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**The association between excess weight and COVID-19 outcomes: an umbrella review**

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REVIEW

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# The association between excess weight and COVID-19 outcomes: An umbrella review

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**Summary**

This umbrella review assessed the association between excess weight and COVID-19 outcomes. MEDLINE, PsycINFO, and CINAHL were systematically searched for reviews that assessed the association between excess weight and COVID-19 outcomes. A second-order meta-analysis was conducted on the available data for intensive care unit admission, invasive mechanical ventilation administration, disease severity, hospitalization, and mortality. The quality of included reviews was assessed using the AMSTAR-2 appraisal tool. In total, 52 systematic reviews were included, 49 of which included meta-analyses. The risk of severe outcomes (OR = 1.86; 95% CI: 1.70 to 2.05), intensive care unit admission (OR = 1.58; 95% CI: 1.45 to 1.72), invasive mechanical ventilation administration (OR = 1.70; 95% CI: 1.57 to 1.83), hospitalization (OR = 1.82; 95% CI: 1.61 to 2.05), and mortality (OR = 1.35; 95% CI: 1.24 to 1.48) following COVID-19 infection was significantly higher in individuals living with excess weight compared with those with a healthy weight. There was limited evidence available in the included reviews regarding the influence of moderating factors such as ethnicity, and the majority of included reviews were of poor quality. Obesity appears to represent an important modifiable pre-infection risk factor for severe COVID-19 outcomes, including death.

KEYWORDS
association, COVID-19, mortality, obesity, overweight

## 1 | INTRODUCTION

In England in 2019, 27% of men and 29% of women were living with obesity, which represents a significant increase in prevalence from 13% of men and 16% of women in 1993.[1] Excess weight increases the risk of other serious diseases and reduces life expectancy,[2] placing a substantial strain on the health services. Indeed obesity and obesity-related illnesses are estimated to cost the UK National Health Service £6.1 billion per annum,[1] with over 1 million hospital admissions between April 2019 and December 2020 linked to obesity.[3] Coronary heart disease,[4] multiple cancers,[5] stroke,[6] type 2 diabetes,[7] and many more non-communicable diseases[8] are more likely to develop in those living with obesity, compared with those living with a healthy weight. Excess weight is also a strong risk factor for multimorbidity.[9] There is a growing evidence base that obesity has strong associations with the communicable Coronavirus disease 2019

(COVID-19),[10–12] with increased risk of infection, hospitalization, severity, and mortality.[13]

COVID-19, also known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), is an infectious disease caused by a novel coronavirus, first identified in Wuhan city, China.[14,15] The COVID-19 pandemic has caused catastrophic global disruption, involving serious morbidity and mortality.[16] Although most COVID-19 cases were asymptomatic or resulted in mild disease, a substantial proportion progressed to critical illness with respiratory failure requiring hospitalization, intensive care unit (ICU) admission, and invasive mechanical ventilation (IMV).[17] Early epidemiological evidence in the United States that showed common comorbidities for COVID-19 were hypertension (56.6%), obesity (41.7%), and diabetes (33.8%). Indeed, obesity has been found to be a risk factor for initial COVID-19 infection,[18] with people living with excess weight found to be more likely to test positive than those of a healthy weight. Additionally, people living with obesity have been found to be at a potentially higher risk of admission to an ICU than their healthy weight counterparts, with disease severity increasing with BMI.[12]

The UK is experiencing a dual epidemic of COVID-19 and obesity, which appear to interact with each other to produce severe outcomes in many groups of patients.[13] Inequalities have been observed in adults and children living with obesity, with those residing in the most deprived areas and those who identify themselves as from Black-African, Caribbean, and South Asian ethnic groups, more likely to be living with excess weight.[1] Similar trends have been identified between socioeconomic status/ethnicity and COVID-19 prevalence and outcomes,[19] with those of lower socioeconomic status and certain ethnic groups such as Black and South Asian communities being more likely to be infected and encounter a poor disease outcome.[20–22] In the UK, obesity has been found to be associated with increased risk of ICU admission, IMV administration, and in-hospital mortality in multiple ethnic groups of patients admitted to hospital with COVID-19, with the strongest associations observed for Black ethnicities.[23]

Given the vast number of reviews rapidly published, there is a need to understand the impact of excess weight on COVID-19 outcomes when looking at the entire body of available evidence and to appraise the strength of currently available reviews. The purpose of the present review was to conduct an umbrella review that investigated the association between excess body weight and the disease course of COVID-19, and whether any associations were influenced by moderating factors such as ethnicity, socioeconomic status, age, sex, or the presence of comorbidities.

## 2 | METHODS

This umbrella review was conducted in accordance with PRISMA guidelines[24] and the recommendations of Cochrane overviews of reviews.[25] This umbrella review was also prospectively registered in the international prospective register of systematic reviews (PROSPERO) under the registration number: CRD42021233235.

### 2.1 | Search strategy

Electronic bibliographic databases MEDLINE, PsycINFO, and CINAHL were searched via EBSCO*host*, and no language or date restrictions were applied. The prospectively registered search strategy utilized Medical Subject Headings (MeSH), Boolean operators, and was run through to May 11, 2022 (see Supporting Information). Search results were exported to EndNote, where automated and manual deduplication was performed. Reference lists of eligible reviews were also screened for any further eligible reviews.

### 2.2 | Article selection

Two researchers (JM & AG) independently assessed the title and abstracts of eligible studies, with disagreements resolved by a third reviewer (LE). Articles were deemed eligible for inclusion if they were systematic reviews (with or without meta-analysis) of solely primary literature that assessed any association between excess weight and COVID-19 infection, severity, or mortality in more than one study. Systematic reviews were required to include studies, in any setting, which presented laboratory-confirmed diagnoses of COVID-19 in people living with overweight or obesity. Where laboratory-confirmed diagnosis was not specified within the potentially eligible systematic review, the protocol/registration for the review and/or the full text of each included primary study was checked to confirm diagnosis methods. If COVID-19 diagnosis method could still not be established, the corresponding author of each included primary study was contacted and allowed 4 weeks to respond. Systematic reviews were excluded if it could not be confirmed that COVID-19 was diagnosed via a laboratory technique in any included primary study. Studies were eligible for inclusion if the authors defined a group of participants as living with excess weight. This included a variety of author-defined classifications (see Table S1), which sometimes differed for specific ethnicities.

Potentially eligible papers were then retrieved, and their full text was assessed for inclusion independently by two reviewers (JM & AG), with a third used for dispute resolution (LE). Reference lists of included articles were then searcher for further potentially relevant systematic reviews.

### 2.3 | Data extraction

A standardized pre-piloted electronic data extraction form (Microsoft Excel) was used by two researchers (AG & OS) to extract data from the included systematic reviews. Extracted data included: review characteristics, search details, characteristics of included studies/participants, COVID-19 diagnosis method, overweight/obesity definition, COVID-19 infection, severity, hospitalization, and mortality data, inferred mechanisms, any relevant data on moderators such as severity of excess weight, ethnicity, socioeconomic status, age, sex, geography, or other comorbidities, author-acknowledged limitations, funding source, and author declarations. All data extraction was then checked by a third reviewer (JM) for accuracy.

We extracted data on COVID-19 severity as it was reported in the included review. Therefore, there are multiple author-defined definitions of COVID-19 severity, such as "poor outcome," "severe COVID," "severe outcome," "severe disease," "severity," "severe complications," "severe illness," and "crucial illness," as well as ICU admission and IMV. Occasionally, these terms include ICU admission, IMV, hospitalization, and mortality; however, it was not possible to disaggregate the data. Therefore, the present review utilizes the descriptions stated within the relevant included review.

It should be noted that where data have been extracted *verbatim* from included reviews, we have altered language that reduced people to their medical condition. The alterations made ensure person first language throughout this report (e.g., "individual living with obesity" has replaced "obese individual").

### 2.4 | Quality assessment

The quality of each included systematic review was assessed by one author (JM), with a selection checked by a second (AG) and disputes solved by a third (OS), using the Assessment of Multiple Systematic Reviews (AMSTAR 2) measurement tool.[26] AMSTAR 2 is a 16-item critical assessment tool for appraising the quality of systematic reviews, which is not intended to generate an overall score. AMSTAR 2 has a rating system based on weaknesses in critical domains and can therefore assist in the identification of high-quality reviews. Review classifications were scored as follows: Critically low: more than one critical flaw with or without non-critical weaknesses; Low: one critical flaw with or without non-critical weaknesses; Moderate: more than one non-critical weakness with no critical flaws; High: no or one non-critical weakness with no critical flaws.

### 2.5 | Quantitative synthesis

We conducted a second-order meta-analysis on the available data for disease severity, hospitalization, and mortality. Within disease severity, we examined severe outcomes, admission to ICU, and IMV separately. The majority of effect sizes were Odds Ratios, which were converted to log Odds for analyses. A small number of effects were expressed as Risk Ratios, which we used interchangeably with Odds Ratios.[27] However, under certain conditions (as the number of event rates increases), Odds Ratios and Risk Ratios diverge, so we also conducted sensitivity analyses removing Risk Ratios.

We estimated the degree of overlap of primary studies in each meta-analysis included in the quantitative synthesis for each outcome using the Corrected Covered Area (CCA). The CCA provides an intuitive approximation of overlap using the formula $[(N - r)/(r \times c) - r]$, where $N$ is the sum of primary studies included across all systematic-reviews/meta-analyses (including double counting), $r$ is the number of primary studies total, and $c$ is the number of systematic-reviews/meta-analyses. We used cut-offs to interpret the degree of overlap, where 0–5 is indicative of slight, 6–10 indicative of moderate, 11–15 indicative of high, and >15 indicative of very high overlap.[28] If it was not possible to establish the primary studies that contributed to the meta-analytic effect size, these were excluded from the calculation of the CCA. We also generated a visual matrix to examine the overlap of included primary studies in each meta-analysis for each outcome, which highlights reviews that were and were not included in the quantitative synthesis.[29]

As there was overlap between the primary studies in the different meta-analyses, this violates the independence of the effect sizes, which in turn can artificially increase the precision of the pooled effect. As such, we conducted a sensitivity analysis in which we adjusted the precision of the pooled effect size by an inflation factor.[30] As this factor was unknown, we reanalyzed each model with a series of inflation factors in 10% increments until the precision meant the effect was no longer significant. We conducted a sensitivity analysis for each outcome excluding pediatric and pregnant populations. We also conducted categorical subgroup analyses on high/moderate quality versus low/critically low quality, wherever there were at least four reviews in both quality groups.[31] Where there were not four studies in each subgroup, we present the pooled effect with the removal of high/moderate quality reviews.

