001 \)). Though weaker, male BMI was also significantly correlated with the total number of COVID-19 associated deaths per million (\( R^2 = 0.3261; p = 0.0125 \)) and the total number of cases per million (0.3757; \( p = 0.0037 \)). Female BMI was not correlated with deaths per million (–0.0276; \( p = 0.8370 \)), whereas the correlation of female BMI with the total number of cases per million was significant (0.3191; \( p = 0.0146 \)). There was a strong correlation of female BMI with nationwide obesity rate (0.8405; \( p \leq 0.000001 \)). Female BMI was not correlated with GDP per capita (0.1756; \( p = 0.1874 \)) or life expectancy (–0.0492; \( p = 0.7136 \)).

Group-wise comparison of various metrics stratified by countries with obesity rates of < 20%, 20–30% and > 30% are shown in Table I. The highest caseload is demonstrated in the > 30% group. The highest mortality was demonstrated in the 20–30% group, while it was the least pronounced in the > 30% group. GDP per capita in the > 30% obesity rate group is more than twice as high as the GDP per capita in the 20–30% group. There is a statistically significant difference in the median population-adjusted COVID-19 cases, COVID-19 deaths, average male BMI, average female BMI, GDP per capita and prevalence of obesity between at least two of the three groups. From the data, although countries with a higher prevalence of obesity have more COVID-19 cases, the mortality is bell-shaped with the greatest mortality being in the 20-30% obesity rate group. A paired \( t \)-test revealed a statistically significant difference
between average male and female BMIs in these countries overall \((p = 0.0130)\) (Table II).

### Population-adjusted case rate univariate and multivariate logistic regression

The univariate associations with population-adjusted COVID-19 cases per 1 million population were examined for average male BMI, average female BMI, life expectancy, GDP per capita, and nationwide obesity rate. COVID-19 cases per 1 million population were further stratified into \(\geq 3000\) per million, \(\geq 4000\) per million, and \(\geq 5000\) per million.

In population-adjusted case rate univariate logistic regression, all variables except average female BMI were significantly associated with each of the COVID-19 cases per 1 million population group (Table III). Average male BMI, GDP per capita, life expectancy, and nationwide obesity rate were included in the multivariate logistic regression model; however, no variable was a significant predictor in the multivariate model. The analyzed variables provided a poor predictive model for COVID-19 cases per 1 million population (area under the ROC curve for each stratum: 0.7867, 0.7614, and 0.7547, respectively) (Table IV).

### Population-adjusted mortality rate univariate and multivariate logistic regression

The univariate associations with population-adjusted COVID-19 deaths per 1 million population were examined for average male BMI, average female BMI, life expectancy, GDP per capita, and nationwide obesity rate. COVID-19 deaths per 1 million population were stratified into \(\geq 100\) per 1 million, \(\geq 150\) per 1 million, and \(\geq 200\) per 1 million (Table V). Only average male BMI and life expectancy were found to be statistically significant in the univariate regression analysis for each of the COVID-19 deaths per 1 million population group. Average male BMI and life expectancy were thus included in the multivariate logistic regression model. While not found to be statistically significant in the univariate logistic regression analysis, we included GDP per capita in the mult-
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Table II. Description of ecological variables stratified by average body mass index