Individual meta-analytic effects were pooled and the second-order meta-analysis was conducted in R using the "metafor" package. Random Effects models with a Restricted Maximum Likelihood Estimator were used. The analysis script and data can be found here [https://osf.io/dkgjn/].

## 3 | RESULTS

### 3.1 | Study selection

Figure 1 outlines the PRISMA flow diagram of study selection, which shows in total 52 systematic reviews[13,32–82] met the inclusion criteria and were included in this umbrella review. A list of the records that were excluded at full text screening, with their accompanying reason for exclusion, can be found in Table S2.

### 3.2 | Characteristics of included reviews

All 52 included reviews were published between 2020 and 2022, from 17 different countries. The reviews originate from China ($n = 16$), USA ($n = 7$), UK ($n = 5$), Indonesia ($n = 3$), Brazil ($n = 3$), Hungary ($n = 2$), Singapore ($n = 2$), Iran ($n = 2$), Australia ($n = 2$), Spain ($n = 2$), Bangladesh ($n = 2$), Canada ($n = 1$), Korea ($n = 1$), South Africa ($n = 1$), Italy ($n = 1$), France ($n = 1$), and Taiwan ($n = 1$). Of the 52 included reviews, 49 were meta-analyses, and three were narrative systematic reviews.[51,58,77] Two reviews were conducted with pediatric populations,[59,66] and three were in pregnant women.[34,71,72] As per

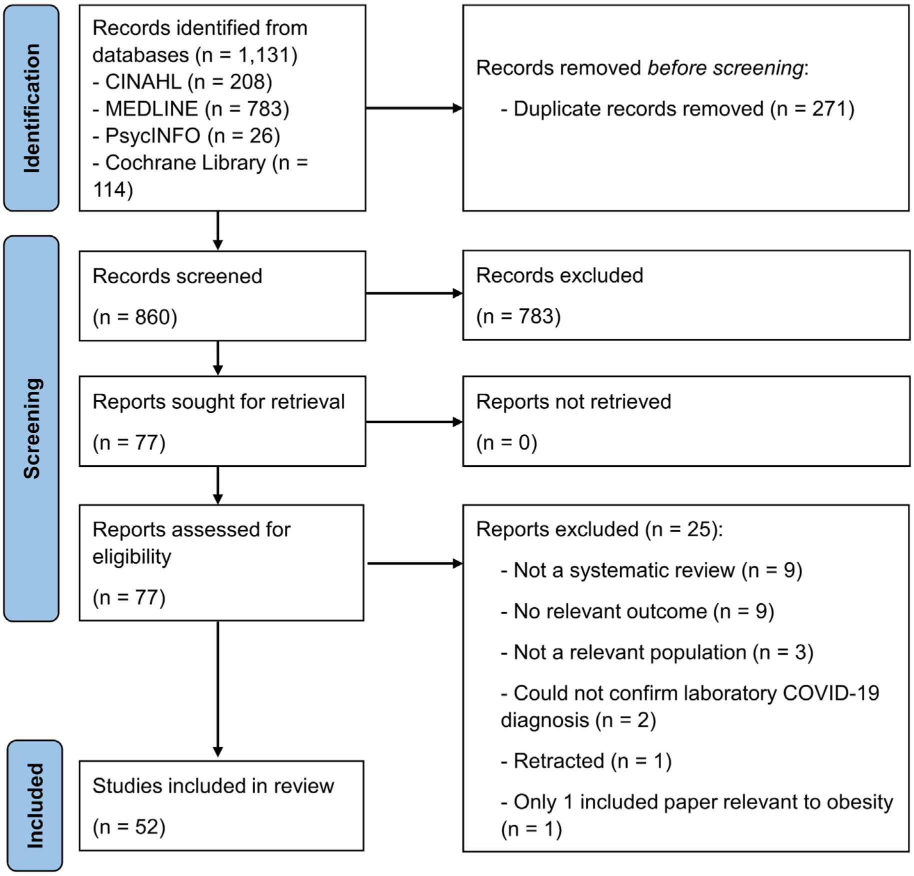


**FIGURE 1** PRISMA flow diagram of study selection.

the inclusion criteria, all reviews included studies that utilized laboratory-confirmed COVID-19 diagnosis methods. Within the included reviews, there were a variety of definitions of excess weight (most commonly BMI > 25 or BMI > 30 and were often lower within included reviews to account for people who identify as Asian ethnicity), which were compared with people of a healthy weight (most commonly defined as BMI < 25). The characteristics of the included reviews, including the excess weight definition of each review, are shown in Table S1, with additional characteristics presented in Table S3. An overview of the findings of the included reviews can be found in Table 1, with additional detailed findings presented in Table S4.

The number of studies included in the excess weight analysis within each included review varied substantially from 138[81] to two.[43] There were larger reviews included that comprised as many as 217 included studies[69]; however, only 27 were relevant to excess weight, as reviews on multiple COVID-19 comorbidities were eligible provided excess weight was examined. The overlap of primary studies included within each review is presented in the Supporting Information for risk of COVID-19 infection (Table S5), ICU admission (Table S6), IMV administration (Table S7), COVID-19 severity (Table S8), hospitalization (Table S9), and mortality (Table S10). These tables are supported by the list of references of included studies, giving a comprehensive list of primary studies examining the association between excess weight and COVID-19 outcomes. The total number of included primary studies relevant to each outcome was as follows: infection risk ($n = 30$), ICU admission ($n = 50$), IMV administration ($n = 38$), severity ($n = 105$), hospitalization ($n = 78$), and mortality ($n = 153$).

### 3.3 | Methodological quality of included reviews

The AMSTAR-2 assessment results for each review are shown in Table S11. Of the 52 included reviews, 40 were classified as "critically low," 11 were classified as "low," and one[51] was classified as "high." The mean (standard deviation) of non-critical and critical weaknesses was 3 (2) and 3 (2), respectively. Notably, all but three[47,51,72] of the included reviews lacked item 7, which requires a full list of references excluded at full-text stage and is classed as a critical domain. With item 7 excluded from the assessment, of the 52 included reviews, 30 were classified as "critically low," 13 were classified as "low," five were classified as moderate,[55,58,70,74,75] and four[45,49,51,61] were classified as "high." It was not possible to statistically explore the differences in findings between those of moderate/high quality and those of lower quality due to the small number of moderate-/high-quality reviews for each respective outcome. Other notable areas of weakness were observed in the included reviews, such as 33/52 (63%) were not prospectively registered, 52/52 (100%) did not report on the sources of funding for the studies included within the review, and

TABLE 1 Main findings and quality of included reviews comparing the risk of COVID-19 infection, hospitalization, severity, and mortality, between individuals living with excess weight and those of a healthy weight.

| Author, year | Infection | Hospitalization | Severity | Mortality | Modified AMSTAR 2 classification |
|---|---|---|---|---|---|
| Aghili et al, 2021[33] | NR | NR | Poor outcome ↑<br>ICU admission ↔<br>IMV ↑ | Mortality ↑ | Critically low |
| Allotey et al, 2021[34] | NR | NR | Severe disease ↑<br>ICU admission ↑<br>IMV ↑ | Maternal mortality ↑ | Low |
| Ashktorab et al., 2021[35] | NR | NR | NR | Mortality ↑ | Critically low |
| Booth et al., 2021[36] | NR | NR | Severe outcome ↑ | Mortality ↑ | Critically low |
| Bunn et al., 2022[64] | NR | NR | ICU admission ↑ | NR | Critically low |
| Cai et al, 2021[65] | NR | Hospitalization ↑ | Severe disease ↑<br>ICU admission ↑<br>IMV ↑ | Mortality ↑ | Critically low |
| Chang et al., 2020[37] | NR | Hospitalization ↑ | Severe disease ↑<br>IMV ↑ | NR | Low |
| Choi et al., 2022[66] | NR | NR | Severe disease ↑ | NR | Critically low |
| Chowdhury et al., 2021[67] | NR | NR | Severe disease ↑ | NR | Critically low |
| Chu et al., 2020[38] | NR | NR | Poor outcome ↑<br>ICU admission ↑<br>IMV ↑ | Mortality ↔ | Low |
| Deng et al., 2021[39] | NR | NR | Severe disease ↑<br>ICU admission ↑<br>IMV ↑ | Mortality ↔ | Critically low |
| Dessie et al., 2021[68] | NR | NR | NR | Mortality ↑ | Critically low |
| Du et al., 2021[40] | NR | NR | Severe disease ↑ | Mortality ↑ | Critically low |
| Ferreira et al., 2021[79] | NR | NR | ICU admission ↑<br>IMV ↑ | Mortality ↔ | Critically low |
| Foldi et al.. 2020[41] | NR | NR | ICU admission ↑<br>IMV ↑ | NR | Low |
| Foldi et al., 2021[42] | NR | NR | ICU admission ↑<br>IMV ↑ | NR | Critically low |
| Geng et al., 2021[69] | NR | NR | Severity ↑<br>ICU admission ↑<br>ARDS ↑ | Mortality ↔ | Critically low |
| Ng et al., 2021[43] | NR | NR (one study) | NR (one study) | Mortality ↔ | Critically low |
| Ho et al., 2020[44] | Positive test ↑ | NR | Severe disease ↑<br>ICU admission ↔<br>IMV ↑ | Mortality ↑ | Low |
| Hoong et al., 2021[45] | NR | NR | Severe disease ↑ | Mortality ↑ | High |
| Hu & Wang, 2020[46] | NR | NR | Severity ↑<br>ICU admission ↑ | NR | Critically low |
| Huang et al, 2020[47] | NR | Hospitalization ↑ | Severity ↑<br>ICU admission ↑<br>IMV ↑ | Mortality ↑ | Critically low |
| Huang et al., 2021[70] | NR | NR | NR | Mortality ↑ | Moderate |
| La Verde et al., 2021[71] | NR | NR | NR | Maternal Mortality ↑ | Low |
| Lassi et al., 2021[72] | NR | NR | Maternal Severity ↑ | NR | Low |
| Li et al., 2021a[73] | NR | NR | Severity ↑ | NR | Critically low |
| Li et al, 2021b[74] | NR | NR | NR | Mortality ↑ | Moderate |
| Mahamat-Saleh et al,2021[75] | NR | NR | NR | Mortality ↑ | Moderate |

(Continues)