| Variable                  | Data         | Overall (n = 58) | Average male BMI < 25 kg/m² (n = 13) | Average male BMI > 25 kg/m² (n = 45) | Kruskal-Wallis test (p-value) | Average female BMI < 25 kg/m² (n = 16) | Average female BMI > 25 kg/m² (n = 42) | Kruskal-Wallis test (p-value) |
|---------------------------|--------------|------------------|--------------------------------------|--------------------------------------|-----------------------------|---------------------------------------|--------------------------------------|-----------------------------|
| Cases per 1 million population | Mean (SD)    | 4173.76 (5144.65) | 2144.46 (4356.67) | 4760 (5248.11) | 0.0001* | 2798 (4002.44) | 4697.86 (5469.49) | 0.0105* |
|                           | Median (IQR) | 2676 (1129–5289) | 539 (197–935) | 3132 (1960–6328) |                       | 886 (260.5–1384) | 2909.5 (1682–6329) |                       |
| Deaths per 1 million population | Mean (SD)    | 147.76 (189.71)  | 13.77 (12.70) | 186.47 (199.35) | 0.0001* | 89.63 (121.80) | 154.26 (181.53) | 0.0202* |
|                           | Median (IQR) | 60.5 (27–226)    | 11 (4–19) | 87 (41–271) |                       | 44.5 (35.5–71) | 74.5 (39–226) |                       |
| GDP per capita ($)        | Mean (SD)    | 27319.67 (23884.66) | 16047.62 (19587.76) | 30576.04 (24207.48) | 0.0026* | 25458.06 (21674.73) | 28028.86 (24886.92) | 0.4236 |
|                           | Median (IQR) | 18848.50 (10536–39733) | 7223 (5250–12320) | 23064 (13976–42969) |                       | 21938 (5642–39265.50) | 18848.50 (11949–39733) |                       |
| Life Expectancy (years)   | Mean (SD)    | 76.22 (5.86)     | 71.59 (8.10) | 77.55 (4.29) | 0.0088* | 75.60 (8.68) | 76.45 (4.47) | 0.7542 |
|                           | Median (IQR) | 76.71 (72.59–81.33) | 71.72 (67.27–76.91) | 77.29 (75.05–81.54) |                       | 77.10 (70.49–83.54) | 76.672 (74.302–80.181) |                       |
| Nationwide obesity rate (%) | Mean (SD)    | 21.59 (7.73)    | 9.63 (8.04) | 25.05 (5.16) | 0.0001* | 12.19 (8.63) | 25.17 (5.58) | 0.0001* |
|                           | Median (IQR) | 22.2 (19.9–27.8) | 6.4 (5.5–8.9) | 23.1 (20.8–28.3) |                       | 7.75 (5.8–20) | 23.6 (21–28.3) |                       |

OR – odds ratio, BMI – body mass index, GDP – gross domestic product.

Table III. Univariate logistic regression for association with population-adjusted case rate

| Variable                  | Cases ≥ 3000 per 1 million population | Cases ≥ 4000 per 1 million population | Cases ≥ 5000 per 1 million population |
|---------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
|                           | OR (95% CI)                           | OR (95% CI)                           | OR (95% CI)                           |
| Average male BMI          | 1.76 (1.17–2.63)                      | 1.72 (1.14–2.60)                      | 1.63 (1.06–2.50)                      |
|                           | 0.006*                                | 0.010*                                | 0.026*                                |
| Average female BMI        | 1.18 (0.92–1.51)                      | 1.25 (0.96–1.62)                      | 1.21 (0.92–1.58)                      |
|                           | 0.187                                 | 0.092                                 | 0.177                                 |
| GDP per capita ($)        | 1.00 (1.00–1.00)                      | 1.00 (1.00–1.00)                      | 1.00 (1.00–1.00)                      |
|                           | 0.001*                                | 0.003*                                | 0.143                                 |
| Life expectancy           | 1.20 (1.05–1.36)                      | 1.14 (1.01–1.29)                      | 1.15 (1.01–1.32)                      |
|                           | 0.006*                                | 0.029*                                | 0.033*                                |
| Nationwide obesity rate (%) | 1.09 (1.01–1.17)                     | 1.10 (1.02–1.20)                     | 1.10 (1.01–1.20)                     |
|                           | 0.023*                                | 0.015*                                | 0.029*                                |

OR – odds ratio, BMI – body mass index, GDP – gross domestic product.
A multivariate logistic regression model as a socially important variable (Table VI). In the multivariate analysis, average male BMI (odds ratio (OR) 1.99, 95% CI: 1.02–3.88, \( p = 0.043 \); OR = 2.67, 95% CI: 1.16–6.15, \( p = 0.021 \); and OR = 2.60, 95% CI: 1.14–5.91, \( p = 0.022 \)) and life expectancy (OR = 1.62, 95% CI: 1.21–2.15, \( p = 0.001 \); OR = 1.85, 95% CI: 1.28–2.67, \( p = 0.001 \); and OR = 1.71, 95% CI: 1.23–2.36, \( p = 0.001 \)) were found to have significant associations in each of the stratified groups.

The model showed that GDP per capita was significantly associated with COVID-19 deaths but only in the deaths ≥ 100 per 1 million group. Importantly, the model demonstrated an excellent predictive ability (area under ROC curve ROC 0.8788, 0.9168, and 0.9033 across the analyzed group; Table VI). The model showed the best predictive ability in the deaths ≥ 150 per 1 million strata (sensitivity 70.6%; specificity 87.9%; positive predictive value 70.6%; negative predictive value 87.8%; correctly classified 82.76%). The final model consisting of average male BMI, life expectancy and GDP per capita predicted population-adjusted COVID-19 death rates globally (using a threshold of 150 deaths per million population) (Figure 2).