TABLE 1 (Continued)

| Author, year | Infection | Hospitalization | Severity | Mortality | Modified AMSTAR 2 classification |
|---|---|---|---|---|---|
| Malik et al., 2021[48] | NR | NR | Poor outcomes ↑ | NR | Critically low |
| Mattey-Mora et al,2022[76] | NR | Hospitalization ↑ | NR | NR | Low |
| Mesas et al., 2020[49] | NR | NR | NR | Mortality ↔ | High |
| Noor & Islam, 2020[50] | NR | NR | NR | Mortality ↑ | Critically low |
| Ovalle et al., 2021[77] | NR | NR | Severity ↑ | NR | Critically low |
| Peres et al., 2020[51] | NR | Hospitalization ↑ | Poor outcome ↑ | Mortality ↔ | High |
| Poly et al., 2021[52] | NR | NR | NR | Mortality ↑ | Low |
| Popkin et al, 2020[13] | Positive test ↑ | Hospitalization ↑ | ICU admission ↑<br>IMV ↑ | Mortality ↑ | Critically low |
| Pranata et al., 2020[53] | NR | NR | Severity ↑<br>Poor outcome ↑ | Mortality ↑ | Critically low |
| Raeisi et al., 2022[78] | COVID-19 risk ↑ | Hospitalization ↑ | Severity ↑<br>ICU admission ↑<br>IMV ↑ | Mortality ↑ | Low |
| Sales-Peres et al., 2020[54] | NR | NR | Severe complications ↔ | NR | Low |
| Seidu et al., 2020[55] | NR | NR | Severe illness ↑ | Mortality ↑ | Moderate |
| Sharma et al., 2020[56] | NR | NR | Critical illness ↑ | NR | Critically low |
| Soeroto et al., 2020[57] | NR | NR | Poor outcome ↑<br>Severe disease ↑<br>ICU admission ↔ | NR | Critically low |
| Tamara & Tahapary, 2020[58] | NR | Hospitalization ↑ | IMV ↑<br>Severe disease ↑ | NR | Moderate |
| Tsankov et al., 2021[59] | NR | NR | Severe disease ↑ | NR | Critically low |
| Wang et al., 2022[80] | NR | NR | ICU admission ↑ | NR | Critically low |
| Wang et al., 2021[81] | NR | NR | NR | Mortality ↑ | Critically low |
| Yang et al., 2020[60] | Infection ↑ | Hospitalization ↑ | Severe disease ↑<br>ICU admission ↑<br>IMV ↑ | Mortality ↑ | Low |
| Yang et al., 2021a[32] | NR | NR | Severe disease ↑<br>Severe outcome ↑ | NR | Critically low |
| Yang et al., 2021b[61] | Positive test ↑ | Hospitalization ↑ | ICU admission ↑<br>IMV ↑ | Mortality ↑ | High |
| Zhang et al., 2021[82] | NR | Hospitalization ↑ | Severe disease ↑<br>ICU admission ↑<br>IMV ↑ | Mortality ↔ | Critically low |
| Zhao et al., 2020[62] | NR | NR | Severe outcome ↑<br>ICU admission ↑ | Mortality ↔↑ | Low |
| Zhou et al., 2020[83] | NR | NR | Severe disease ↑<br>IMV ↑ | Mortality ↔ | Critically low |

*Note*: Arrows represent a significantly increased (↑), no difference (↔), or significantly decreased (↓) risk between those living with excess weight and a healthy weight control group. Reported outcome variables are defined as per included review article.
Abbreviations: ICU, intensive care unit; IMV, invasive mechanical ventilation; NR, not reported.

37/52 (71%) did not assess the potential impact of risk of bias in individual studies on the results of the meta-analysis, nor did 36/52 (69%) account for risk of bias when interpreting/discussing the results of the review.

## 3.4 | Infection

Five of the 52 included reviews reported COVID-19 infection as an outcome (see Table 1), which was deemed too few for second-order meta-analysis. All five concluded a stronger association between COVID-19 infection and excess weight, compared with those of a healthy weight, with odds ratios ranging from 1.39 to 2.42. A narrative description of these five studies is presented in the Supporting Information.

## 3.5 | Severity

Of the included 52 reviews, 40 reported a minimum of one measure of COVID-19 severity, which resulted in a total of 76 author reported outcomes (see Table 1). Of the 76 author-reported COVID-19 severity outcomes that were extracted from the included reviews, 72 showed that living with excess weight was associated with an increased COVID-19 severity compared with living with a healthy weight. The remaining four outcomes showed no association between disease severity and excess weight; these outcomes were ICU admission[33,44,57] and severe complications.[54]

For ICU admissions, the second-order meta-analysis had a pooled OR = 1.58 (95% CI: 1.45 to 1.72), $Z = 10.67$, $p < .001$, $I^2 = 74\%$, from 21 effects (Figure 2). Seventeen of the 21 individual meta-analyses

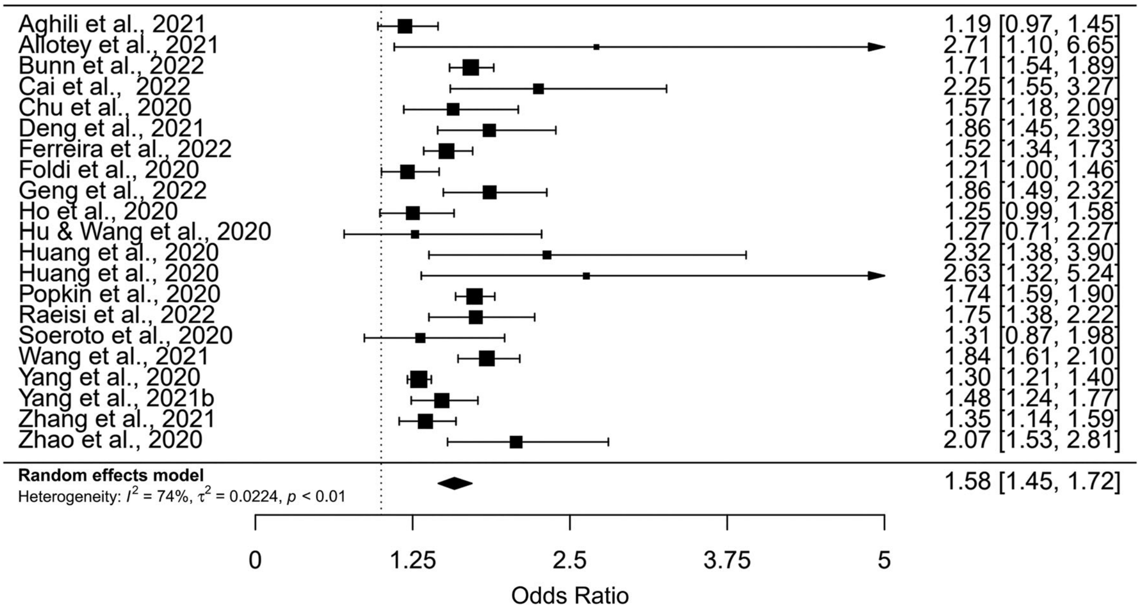


**FIGURE 2** Forest plot showing the association between excess weight and intensive care unit admission with COVID-19. A higher odds ratio represents a higher risk of ICU admission in those living with excess weight compared with those of a healthy weight.

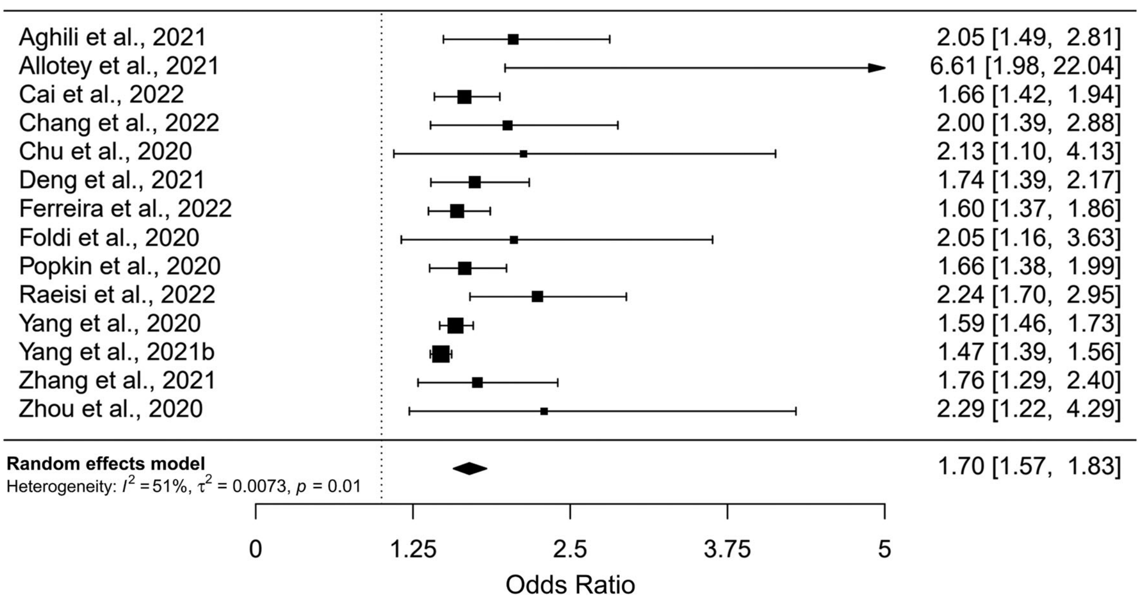


**FIGURE 3** Forest plot showing the association between excess weight and invasive mechanical ventilation with COVID-19. Higher odds ratio represents a higher risk of invasive mechanical ventilation in those living with excess weight compared with those of a healthy weight.

were significant. An inflation factor of 550% would be required to reduce the precision to the point the model was non-significant. The CCA was 11.6% indicative of high overlap.

For IMV administration, the second-order meta-analysis had a pooled OR = 1.70 (95% CI: 1.57 to 1.83), $Z = 13.42$, $p < .001$, $I^2 = 51\%$, from 14 effects (Figure 3). All individual meta-analyses were statistically significant. An inflation factor of 550% would be required to reduce the precision to the point the model was non-significant. The CCA was 14.6% indicative of high overlap.

The second-order meta-analysis on disease severity demonstrated a pooled OR = 1.86 (95% CI: 1.70 to 2.05), $Z = 12.73$, $p < .001$, $I^2 = 77\%$, from 27 effects (Figure 4). All individual meta-analyses were statistically significant. Removal of three effect sizes that used Risk Ratios had minimal impact on the overall OR (OR = 1.91 [95% CI: 1.73 to 2.12], $Z = 12.41$, $p < .001$, $I^2 = 76\%$). An inflation factor of 650% would be required to reduce the precision to the point the model was non-significant. The CCA was 6.8% indicative of moderate overlap.