**Discussion**

The current study might have major public health implications with novel findings regarding the associations between COVID-19 and obesity.

### Table IV. Multivariate logistic regression for association with case load per million population

| Variable          | Cases ≥ 3000 per 1 million population | Cases ≥ 4000 per 1 million population | Cases ≥ 5000 per 1 million population |
|-------------------|--------------------------------------|--------------------------------------|--------------------------------------|
|                   | OR P-value                            | OR P-value                            | OR P-value                            |
| Average male BMI  | 1.41 (0.90–2.22) 0.137                | 1.42 (0.91–2.23) 0.127                | 1.31 (0.82–2.08) 0.261                |
| Life expectancy   | 1.04 (0.87–1.24) 0.650                | 0.99 (0.84–1.17) 0.888                | 1.04 (0.87–1.23) 0.689                |
| GDP per capita    | 1.00 (1.00–1.00) 0.129                | 1.00 (1.00–1.00) 0.199                | 1.00 (1.00–1.00) 0.164                |

ROC of the multivariate regression model 0.7867** 0.7614** 0.7547**

**n = 58 countries. Average male BMI, life expectancy and GDP per capita provide a poor predictive model for cases per 1 million population (each variable is non-significant in multivariate analysis). OR – odds ratio, BMI – body mass index, GDP – gross domestic product, ROC – receiver operating characteristic curve.

### Table V. Univariate logistic regression for association with population-adjusted cause-specific death rates due to COVID-19

| Variable          | Cause-specific deaths ≥ 100 per 1 million population | Cause-specific deaths ≥ 150 per 1 million population | Cause-specific deaths ≥ 200 per 1 million population |
|-------------------|----------------------------------------------------|----------------------------------------------------|----------------------------------------------------|
|                   | OR P-value                                         | OR P-value                                         | OR P-value                                         |
| Average male BMI  | 1.56 (1.07–2.27) 0.02*                            | 1.67 (1.08–2.60) 0.022*                            | 1.72 (1.08–2.74) 0.021*                            |
| Average female BMI| 1.01 (0.79–1.29) 0.922                             | 0.96 (0.74–1.24) 0.762                             | 0.99 (0.76–1.28) 0.888                             |
| GDP per capita    | 1.00 (1.00–1.00) 0.317                             | 1.00 (1.00–1.00) 0.147                             | 1.00 (1.00–1.00) 0.143                             |
| Life expectancy   | 1.33 (1.13–1.56) 0.001*                            | 1.44 (1.17–1.76) 0.0001*                           | 1.40 (1.15–1.70) 0.001*                            |
| Nationwide obesity rate | 1.04 (0.98–1.11) 0.208 | 1.00 (1.00–1.00) 0.325 | 1.00 (1.00–1.00) 0.315 |

OR – odds ratio, BMI – body mass index, GDP – gross domestic product.

### Table VI. Multivariate logistic regression for association with population-adjusted mortality rates due to COVID-19

| Variable          | Cause-specific deaths ≥ 100 per 1 million population | Cause-specific deaths ≥ 150 per 1 million population | Cause-specific deaths ≥ 200 per 1 million population |
|-------------------|----------------------------------------------------|----------------------------------------------------|----------------------------------------------------|
|                   | OR P-value                                         | OR P-value                                         | OR P-value                                         |
| Average male BMI  | 1.99 (1.02–3.88) 0.043*                            | 2.67 (1.16–6.15) 0.021*                            | 2.60 (1.14–5.91) 0.022*                            |
| Life expectancy   | 1.62 (1.21–2.15) 0.001*                            | 1.85 (1.28–2.67) 0.001*                            | 1.71 (1.23–2.36) 0.001*                            |
| GDP per capita    | 0.9999369 (0.99878–0.999995) 0.033*                 | 0.9999379 (0.9998717–0.9999995) 0.066               | 0.9999495 (0.9998923–0.9999997) 0.083               |
| ROC of the multivariate regression model | 0.8788** | 0.9168** | 0.9033** |

**n = 58 countries. OR – odds ratio, BMI – body mass index, GDP – gross domestic product, ROC – receiver operating characteristic curve.
This builds on our previous work where we provided recommendations based on Intensive Care National Audit and Research Centre (ICNARC) United Kingdom (UK) data on COVID-19 critical care patients – that the BMI ≥ 30 was a significant predictor of mortality in this population [2], hence raising the need for targeted algorithm and risk-based management/ triage approach [2, 27–29]. We found that male BMI and life expectancy were independent predictors of COVID-19 mortality and not the COVID-19 confirmed cases per million population.