Five of the nine reviews classified as either moderate or high confidence using the modified AMSTAR-2 assessment found that people living with excess weight were associated with severe disease,[45,61] poor outcome,[51] severe illness,[55] IMV,[58,61] and ICU admission,[61] compared with living with a healthy weight, with the remaining four not reporting on disease severity.[49,70,74,75] Removal of moderate or high-rated studies did not substantially influence the pooled ORs from the second-order meta-analyses (Severity OR = 1.84 [95% CI: 1.67 to 2.03]; ICU OR = 1.59 [95% CI: 1.45 to 1.74]; IMV OR = 1.72 [95% CI: 1.60 to 1.84]).

## 3.6 | Hospitalization

The risk of hospitalization in people living with excess weight compared with people of a healthy weight was reported in 11 of the 52 included reviews.[13,37,47,51,58,60,61,65,76,78,82] All 11, two of which were systematic reviews, reported a significantly stronger association in people living with excess weight for hospital admission, compared with those of a healthy weight. Two were systematic reviews, and the odds ratios from the nine meta-analyses for hospitalization ranged from 1.4 to 2.45.

The second-order meta-analysis on hospitalization rates demonstrated a pooled OR = 1.82 (95% CI: 1.61 to 2.05), $Z = 9.67$, $p < .001$, $I^2 = 83\%$, from nine effects (Figure 5). All individual meta-analyses were statistically significant. An inflation factor of 500% would be required to reduce the precision to the point the second-order model was non-significant. The CCA was 5.2% indicative of moderate overlap.

Of the 11 reviews that investigated hospitalization, two systematic reviews were classified as high quality,[51,58] one meta-analysis was classified as high quality,[61] and the remaining eight meta-analyses were classified as either low or critically low, using the AMSTAR-2 assessment tool. Removal of moderate- or high-rated studies did not substantially influence the pooled ORs from the second-order meta-analyses (OR = 1.86 [95% CI: 1.63 to 2.12).

## 3.7 | Mortality

Of the 52 included reviews, 33 reported on the mortality of patients with COVID-19 (see Table 1). Of those 33, 23 (70%) reported an

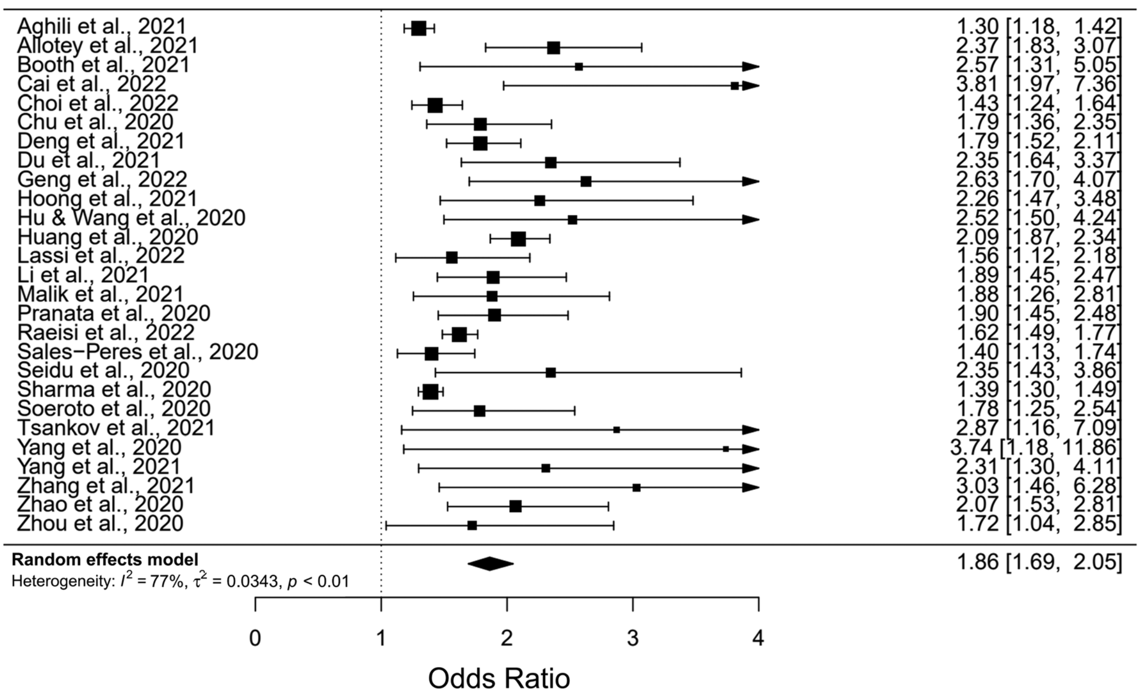


FIGURE 4 Forest plot showing the association between excess weight and COVID-19 severity. Higher odds ratio represents a higher risk of severe COVID-19 in those living with excess weight compared with those of a healthy weight.

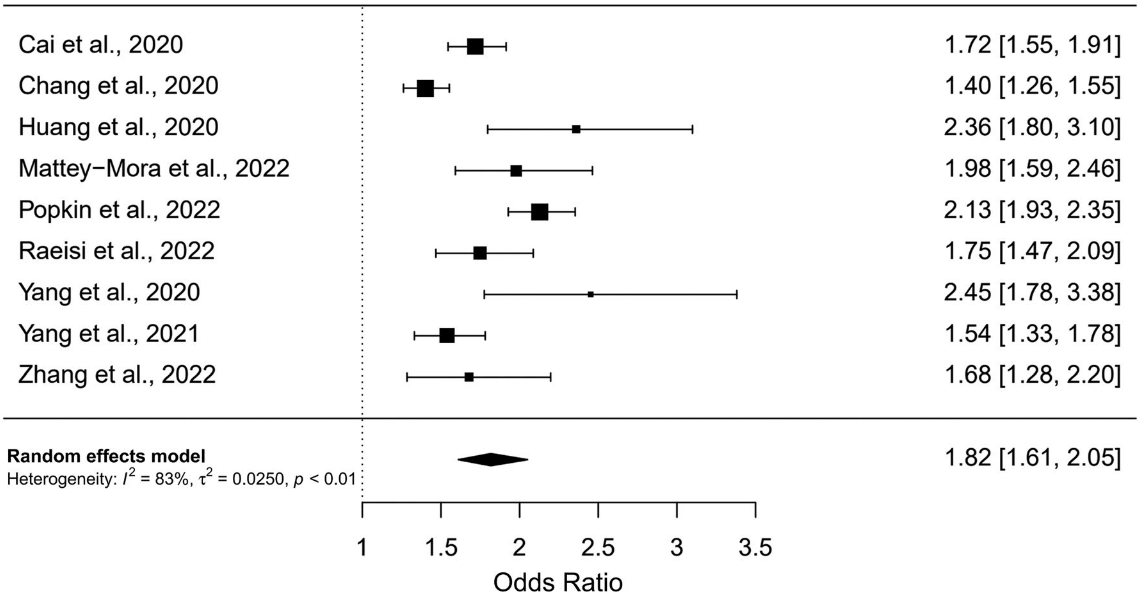


**FIGURE 5** Forest plot showing the association between excess weight and hospitalization with COVID-19. Higher odds ratio represents a higher risk of hospitalization in those living with excess weight compared with those of a healthy weight.

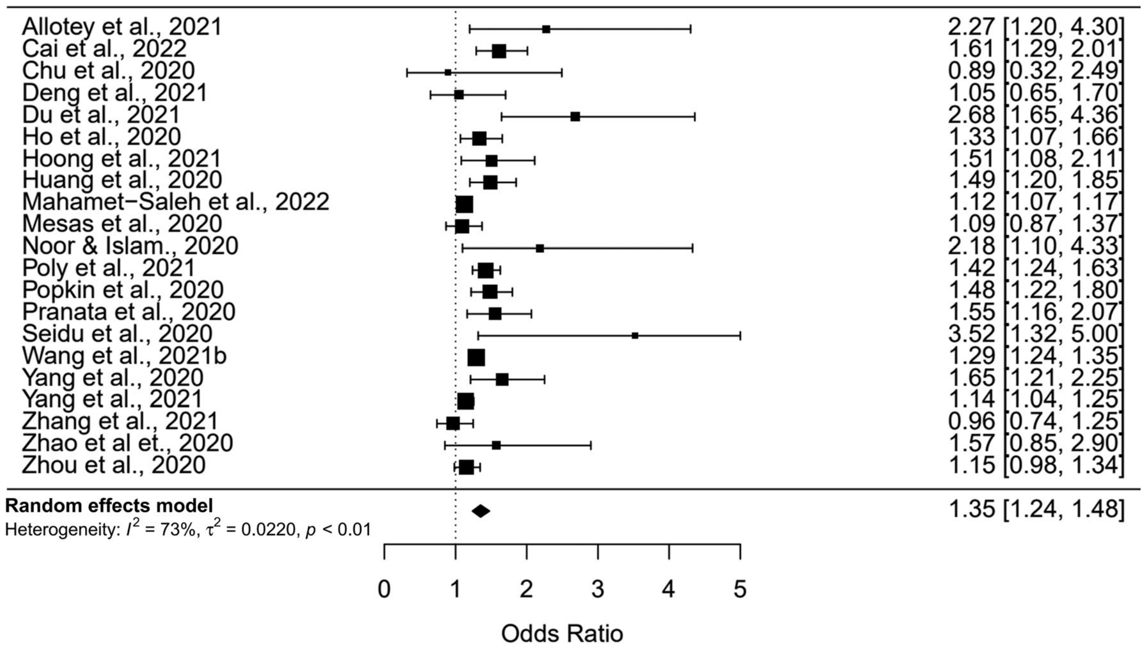


**FIGURE 6** Forest plot showing the association between excess weight and mortality with COVID-19. Higher odds ratio represents a higher risk of mortality in those living with excess weight compared with those of a healthy weight.

increased mortality, nine (27%) reported no association, and Zhao et al.[62] reported no association for BMI ≥ 30 kg/m$^2$ but a significant association for BMI ≥ 35 kg/m$^2$.

The second-order meta-analysis on mortality demonstrated a pooled OR = 1.35 (95% CI: 1.24 to 1.48), $Z = 6.67$, $p < .001$, $I^2 = 73\%$, from 21 effects (Figure 6). Fifteen of the 21 individual meta-analyses were statistically significant. Removal of four effect sizes that used a Risk Ratio did not substantially influence this (OR = 1.35 [95% CI: 1.22 to 1.49], $Z = 6.05$, $p < .001$, $I^2 = 72\%$). An inflation factor of 350% would be required to reduce the precision to the point the model was non-significant. The CCA was 5.1% indicative of moderate overlap.

Of the nine reviews classified as either moderate or high confidence by AMSTAR-2 assessment, one did not report on mortality,[58] six reported an association between mortality and excess weight,[45,55,61,70,74,75] and two reported no association.[49,51] A subgroup analysis demonstrated no significant difference between studies rated as low versus moderate or high ($X^2(1) = 1.78$, p = .182). Low quality OR = 1.40 (95% CI: 1.26 to 1.56), moderate or high quality OR = 1.23 (95% CI: 1.08 to 1.40).

## 3.8 | Moderators

### 3.8.1 | Excess weight

Deng et al.[39] observed for every 5 kg/m$^2$ increase in BMI the OR values for IMV use and ICU admission in COVID-19 patients were 1.16 (95% CI: 1.10–1.23) and 1.2 (95% CI: 1.11–1.30), respectively. Similarly, Du et al.[40] found a 1.09-fold increased risk (OR: 1.09, 95% CI: 1.04–1.14) of critical COVID-19 for each 1 kg/m$^2$ increase in BMI and a 1.19-fold increased risk (OR: 1.19, 95% CI: 1.08–1.30) of critical COVID-19 for each 2 kg/m$^2$ increase in BMI. They also found the mortality of patients with COVID-19 increased by 6% (OR = 1.06, 95% CI = 1.02–1.10) for each 1 kg/m$^2$ increase in BMI. Huang et al.[70] demonstrated a J-curved relationship between BMI and COVID-19 mortality, indicating that both individuals with a COVID-19 diagnosis and living with underweight or obesity had a higher mortality risk than patients with a healthy weight.

### 3.8.2 | Ethnicity, socioeconomic status, and geography

Although some reviews used a lower BMI cut-off for the definition of overweight/obesity in studies including data from those of Asian ethnicity (see Table S1), just one of the 52 included reviews explicitly investigated how the relationship between obesity and COVID-19 may be influenced by ethnicity. Raeisi et al.[78] categorized participants from just two ethnicities (Caucasian and East-Asian) and found that obesity was consistently associated with hospitalization, IMV, ICU admission, and mortality in Caucasians with COVID-19. However, the relationship between obesity and IMV, ICU admission, and mortality was non-significant in East-Asian populations with a COVID-19 diagnosis. Two studies included in their limitations that data on ethnicity and socioeconomic status were limited and precluded analysis.[40,55] Seidu et al.[55] reported that ethnicity and socioeconomic status are linked to obesity and worse COVID-19 outcomes; however, they were unable to investigate these links due to insufficient data. Additionally, we did not find any evidence within the included reviews on the relationship between excess weight and COVID-19 risk, or prognosis being moderated by geography.

### 3.8.3 | Age

Chu et al.[38] found that people living with excess weight who were <60 years had a strong positive association between excess weight and poor composite outcomes of COVID-19, which included severe COVID-19, need for ICU care, IMV, mortality, and disease progression (OR: 2.86, 95% CI: 1.55–5.28). They found that this association became weaker in people ≥60 years (OR: 1.52, 95% CI: 1.05–2.19). This finding is mirrored by the findings of Mesas et al.[49] who observed a stronger association, albeit not significant, between excess weight and COVID-19 mortality for people ≤60 years (OR:1.62, 95% CI: 0.92–2.83) compared with people ≥60 years (OR: 0.90, 95% CI: 0.67–1.20).

### 3.8.4 | Sex

There was no evidence that the relationship between excess weight and COVID-19 outcomes is moderated by sex.[40,49]

### 3.8.5 | Comorbidities

A detailed list of the reported comorbidities in each review can be found in Appendix S3. The majority of the included reviews included studies with multiple patient comorbidities or did not report on patient comorbidities. However, Zhao et al.[62] excluded studies in which subjects had known diabetes or other fatal chronic diseases that may induce the severity of COVID-19 such as cancer, severe autoimmune disease, chronic kidney disease, cirrhosis, and liver failure. They found that excess weight was a risk factor for a severe COVID-19 outcome (severe manifestations, admission to ICU, and requirement for mechanical supports), but not for mortality. Additionally, Mesas, Cavero-Redondo, Álvarez-Bueno, Sarriá Cabrera, Maffei de Andrade, Sequí-Dominguez, and Martínez-Vizcaíno[49] found that living with excess weight was associated only with mortality in studies with fewer comorbidities.

## 4 | DISCUSSION

This umbrella review provides a comprehensive summary of the evidence on the association between excess weight and COVID-19 outcomes. The findings suggest a stronger association between weight and risk of disease severity, hospitalization, and mortality in those living with excess weight compared with their healthy-weight counterparts. Additionally, we found some evidence that the association between excess weight and COVID-19 outcomes is moderated by the severity of excess weight, age, and comorbidities. Specifically, weight associations with adverse outcomes were stronger in individuals living with a higher degree of excess weight, who were younger, and who had fewer comorbidities. It appears that older age, and larger number of comorbidities, confound the observed association between excess weight and COVID-19 prognosis, as these factors are significant independent risk factors,[84,85] and weight often declines with comorbidities due to reverse causality linked to unintentional weight loss. Interestingly, within the included reviews, we found limited data on how ethnicity may influence the observed association, with no data presented on socioeconomic status, or geography. The lack of reporting in this area should be addressed in any future reviews. Although the overall quality of the included reviews was poor, there was no observed difference in terms of the findings between the higher and lower ranking reviews.

The finding that excess weight is associated with a higher risk of catching COVID-19, compared with healthy weight, is supported by analyses of data from UK Biobank. Yates et al[86] found that both BMI and waist circumference were associated with testing positive for COVID-19 in a dose–response fashion, and adjustment for possible confounders did not change the results. The adjusted odds ratio for BMI ranges of 25–<30, 30–<35, and ≥35 kg/m$^2$ was 1·31 (95% CI: 1·05–1·62), 1·55 (1·19–2·02), and 1·57 (1·14–2·17), respectively, compared with a healthy weight reference group. These UK-derived odds ratios broadly align with the odds ratios reported in the five included reviews,[13,44,60,61,78] which ranged from 1.39 to 2.42. It should be noted that in many primary studies exploring the association between excess weight and COVID-19 infection, testing was done in hospitals. Therefore, it is possible that this finding, to some extent, is artefactual linked to ascertainment bias as the individuals living with excess weight were more likely to be admitted to hospital with COVID-19.[87]

Of the 76 author-reported COVID-19 severity outcomes that were extracted from the included reviews, 72 (96%) showed a stronger association between weight and COVID-19 severity in people living with excess weight compared with those of a healthy weight. The remaining four outcomes showed no association between disease severity and excess weight; these outcomes were ICU admission[33,44,57] and severe complications.[54] These four reviews were all classified as critically low confidence using the AMSTAR-2 assessment. Additionally, the three reviews t showed no association for ICU admission; all showed other metrics of COVID-19 severity to be worsened in people living with excess weight.[33,44,57] These findings therefore support the conclusion that living with excess weight is associated with a more severe COVID-19 prognosis compared with living with a healthy weight. This finding also aligns with a prospective community-based cohort study of 6.9 million people in England, which identified J-shaped associations between BMI and admission to hospital due to COVID-19 and death.[87] This was in addition to a linear association between BMI and ICU admission. UK Biobank analyses have shown BMI to be linearly associated with higher risk of hospitalization and death from COVID-19.[88] Therefore, hospital admission and ICU admission processes could consider expediting ICU admission based on the expectation of more severe disease prognosis in people living with excess weight.

A significant association between excess weight and COVID-19-related mortality was observed in 15 of the 21 meta-analyses in which data were available for umbrella meta-analysis. Our findings are substantiated by recent large cohort studies in England,[89] Brazil,[90] and the United States.[91] The OpenSAFELY study examined over 17 million adults in England and showed that a BMI > 40 was associated with a near doubling (HR: 1.92 CI: 1.72–2.13) of death from COVID-19 compared with people who were not living with obesity, in a model adjusted potential confounders including for age, sex, smoking, index of multiple deprivation quintile, and comorbidities.[92] In addition, UK Biobank analyses have shown BMI to be associated with a higher risk of hospitalization and death from COVID-19, particularly in people under 70 years (in agreement with our age-related findings), and in South Asian and African-Caribbean populations.[88] It should be noted that the observed association between excess weight and COVID-19-related mortality may be influenced by reverse causality, as those who are most likely to die with COVID-19 include the elderly and those with other conditions associated with underweight weight status.

Findings from included reviews,[39,40,53] and findings from large UK studies,[86–88,92] suggest a broadly linear relationship between excess weight and COVID-19 outcomes, with higher risk of COVID-19 infection and worse outcomes as BMI increases. These data suggest that if an individual could lower their BMI, for example, from 36 to 31 kg/m$^2$, it could meaningfully reduce their risk of COVID-19 infection and severe disease, despite their BMI still classifying them as living with obesity. However, this remains to be proven as adequately powered randomized controlled trials of the effects of weight loss on COVID-19 risk and severity are yet to be concluded. Whether relatively small amounts of weight loss can decrease COVID-19 severity is an area for future research.

Despite the lack of available data in the included reviews that examined the potential influence of ethnicity and socioeconomic status as effect moderators, there are relevant primary studies that have investigated this. A large prospective study in England[87] found a significant interaction ($p$ < 0.0001) between BMI and ethnicity with a higher HR per kg/m$^2$ above 23 kg/m$^2$ for people who identify as Black ethnicity when compared with those who identify as White ethnicity, for hospital admission (1·07 [1·06–1·08] vs. 1·04 [1·04–1·05]) and mortality (1·08 [1·06–1·10] vs. 1·04 [1·03–1·04]). No differences were observed between other ethnic group and those who identify as a white ethnicity. More research is needed on the effect of ethnicity on the association between excess weight and COVID-19 outcomes, as well as the potential influence of regional fat distribution.

We observed no evidence in the included reviews to suggest that sex moderates the association between excess weight and COVID-19 risk/outcomes. However, it does appear that age has an important moderating influence, with the association being stronger in individuals below 60 years of age. This is supported by prospective data collected in 6.9 million community-based people in England that suggests that BMI is a greater risk factor for COVID-19 severity for younger people (aged 20–39 years) than for older people (≥80 years),[87] and also supported by data from the UK biobank that showed a clear interaction in BMI to COVID-19 outcome risks in those below and above 70 years of age.[88] These data also fit with findings in the general population where BMI is more strongly linked to all-cause mortality in younger people, likely due to less reverse causality in this group,[93] with strengths of association closer to findings from genetic studies, as summarized.[94] As expected, when comorbidities were examined, they confounded the association between excess weight and COVID-19 outcomes. Many comorbidities, which are associated with weight loss, are significant independent risk factors for COVID-19 severity;[84,85] therefore, this reverse causality may help explain the confounding of the association between COVID-19 outcomes and excess weight.