Countries with a nationwide obesity rate of 20–30% (e.g., Brazil, Russia, the UK, Iran, Spain) [30] had a significantly higher (approximately double) number of deaths per million population compared to those in < 20% and > 30% obesity rate slabs. We postulate that there may be a U-shaped paradoxical relationship between obesity and COVID-19 mortality burden more pronounced in the countries with 20–30% obesity rates. Our findings are relevant especially in the light of the recently released Public Health England (PHE) report on excess weight and COVID-19 [31]. The increased prevalence and disease burden due to excess weight in general, and obesity in particular, is a public health concern globally, with the burden being higher in western countries [32]. The PHE report highlights that the people belonging to Black, Asian and Minority Ethnic (BAME) communities, those living in deprived areas, and those aged 55–74 years are disproportionately affected by excess weight [31]. Moreover, it is well known that the health risks related to excess weight are more prevalent in BAME communities, even at a lower BMI than in those from Caucasian backgrounds. Given the disproportionate impact of COVID-19 on vulnerable communities [33], such as racial/ethnic minority groups, which are particularly vulnerable to increased prevalence and incidence of obesity and diabetes [34], targeted multilevel interventions against obesity may provide protection [35], and hence mitigate the impact of COVID-19.

Notably, the obesity paradox, i.e. the association of higher BMI with lower mortality, longer hospital stays and longer ventilation period, in ICU patients requiring mechanical ventilation, has also been a subject of debate [36, 37]. However, the hypothesis has been challenged [38]. The protective role of obesity, as proposed in this hypothesis, in reduced mortality may be due to lack of adjustment for comorbidities or potential confounders including a history of smoking, disease severity and socioeconomic variables [38]. Moreover, it has been suggested that BMI does not account for body composition, adiposity, and their variations due to gender and ethnicity [39]. It also fails to detect “normal obese subjects” [38]. Last, but not least, since severe infections in general and more specifically COVID-19 represent catabolic and high energy-consuming situations, obese patients may have a more favorable prognosis due to their augmented metabolic reserve [40]. This hypothesis holds also true in heart failure (HF) as the well-known catabolic state in which it seems that patients who are obese have better clinical outcomes compared to their leaner counterparts [40, 41]. Our findings are distinct, as it takes a population or systems-level approach to address the impact of COVID-19 on obese patients. We have included ecological variables such as GDP which are often not considered or adjusted for in clinical trials or case-controlled studies.

We hypothesized that countries with a nationwide obesity rate of > 30% may have better-developed health systems delivering a higher quality of care including tailored treatment options and/or have well-coordinated health services targeted toward obese people embedded within the system. One of the obesity programs’ strategies may have been strongly advising obese people to adhere to physical distancing and wearing masks whenever distancing of 6 feet cannot be ensured [31]. Better treatments and/or well-organized support programs for obese people are likely associated with higher GDP per capita as well. The values of GDP per capita are indeed much higher for countries with a nationwide obesity rate >30%: twice as high GDP per capita in countries with obesity rates of 20–30% (mean $52,818 (SD 42259.32); median $50,244.50 (IQR 16380–69041)) vs. mean $26,145.12 (SD14353.04); median $23,064 (IQR 16380–69041)) vs. GDP per capita in the > 30% stratum are countries with high GDP per capita, i.e., the US, Saudi Arabia, the UAE, Kuwait, and Qatar, presenting 62.5% of the population of the group. While GDP per capita in the > 30% obesity rate group is even higher compared to the < 20% group ($17,600.47 (SD 20265.77); median: $10,511
The COVID-19 pandemic is causing an unprecedented public health crisis impacting healthcare systems, healthcare workers and communities. The COVID-19 Pandemic Health System REsilience PROGRAM (REPROGRAM) is a not-for-profit consortium of international healthcare physicians, researchers and policymakers formed to champion the safety of healthcare workers, policy development and advocacy for global pandemic preparedness and action.