There are a variety of plausible biological mechanisms linking excess weight and COVID-19 risk and outcomes. It appears likely that these may act cumulatively, and to different extents in different individuals, to influence the observed association. An in-depth examination of potential biological mechanisms is provided in a number of reviews,[95–99] including some previously mentioned reviews.[33,42,47,48,53] Although these reviews highlight multiple potential biological mechanisms, further research is needed to fully elucidate the mechanistic explanations for the observed association.

It is important to note that factors not described in the included reviews may play a role in the differentiation of disease outcomes by weight status. People living with excess weight face not only unique biological vulnerabilities and structural disparities but also weight stigma. This stigma can lead to, and exacerbate, mental health conditions and result in the delayed or avoidance of care because of bias and humiliation experienced in healthcare settings.[100,101] Additionally, it appears likely that physical activity levels are also associated with COVID-19 prognosis. Sallis et al.[102] identified 48,440 adult patients with a COVID-19 diagnosis and linked their self-reported physical activity levels to their disease outcome. They found that patients with COVID-19 who were consistently inactive (<10 min per week) had a greater risk of hospitalization (OR: 2.26; 95% CI: 1.81 to 2.83), ICU admission (OR: 1.73; 95% CI: 1.18 to 2.55), and death (OR: 2.49; 95% CI: 1.33 to 4.67) due to COVID-19 than patients who were consistently physically active for >150 min per week. This threshold aligns with the UK Chief Medical Officers' Physical Activity Guidelines.[103] Although physical activity and excess weight are interlinked, a sensible recommendation to reduce population-level COVID-19 hospitalization and mortality is to promote physical activity. This is particularly important given the pandemic has been found to have reduced physical activity levels.[104]

## 4.1 | Limitations

There are limitations to the present umbrella review. First, the overall quality of the included reviews was generally poor, likely associated with the rapid publication rate that occurred during the peak of the COVID-19 pandemic. Despite this, we did not identify any systematic differences in outcomes between the different levels of quality rated using the AMSTAR-2 tool. Second, it should be noted that the semantics of disease severity differ between primary studies and between reviews. Additionally, the criteria for outcomes such as hospitalization, ICU admission, IMV administration, and even mortality reporting may be different between hospitals and between countries. Definitions of excess weight/overweight/obesity within the included reviews also varied. We did not include reviews that were published in languages other than English, and this may impact the results.

It should be noted that this umbrella review includes reviews published up to May 2022. Since this date, a large Cochrane Review has been published that concludes the association of obesity with mortality, and requiring a breathing tube is of high certainty but presents no data on the potential moderating influences of ethnicity or socioeconomic status.[105] The findings of this Cochrane Review, which includes studies published up to April 2021, largely align with the findings of this umbrella review. Although it appears that new evidence is being published at pace in this area, there seems to be consensus that excess weight is substantially associated with more severe adverse outcomes of COVID-19. However, importantly, the influence of moderating factors appears to be missing in systematic reviews.

## 4.2 | Future considerations

Further research on the mechanisms explaining the association between excess weight and COVID-19 would be beneficial. This research may lead to the possibility of identifying therapeutic targets and creating tailored treatment approaches to mitigate the risk of COVID-19 infection and/or poor outcomes in people living with excess weight. Additionally, large-scale interventions that show the effect of meaningful intentional weight loss (via lifestyle, pharmacotherapy, or surgery) on risk of COVID-19 infection, and risk of poor outcomes of COVID-19, would be of interest.

The COVID-19 pandemic has reduced access to weight management services and support for individuals living with excess weight, particularly around lockdowns, when face-to-face weight management services were suspended.[106] It is vital that people living with excess weight are offered weight management services where needed. Finally, the most effective strategy to protect against severe COVID-19 outcomes is vaccination. To the best of our knowledge, COVID-19 vaccine trials have shown no difference in vaccine efficacy between BMI groups.[107–109] Indeed, a population-based cohort study has found a similar level of protection from severe COVID-19 in individuals with excess weight compared with those of a healthy weight.[110]

## 4.3 | Conclusions

This umbrella review found evidence that living with excess weight was associated with worse COVID-19 outcomes, and potentially COVID-19 infection. The COVID-19 pandemic has highlighted excess weight as a modifiable risk factor, that if appropriately addressed, could help mitigate the impact of COVID-19. The pandemic has therefore expediated the need for renewed emphasis on, and investment in, weight management services, as well as population strategies to help people live healthier lives. Unfortunately, we identified very limited reporting on the influence of factors that may moderate the association between excess weight and adverse COVID-19 outcomes. This should be addressed in future systematic reviews and meta-analyses.

## AUTHOR CONTRIBUTIONS

Jamie Matu, Alison Feeley, Lisa Mabbs, Jamie Blackshaw, and Louisa Ells conceived the study. Jamie Matu, Alison Feeley, Lisa Mabbs, Jamie Blackshaw, and Louisa Ells designed the study protocol. Jamie Matu searched the literature. Jamie Matu, Alex Griffiths, Oliver M. Shannon, Rhiannon Day, and Duncan Radley conducted literature sifting and data extraction. Andrew Jones conducted statistical analyses. All authors contributed to critically appraising the analyzed data. Jamie Matu and Naveed Sattar wrote the manuscript. All authors revised and approved the final manuscript. The corresponding author attests that all authors listed meet authorship criteria and that no others meeting the criteria have been omitted. All authors had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

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## CONFLICT OF INTEREST STATEMENT

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## DATA AVAILABILITY STATEMENT

The analysis script and data can be found here [https://osf.io/dkgjn/].

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## REFERENCES

1. Health Survey for England 2019 Overweight and obesity in adults and children (2020).
2. Bhaskaran K, Dos-Santos-Silva I, Leon DA, Douglas IJ, Smeeth L. Association of BMI with overall and cause-specific mortality: a population-based cohort study of 3.6 million adults in the UK. *Lancet Diab Endocrinol*. 2018;6(12):944-953. doi:10.1016/S2213-8587(18)30288-2
3. Statistics on Obesity, Physical Activity and Diet, England (2021).
4. Mongraw-Chaffin ML, Peters SAE, Huxley RR, Woodward M. The sex-specific association between BMI and coronary heart disease: a systematic review and meta-analysis of 95 cohorts with 1·2 million participants. *Lancet Diabetes Endocrinol*. 2015;3(6):437-449. doi:10.1016/S2213-8587(15)00086-8
5. De Pergola G, Silvestris F. Obesity as a major risk factor for cancer. *J Obes*. 2013;2013:291546. doi:10.1155/2013/291546
6. Hu G, Tuomilehto J, Silventoinen K, Sarti C, Männistö S, Jousilahti P. Body mass index, waist circumference, and waist-hip ratio on the risk of total and type-specific stroke. *Arch Intern Med*. 2007;167(13):1420-1427. doi:10.1001/archinte.167.13.1420
7. Abdullah A, Peeters A, de Courten M, Stoelwinder J. The magnitude of association between overweight and obesity and the risk of diabetes: a meta-analysis of prospective cohort studies. *Diabetes Res Clin Pract*. 2010;89(3):309-319. doi:10.1016/j.diabres.2010.04.012
8. Khaodhiar L, McCowen KC, Blackburn GL. Obesity and its comorbid conditions. *Clin Cornerstone*. 1999;2(3):17-31. doi:10.1016/s1098-3597(99)90002-9
9. Sattar N, McMurray JJV, McInnes IB, Aroda VR, Lean MEJ. Treating chronic diseases without tackling excess adiposity promotes multimorbidity. *Lancet Diabetes Endocrinol*. 2023;11(1):58-62. doi:10.1016/s2213-8587(22)00317-5
10. 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(20):2052-2059. doi:10.1001/jama.2020.6775
11. Docherty AB, Harrison EM, Green CA, et al. Features of 20 133 UK patients in hospital with covid-19 using the ISARIC WHO Clinical Characterisation Protocol: prospective observational cohort study. *BMJ*. 2020;369:m1985. doi:10.1136/bmj.m1985
12. 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(7):1195-1199. doi:10.1002/oby.22831
13. Popkin BM, Du S, Green WD, et al. Individuals with obesity and COVID-19: a global perspective on the epidemiology and biological relationships. *Obes Rev*. 2020;21(11):e13128. doi:10.1111/obr.13128
14. Phelan AL, Katz R, Gostin LO. The novel coronavirus originating in Wuhan, China: challenges for global health governance. *Jama*. 2020;323(8):709-710. doi:10.1001/jama.2020.1097
15. Viruses CSGotICoTo. The species severe acute respiratory syndrome-related coronavirus: classifying 2019-nCoV and naming it SARS-CoV-2. *Nat Microbiol*. 2020;5(4):536-544. doi:10.1038/s41564-020-0695-z
16. Peeri NC, Shrestha N, Rahman MS, et al. The SARS, MERS and novel coronavirus (COVID-19) epidemics, the newest and biggest global health threats: what lessons have we learned? *Int J Epidemiol*. 2020;49(3):717-726. doi:10.1093/ije/dyaa033
17. 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(10229):1054-1062. doi:10.1016/S0140-6736(20)30566-3
18. Ji W, Lee R, Huh K, et al. Overweight and obesity are risk factors for coronavirus disease 2019: a propensity score-matched case-control study. *Endocrinol Metabol (Seoul, Korea)*. 2021;36(1):196-200. doi:10.3803/EnM.2020.856
19. Webb Hooper M, Nápoles AM, Pérez-Stable EJ. COVID-19 and racial/ethnic disparities. *Jama*. 2020;323(24):2466-2467. doi:10.1001/jama.2020.8598
20. Tai DBG, Shah A, Doubeni CA, Sia IG, Wieland ML. The disproportionate impact of COVID-19 on racial and ethnic minorities in the United States. *Clin Infect Dis*. 2021;72(4):703-706. doi:10.1093/cid/ciaa815
21. Mackey K, Ayers CK, Kondo KK, et al. Racial and ethnic disparities in COVID-19-related infections, hospitalizations, and deaths: a systematic review. *Ann Intern Med*. 2021;174(3):362-373. doi:10.7326/M20-6306
22. Patel JA, Nielsen FBH, Badiani AA, et al. Poverty, inequality and COVID-19: the forgotten vulnerable. *Public Health*. 2020;183:110-111. doi:10.1016/j.puhe.2020.05.006
23. Yates T, Zaccardi F, Islam N, et al. Obesity, ethnicity, and risk of critical care, mechanical ventilation, and mortality in patients admitted to hospital with COVID-19: analysis of the ISARIC CCP-UK cohort.

*Obesity (Silver Spring, md)*. 2021;29(7):1223-1230. doi:10.1002/oby.23178
24. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. doi:10.1136/bmj.n71
25. Pollock M, Fernandes RM, Becker LA, Pieper D, Hartling L. Chapter V: Overviews of Reviews. In: Higgins JPT, Thomas J, Chandler J, et al., eds. *Cochrane handbook for systematic reviews of interventions version 62*. Cochrane; 2021.
26. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ*. 2017;358:j4008. doi:10.1136/bmj.j4008
27. Ranganathan P, Aggarwal R, Pramesh CS. Common pitfalls in statistical analysis: odds versus risk. *Perspect Clin Res*. 2015;6(4):222-224. doi:10.4103/2229-3485.167092
28. Pieper D, Antoine SL, Mathes T, Neugebauer EA, Eikermann M. Systematic review finds overlapping reviews were not mentioned in every other overview. *J Clin Epidemiol*. 2014;67(4):368-375. doi:10.1016/j.jclinepi.2013.11.007
29. Hennessy EA, Johnson BT. Examining overlap of included studies in meta-reviews: guidance for using the corrected covered area index. *Res Synth Methods*. 2020;11(1):134-145. doi:10.1002/jrsm.1390
30. Tang LL, Caudy M, Taxman F. A statistical method for synthesizing meta-analyses. *Comput Math Methods Med*. 2013;2013:732989. doi:10.1155/2013/732989
31. Rongwei Fu GG, Grant M, Shamliyan T, et al. Conducting Quantitative Synthesis When Comparing Medical Interventions: AHRQ and the Effective Health Care Program *Methods Guide for Effectiveness and Comparative Effectiveness Reviews* Rockville 2008.
32. Yang J, Hu J, Zhu C. Obesity aggravates COVID-19: a systematic review and meta-analysis. *J Med Virol*. 2021;93(1):257-261. doi:10.1002/jmv.26237
33. Aghili SMM, Ebrahimpur M, Arjmand B, et al. Obesity in COVID-19 era, implications for mechanisms, comorbidities, and prognosis: a review and meta-analysis. *Int J Obes (Lond)*. 2005;45(5):998-1016. doi:10.1038/s41366-021-00776-8
34. Allotey J, Stallings E, Bonet M, et al. Clinical manifestations, risk factors, and maternal and perinatal outcomes of coronavirus disease 2019 in pregnancy: living systematic review and meta-analysis. *BMJ*. 2020;370:m3320. doi:10.1136/bmj.m3320
35. Ashktorab H, Pizuomo A, González NAF, et al. A comprehensive analysis of COVID-19 impact in Latin America. *Res Square*. 2021; rs.3.rs-141245. doi:10.21203/rs.3.rs-141245/v1
36. Booth A, Reed AB, Ponzo S, et al. Population risk factors for severe disease and mortality in COVID-19: a global systematic review and meta-analysis. *PLoS ONE*. 2021;16(3):e0247461. doi:10.1371/journal.pone.0247461
37. Chang TH, Chou CC, Chang LY. Effect of obesity and body mass index on coronavirus disease 2019 severity: a systematic review and meta-analysis. *Obes Rev*. 2020;21(11):e13089. doi:10.1111/obr.13089
38. Chu Y, Yang J, Shi J, Zhang P, Wang X. Obesity is associated with increased severity of disease in COVID-19 pneumonia: a systematic review and meta-analysis. *Eur J Med Res*. 2020;25(1):64. doi:10.1186/s40001-020-00464-9
39. Deng L, Zhang J, Wang M, Chen L. Obesity is associated with severe COVID-19 but not death: a dose-response meta-analysis. *Epidemiol Infect*. 2021;149:e144. doi:10.1017/s0950268820003179
40. Du Y, Lv Y, Zha W, Zhou N, Hong X. Association of body mass index (BMI) with critical COVID-19 and in-hospital mortality: a dose-response meta-analysis. *Metabol Clin Exp*. 2021;117:154373. doi:10.1016/j.metabol.2020.154373
41. Földi M, Farkas N, Kiss S, et al. Obesity is a risk factor for developing critical condition in COVID-19 patients: a systematic review and meta-analysis. *Obes Rev*. 2020;21(10):e13095. doi:10.1111/obr.13095
42. Földi M, Farkas N, Kiss S, et al. Visceral adiposity elevates the risk of critical condition in COVID-19: a systematic review and meta-analysis. *Obesity (Silver Spring, Md)*. 2021;29(3):521-528. doi:10.1002/oby.23096
43. Ng WH, Tipih T, Makoah NA, et al. Comorbidities in SARS-CoV-2 patients: a systematic review and meta-analysis. *MBio*. 2021;12(1):e03647-20. doi:10.1128/mBio.03647-20
44. Ho JSY, Fernando DI, Chan MY, Sia CH. Obesity in COVID-19: a systematic review and meta-analysis. *Ann Acad Med Singapore*. 2020;49(12):996-1008. doi:10.47102/annals-acadmedsg.2020299
45. Hoong CWS, Hussain I, Aravamudan VM, Phyu EE, Lin JHX, Koh H. Obesity is associated with poor Covid-19 outcomes: a systematic review and meta-analysis. *Horm Metab Res*. 2021;53(2):85-93. doi:10.1055/a-1326-2125
46. Hu J, Wang Y. The clinical characteristics and risk factors of severe COVID-19. *Gerontology*. 2021;67(3):255-266. doi:10.1159/000513400
47. Huang Y, Lu Y, Huang Y-M, et al. Obesity in patients with COVID-19: a systematic review and meta-analysis. *Metabol Clin Exp*. 2020;113:154378. doi:10.1016/j.metabol.2020.154378
48. Malik P, 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*. 2021;93(2):1188-1193. doi:10.1002/jmv.26555
49. Mesas AE, Cavero-Redondo I, Álvarez-Bueno C, et al. Predictors of in-hospital COVID-19 mortality: a comprehensive systematic review and meta-analysis exploring differences by age, sex and health conditions. *PLoS ONE*. 2020;15(11):e0241742. doi:10.1371/journal.pone.0241742
50. Noor FM, Islam MM. Prevalence and associated risk factors of mortality among COVID-19 patients: a meta-analysis. *J Community Health*. 2020;45(6):1270-1282. doi:10.1007/s10900-020-00920-x
51. Peres KC, Riera R, Martimbianco ALC, Ward LS, Cunha LL. Body mass index and prognosis of COVID-19 infection. A systematic review. *Front Endocrinol (Lausanne)*. 2020;11:562. doi:10.3389/fendo.2020.00562
52. Poly TN, Islam MM, Yang HC, et al. Obesity and mortality among patients diagnosed with COVID-19: a systematic review and meta-analysis. *Front Med*. 2021;8:620044. doi:10.3389/fmed.2021.620044
53. Pranata R, Lim MA, Yonas E, et al. Body mass index and outcome in patients with COVID-19: a dose-response meta-analysis. *Diabetes Metab*. 2021;47(2):101178. doi:10.1016/j.diabet.2020.07.005
54. Sales-Peres SHC, de Azevedo-Silva LJ, Bonato RCS, Sales-Peres MC, Pinto A, Santiago Junior JF. Coronavirus (SARS-CoV-2) and the risk of obesity for critically illness and ICU admitted: meta-analysis of the epidemiological evidence. *Obes Res Clin Pract*. 2020;14(5):389-397. doi:10.1016/j.orcp.2020.07.007
55. Seidu S, Gillies C, Zaccardi F, et al. The impact of obesity on severe disease and mortality in people with SARS-CoV-2: a systematic review and meta-analysis. *Endocrinol Diab Metab*. 2020;4(1):e00176. doi:10.1002/edm2.176
56. Sharma A, Garg A, Rout A, Lavie CJ. Association of obesity with more critical illness in COVID-19. *Mayo Clin Proc*. 2020;95(9):2040-2042. doi:10.1016/j.mayocp.2020.06.046
57. Soeroto AY, Soetedjo NN, Purwiga A, et al. Effect of increased BMI and obesity on the outcome of COVID-19 adult patients: a systematic review and meta-analysis. *Diab Metab Syndr*. 2020;14(6):1897-1904. doi:10.1016/j.dsx.2020.09.029
58. Tamara A, Tahapary DL. Obesity as a predictor for a poor prognosis of COVID-19: a systematic review. *Diab Metab Syndr*. 2020;14(4):655-659. doi:10.1016/j.dsx.2020.05.020