Acknowledgments

We would like to acknowledge the REPROGRAM consortium members who have worked tirelessly over the last days in contributing to various guidelines, recommendations, policy briefs, and ongoing discussions during these unprecedented and challenging times despite the incredibly short timeframe. We would like to dedicate this work to our healthcare workers who have died due to COVID-19 while serving the patients at the frontline and to those who continue to serve during these challenging times despite the lack of personal protective equipment.

Conflict of interest

The authors declare no conflict of interest.

References

1. Jones DS. History in a crisis – lessons for Covid-19. N Engl J Med 2020; 382: 1681-3.
2. Bhaskar S, Rastogi A, Chattu VK, et al. Key strategies for clinical management and improvement of healthcare services for cardiovascular disease and diabetes patients in the coronavirus (COVID-19) settings: recommendations from the REPROGRAM consortium. Front Cardiovasc Med 2020; 7: 112.
3. Zhou F, Yu T, Du R, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet 2020; 395: 1054-62.
4. Cai Q, Chen F, Wang T, et al. Obesity and COVID-19 severity in a designated hospital in Shenzhen, China. Diabetes Care 2020; 43: 1392-8.
5. Katsiki N, Banach M, Mikhailidis DP. Lipid-lowering therapy and renin-angiotensin-aldosterone system inhibitors in the era of the COVID-19 pandemic. Arch Med Sci 2020; 16: 485-9.
6. Monteiro AC, Suri R, Emeruwa IO, et al. Obesity and smoking as risk factors for invasive mechanical ventilation in COVID-19: a retrospective, observational cohort study. PLoS One 2020; 15: e0238552.
7. Azzolina D, Cesari M. Obesity and COVID-19. Front Endocrinol 2020; 11: 581356.
8. Caussy C, Pattou F, Wallet F, et al. Prevalence of obesity among adult inpatients with COVID-19 in France. Lancet Diabetes Endocrinol 2020; 8: 562-4.
9. Goyal P, Choi J, Pinheiro LC, et al. Clinical characteristics of Covid-19 in New York City. N Engl J Med 2020; 382: 2372-4.
10. Hamer M, Kivimäki M, Gale CR, Batty GD. Lifestyle risk factors, inflammatory mechanisms, and COVID-19 hospitalization: a community-based cohort study of 387,109 adults in UK. Brain Behav Immun 2020; 87: 184-7.
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11. Klang E, Kassim G, Soffer S, Freeman R, Levin MA, Reich DL. Morbid obesity as an independent risk factor for COVID-19 mortality in hospitalized patients younger than 50. Obesity 2020; 28: 1595-9.

12. Lighter J, Phillips M, Hochman S, et al. Obesity in patients younger than 60 years is a risk factor for COVID-19 hospital admission. Clin Infect Dis 2020; 71: 896-7.

13. Petrelli CM, Jones SA, Yang J, et al. Factors associated with hospital admission and critical illness among 5279 people with coronavirus disease 2019 in New York City: prospective cohort study. BMI 2020; 369: m1966-m.

14. Richardson S, Hirsch JS, Narasimhan M, et al. Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York City Area. JAMA 2020; 323: 2052-9.

15. Rottoli M, Bernante B, Belvedere A, et al. How important is obesity as a risk factor for respiratory failure, intensive care admission and death in hospitalised COVID-19 patients? Results from a single Italian centre. Eur J Endocrinol 2020; 183: 389-97.

16. Simonnet A, Chetboun M, Poissy J, et al. High prevalence of obesity in severe acute respiratory syndrome Coronavirus-2 (SARS-CoV-2) requiring invasive mechanical ventilation. Obesity 2020; 28: 1195-9.

17. Yang V, Ding L, Zou X, et al. Visceral adiposity and high intramuscular fat deposition independently predict critical illness in patients with SARS-CoV-2. Obesity 2020; 28: 2040-8.

18. Malik R, Patel U, Patel K, et al. Obesity a predictor of outcomes of COVID-19 hospitalized patients – a systematic review and meta-analysis. J Med Virol 2020; 93: 1188-93.

19. Tamara A, Tahapary DL. Obesity as a predictor for a poor prognosis of COVID-19: a systematic review. Diabetes Metab Syndr 2020; 14: 655-9.

20. Al Heialy S, Kassim G, Soffer S, Freeman R, Levin MA, Reich DL. Morbid obesity as an independent risk factor for COVID-19 mortality in hospitalized patients younger than 50. Obesity 2020; 28: 1595-9.

21. Yang V, Ding L, Zou X, et al. Visceral adiposity and high intramuscular fat deposition independently predict critical illness in patients with SARS-CoV-2. Obesity 2020; 28: 2040-8.

22. Battistí S, Pedone C, Napoli N, et al. Computed tomography highlighted increased visceral adiposity associated with critical illness in COVID-19. Diabetes Care 2020; 43: e129-30.

23. Petersen A, Bressem K, Albrecht J, et al. The role of visceral adiposity in the severity of COVID-19: highlights from a unicenter cross-sectional pilot study in Germany. Metabolism 2020; 110: 154317.

24. Lewek J, Jatczak-Pawlik I, Maciejewski M, Jankowski P Banach M. COVID-19 and cardiovascular complications – the preliminary results of the LATE-COVID study. Arch Med Sci 2021; 17: 818-22.

25. COVID-19 Models, Scenarios and Thresholds Canada: https://www.albertahealthservices.ca/assets/info/ppih/if-ppih- covid-19-sag-models-scenarios-and-thresholds-rapid-review.pdf

26. COVID-19 Models, Scenarios and Thresholds Canada: https://www.albertahealthservices.ca/assets/info/ppih/if-ppih cov-19-sag-models-scenarios-and-thresholds-rapid-review.pdf

27. Bhaskar S, Bradley S, Israeli-Korn S, et al. Chronic neurology in COVID-19 era: clinical considerations and recommendations from the REPROGRAM Consortium. Front Neurol 2020; 11: 664.

28. Bhaskar S, Sharma D, Walker AH, et al. Acute neurological care in the COVID-19 era: the Pandemic Health System Resilience PROGRAM (REPROGRAM) Consortium Pathway. Front Neurol 2020; 11: 579.

29. Bhaskar S, Sinha A, Banach M, et al. Cytokine storm in COVID-19 – immunopathological mechanisms, clinical considerations, and therapeutic approaches: the REPROGRAM Consortium Position Paper. Front Immunol 2020; 11: 1648.

30. Abarca-Gómez L, Abdeen ZA, Hamid ZA, et al. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. Lancet 2017; 390: 2627-42.

31. PHE. Excess weight and COVID-19: insights from new evidence. Public Health England, London 2020.

32. Collaboration NCDF. Rising rural body-mass index is the main driver of the global obesity epidemic in adults. Nature 2019; 569: 260-4.

33. Bhaskar S, Rastogi A, Menon KV, Kunheri B, Balakrishnan S, Howick J. Call for action to address obesity and justice divide during COVID-19. Front Psychiatry 2020; 11: 55905.

34. Candilis P. Obesity and diabetes in vulnerable populations: reflection on proximal and distal causes. Ann Fam Med 2007; 5: 547-56.

35. Stevens J, Pratt C, Boyington J, et al. Multilevel interventions targeting obesity: research recommendations for vulnerable populations. Am J Prev Med 2017; 52: 115-24.

36. Zhao Y, Li Z, Yang T, Wang M, Xi X. Is body mass index associated with outcomes of mechanically ventilated adult patients in intensive critical units? A systematic review and meta-analysis. PLoS One 2018; 13: e0198669.

37. Mukhopadhayay A, Kowitlawakul Y, Henry J, Ong V, Leong CS, Tai BC. Higher BMI is associated with reduced mortality but longer hospital stays following ICU discharge in critically ill Asian patients. Clin Nutr ESPEN 2018; 28: 165-70.

38. Donini LM, Pinto A, Giusti AM, Lenzi A, Poggiogalle E. Obesity or BMI paradox? Beneath the tip of the iceberg. JAMA 2020; 323: 2052-9.

39. Candilis P. Obesity and diabetes in vulnerable populations: reflection on proximal and distal causes. Ann Fam Med 2007; 5: 547-56.
45. Bhaskar S, Nurtazina A, Mittoo S, Banach M, Weissert R. Editorial: telemedicine during and beyond COVID-19. Front Public Health 2021; 9: 662617.
46. Batsis JA, Mackenzie TA, Bartels SJ, Sahakyan KR, Somers VK, Lopez-Jimenez F. Diagnostic accuracy of body mass index to identify obesity in older adults: NHANES 1999-2004. Int J Obes 2016; 40: 761-7.
47. Nuttall FQ. Body mass index: obesity, BMI, and health: a critical review. Nutr Today 2015; 50: 117-28.