59. Tsankov BK, Allaire JM, Irvine MA, et al. Severe COVID-19 infection and pediatric comorbidities: a systematic review and meta-analysis. *Int J Infect Dis*. 2021;103:246-256. doi:10.1016/j.ijid.2020.11.163
60. Yang J, Ma Z, Lei Y. A meta-analysis of the association between obesity and COVID-19. *Epidemiol Infect*. 2020;149:e11. doi:10.1017/s0950268820003027
61. Yang J, Tian C, Chen Y, Zhu C, Chi H, Li J. Obesity aggravates COVID-19: an updated systematic review and meta-analysis. *J Med Virol*. 2021;93(5):2662-2674. doi:10.1002/jmv.26677
62. Zhao X, Gang X, He G, et al. Obesity increases the severity and mortality of influenza and COVID-19: a systematic review and meta-analysis. *Front Endocrinol (Lausanne)*. 2020;11:595109. doi:10.3389/fendo.2020.595109
63. Zhou Y, Yang Q, Chi J, et al. Comorbidities and the risk of severe or fatal outcomes associated with coronavirus disease 2019: a systematic review and meta-analysis. *Int J Infect Dis*. 2020;99:47-56. doi:10.1016/j.ijid.2020.07.029
64. Bunn C, Al-Naimi S, Rajic A, Ibrahim F. Obesity as a risk factor for the admission of COVID-19 patients into ICU: a systematic review and meta-analysis. *Proc Nutr Soc*. 2022;81(OCE1):E23. doi:10.1017/S0029665122000234
65. Cai Z, Yang Y, Zhang J. Obesity is associated with severe disease and mortality in patients with coronavirus disease 2019 (COVID-19): a meta-analysis. *BMC Public Health*. 2021;21(1):1505. doi:10.1186/s12889-021-11546-6
66. Choi JH, Choi SH, Yun KW. Risk factors for severe COVID-19 in children: a systematic review and meta-analysis. *J Korean Med Sci*. 2022;37(5):e35. doi:10.3346/jkms.2022.37.e35
67. Chowdhury AI, Alam MR, Rabbi MF, Rahman T, Reza S. Does higher body mass index increase COVID-19 severity? A systematic review and meta-analysis. *Obes Med*. 2021;23:100340. doi:10.1016/j.obmed.2021.100340
68. Dessie ZG, Zewotir T. Mortality-related risk factors of COVID-19: a systematic review and meta-analysis of 42 studies and 423,117 patients. *BMC Infect Dis*. 2021;21(1):855. doi:10.1186/s12879-021-06536-3
69. Geng J, Yu X, Bao H, et al. Chronic diseases as a predictor for severity and mortality of COVID-19: a systematic review with cumulative meta-analysis. *Front Med*. 2021;8:588013. doi:10.3389/fmed.2021.588013
70. Huang HK, Bukhari K, Peng CC, et al. The J-shaped relationship between body mass index and mortality in patients with COVID-19: a dose-response meta-analysis. *Diabetes Obes Metab*. 2021;23(7):1701-1709. doi:10.1111/dom.14382
71. La Verde M, Riemma G, Torella M, et al. Maternal death related to COVID-19: a systematic review and meta-analysis focused on maternal co-morbidities and clinical characteristics. *Int J Gynaecol Obstet*. 2021;154(2):212-219. doi:10.1002/ijgo.13726
72. Lassi ZS, Ana A, Das JK, et al. A systematic review and meta-analysis of data on pregnant women with confirmed COVID-19: clinical presentation, and pregnancy and perinatal outcomes based on COVID-19 severity. *J Glob Health*. 2021;11:05018. doi:10.7189/jogh.11.05018
73. Li X, Zhong X, Wang Y, Zeng X, Luo T, Liu Q. Clinical determinants of the severity of COVID-19: a systematic review and meta-analysis. *PLoS ONE*. 2021;16(5):e0250602. doi:10.1371/journal.pone.0250602
74. Li Y, Ashcroft T, Chung A, et al. Risk factors for poor outcomes in hospitalised COVID-19 patients: a systematic review and meta-analysis. *J Glob Health*. 2021;11:10001. doi:10.7189/jogh.11.10001
75. Mahamat-Saleh Y, Fiolet T, Rebeaud ME, et al. Diabetes, hypertension, body mass index, smoking and COVID-19-related mortality: a systematic review and meta-analysis of observational studies. *BMJ Open*. 2021;11(10):e052777. doi:10.1136/bmjopen-2021-052777
76. Mattey-Mora PP, Begle CA, Owusu CK, Chen C, Parker MA. Hospitalised versus outpatient COVID-19 patients' background characteristics and comorbidities: a systematic review and meta-analysis. *Rev Med Virol*. 2022;32(3):e2306. doi:10.1002/rmv.2306
77. Ovalle DLP, Rodrigo-Cano S, González A, et al. COVID obesity: a one-year narrative review. *Nutrients*. 2021;13(6):2060. doi:10.3390/nu13062060
78. Raeisi T, Mozaffari H, Sepehri N, et al. The negative impact of obesity on the occurrence and prognosis of the 2019 novel coronavirus (COVID-19) disease: a systematic review and meta-analysis. *Eat Weight Disord*. 2022;27(3):893-911. doi:10.1007/s40519-021-01269-3
79. Rosário Ferreira ME, Santos de Andrade AV, Ferreira Queiroz AA, et al. COVID-19 and obesity: a systematic review and meta-analysis on the pre-existing clinical conditions, COVID-19 symptoms, laboratory findings and clinical outcomes. *EXCLI j*. 2021;20:1610-1614. doi:10.17179/excli2021-4226
80. Wang Y, Hou H, Xu J, Wang Y, Yang H. The association between obesity and ICU admission among COVID-19 patients: a meta-analysis of adjusted risk estimates. *Am J Emerg Med*. 2022;56:318-320. doi:10.1016/j.ajem.2021.08.054
81. Wang Y, Xu J, Wang Y, Hou H, Feng H, Yang H. An updated meta-analysis on the relationship between obesity and COVID-19 mortality. *Metabol Clin Exp*. 2021;122:154820. doi:10.1016/j.metabol.2021.154820
82. Zhang X, Lewis AM, Moley JR, Brestoff JR. A systematic review and meta-analysis of obesity and COVID-19 outcomes. *Sci Rep*. 2021;11(1):7193. doi:10.1038/s41598-021-86694-1
83. Zhou P, Yang X-L, Wang X-G, et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature*. 2020;579(7798):270-273. doi:10.1038/s41586-020-2012-7
84. O'Driscoll M, Ribeiro Dos Santos G, Wang L, et al. Age-specific mortality and immunity patterns of SARS-CoV-2. *Nature*. 2021;590(7844):140-145. doi:10.1038/s41586-020-2918-0
85. Yang J, Zheng Y, Gou X, et al. Prevalence of comorbidities and its effects in patients infected with SARS-CoV-2: a systematic review and meta-analysis. *Int J Infect Dis*. 2020;94:91-95. doi:10.1016/j.ijid.2020.03.017
86. Yates T, Razieh C, Zaccardi F, Davies MJ, Khunti K. Obesity and risk of COVID-19: analysis of UK biobank. *Prim Care Diabetes*. 2020;14(5):566-567. doi:10.1016/j.pcd.2020.05.011
87. Gao M, Piernas C, Astbury NM, et al. Associations between body-mass index and COVID-19 severity in 6·9 million people in England: a prospective, community-based, cohort study. *Lancet Diab Endocrinol*. 2021;9(6):350-359. doi:10.1016/S2213-8587(21)00089-9
88. Sattar N, Ho FK, Gill JMR, et al. BMI and future risk for COVID-19 infection and death across sex, age and ethnicity: preliminary findings from UK biobank. *Diabetes Metab Syndr Clin Res Rev*. 2020;14(5):1149-1151. doi:10.1016/j.dsx.2020.06.060
89. Yates T, Summerfield A, Razieh C, et al. A population-based cohort study of obesity, ethnicity and COVID-19 mortality in 12.6 million adults in England. *Nat Commun*. 2022;13(1):624. doi:10.1038/s41467-022-28248-1
90. Paravidino VB, Leite TH, Mediano MFF, et al. Association between obesity and COVID-19 mortality and length of stay in intensive care unit patients in Brazil: a retrospective cohort study. *Sci Rep*. 2022;12(1):13737. doi:10.1038/s41598-022-17197-w
91. Hendren NS, de Lemos JA, Ayers C, et al. Association of body mass index and age with morbidity and mortality in patients hospitalized with COVID-19: results from the American Heart Association COVID-19 Cardiovascular Disease Registry. *Circulation*. 2021;143(2):135-144. doi:10.1161/circulationaha.120.051936
92. Williamson EJ, Walker AJ, Bhaskaran K, et al. Factors associated with COVID-19-related death using OpenSAFELY. *Nature*. 2020;584(7821):430-436. doi:10.1038/s41586-020-2521-4

93. Di Angelantonio E, Bhupathiraju SN, Wormser D, et al. Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents. *Lancet*. 2016; 388(10046):776-786. doi:10.1016/s0140-6736(16)30175-1
94. Sattar N, Valabhji J. Obesity as a risk factor for severe COVID-19: summary of the best evidence and implications for health care. *Curr Obes Rep*. 2021;10(3):282-289. doi:10.1007/s13679-021-00448-8
95. Ritter A, Kreis N-N, Louwen F, Yuan J. Obesity and COVID-19: molecular mechanisms linking both pandemics. *Int J Mol Sci*. 2020; 21(16):5793. doi:10.3390/ijms21165793
96. Maurya R, Sebastian P, Namdeo M, Devender M, Gertler A. COVID-19 severity in obesity: leptin and inflammatory cytokine interplay in the link between high morbidity and mortality. *Front Immunol*. 2021; 12:649359. doi:10.3389/fimmu.2021.649359
97. Gammone MA, D'Orazio N. Review: obesity and COVID-19: a detrimental intersection. *Front Endocrinol (Lausanne)*. 2021;12:652639. doi:10.3389/fendo.2021.652639
98. Korakas E, Ikonomidis I, Kousathana F, et al. Obesity and COVID-19: immune and metabolic derangement as a possible link to adverse clinical outcomes. *Am J Physiol Endocrinol Metab*. 2020;319(1):E105-E109. doi:10.1152/ajpendo.00198.2020
99. Sattar N, McInnes IB, McMurray JJV. Obesity is a risk factor for severe COVID-19 infection: multiple potential mechanisms. *Circulation*. 2020;142(1):4-6. doi:10.1161/circulationaha.120.047659
100. Alberga AS, Edache IY, Forhan M, Russell-Mayhew S. Weight bias and health care utilization: a scoping review. *Prim Health Care Res Dev*. 2019;20:e116. doi:10.1017/s1463423619000227
101. Le Brocq S, Clare K, Bryant M, et al. Obesity and COVID-19: a call for action from people living with obesity. *Lancet Diabetes Endocrinol*. 2020;8(8):652-654. doi:10.1016/S2213-8587(20)30236-9
102. Sallis R, Young DR, Tartof SY, et al. Physical inactivity is associated with a higher risk for severe COVID-19 outcomes: a study in 48 440 adult patients. *Br J Sports Med*. 2021;55(19):1099-1105. doi:10.1136/bjsports-2021-104080
103. UK Chief Medical Officers' Physical Activity Guidelines (2019).
104. Khan MA, Menon P, Govender R, et al. Systematic review of the effects of pandemic confinements on body weight and their determinants. *Br J Nutr*. 2021;12(2):1-74. doi:10.1017/s0007114521000921
105. Tadayon Najafabadi B, Rayner DG, Shokraee K, et al. Obesity as an independent risk factor for COVID-19 severity and mortality. *Cochrane Database Syst Rev*. 2023;5(5):Cd015201. doi:10.1002/14651858.Cd015201
106. Supporting weight management services during the COVID-19 pandemic - Phase I insights (Public Health England) (2020).
107. Polack FP, Thomas SJ, Kitchin N, et al. Safety and efficacy of the BNT162b2 mRNA Covid-19 vaccine. *N Engl J Med*. 2020;383(27): 2603-2615. doi:10.1056/NEJMoa2034577
108. Baden LR, El Sahly HM, Essink B, et al. Efficacy and safety of the mRNA-1273 SARS-CoV-2 vaccine. *N Engl J Med*. 2021;384(5):403-416. doi:10.1056/NEJMoa2035389
109. Voysey M, Clemens SAC, Madhi SA. Safety and efficacy of the ChAdOx1 nCoV-19 vaccine (AZD1222) against SARS-CoV-2: an interim analysis of four randomise d controlled trials in Brazil, South Africa, and the UK. *Lancet*. 2021;397(10269):99-111. doi:10.1016/S0140-6736(20)32661-1
110. Piernas C, Patone M, Astbury NM, et al. Associations of BMI with COVID-19 vaccine uptake, vaccine effectiveness, and risk of severe COVID-19 outcomes after vaccination in England: a population-based cohort study. *Lancet Diabetes Endocrinol*. 2022;10(8):571-580. doi:10.1016/s2213-8587(22)00158-9

## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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