A meta-analysis of the association between obesity and COVID-19

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Abstract

Owing to limited data, we conducted a meta-analysis to re-evaluate the relationship between obesity and coronavirus-2019 (COVID-19). Literature published between 1 January 2020 and 22 August 2020 was comprehensively analysed, and RevMan3.5 was used for data analysis. A total of 50 studies, including data on 18,260,378 patients, were available. Obesity was associated with a higher risk of severe acute respiratory syndrome-coronavirus 2 (SARS-CoV2) infection (odds ratio (OR): 1.39, 95% confidence interval (CI) 1.25–1.54; P < 0.00001) and increased severity of COVID-19 (hospitalisation rate: OR: 2.45, 95% CI 1.78–3.39; P < 0.00001; severe cases: OR: 3.74, 95% CI 1.18–11.87; P: 0.02; need for intensive care unit admission: OR: 1.30, 95% CI 1.21–1.40; P < 0.00001; need for invasive mechanical ventilation: OR: 1.59, 95% CI 1.35–1.88; P < 0.00001 and mortality: OR: 1.65, 95% CI 1.21–2.25; P: 0.001). However, we found a non-linear association between BMI and the severity of COVID-19. In conclusion, we found that obesity could increase the risk of SARS-CoV2 infection and aggregate the severity of COVID-19. Further studies are needed to explore the possible mechanisms behind this association.

Introduction

In late December 2019, a pneumonia-like disease of unknown aetiology was reported in Wuhan [1], China, which was eventually identified to be caused by severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2). This pneumonia was renamed coronavirus disease 2019 (COVID-19) and was announced by the World Health Organization (WHO) as a global pandemic on 11 March 2020. As of 8 November 2020, there have been 49,578,590 infected cases and 1,245,717 deaths reported on the WHO dashboard [2]. Clinical manifestations of COVID-19 range from no or mild symptoms to severe pneumonia, acute respiratory distress syndrome (ARDS), or even multiorgan failure and death.

A meta-analysis compromising 18,506 patients investigated the association between diabetes and COVID-19 and found diabetes was associated with a 65% higher risk for death [3]. Other risk factors, such as cardiovascular disease and hypertension, have also been shown to increase the severity of COVID [4–6]. The diseases mentioned above are usually associated with excessive adipose tissue accumulation causing metabolic and inflammatory changes [7–9]. Obesity has been identified as an independent predisposition factor for severe cases of severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS) infection [10], and a high genetic similarity was observed between SARS-CoV-2 and SARS-CoV (80%) and MERS-CoV (50%) [11]. These data indicate that obesity might be a risk factor for the severity of COVID-19.

One previous study in China showed that only 18.95% of survivors were overweight, and 88.24% of non-survivors had a higher body mass index (BMI) [12]. In Germany, patients with ARDS were more overweight or obese (83%) than those with healthy BMI (42%) [13]. More recently, some meta-analyses showed that obesity was associated with mortality, severity and predicted poor outcome in COVID-19 patients [14–17]. However, there are some limitations to these meta-analyses. First, the number of eligible studies is small, ranging from 9 to 14. Second, the data from other countries are scarce, and most eligible studies are from China and the USA. Third, the definition of obesity is different between Eastern and Western countries. Last, the conclusions of previous meta-analyses may be altered due to the recent emergence of a large number of studies about the association between obesity and COVID-19. Europe and North America, which have the highest prevalence of obesity cases, has become the epicentre of the COVID-19 pandemic [18]. Therefore, it is necessary to re-explore the relationship between obesity and COVID-19, including susceptibility to SARS-CoV-2 infection, which was not analysed in previous meta-analyses and poor outcomes, as we have performed in the meta-analysis presented here.
**Methods**

**Research strategy**

This meta-analysis was performed following the PRISMA guidelines. A comprehensive search was performed using the PubMed, EMBASE and Cochrane Library databases for literature published between 1 January 2020 and 25 August 2020. The following words were utilised during the search: (COVID-19 or coronavirus or SARS-CoV-2) and (obesity or overweight or body mass index). Reference lists of eligible studies and relevant review articles were screened and evaluated for additional studies that could be used in analyses.

**Inclusion and exclusion criteria**

Inclusion criteria for the studies in our analyses were as follows:

1. Studies published in English
2. Studies investigating the association between obesity or overweight and COVID-19.
3. Studies including both adults and children diagnosed with COVID-19.
4. Cohort studies with prospective or retrospective designs.

Exclusion criteria from analyses were:
Table 1. Baseline characteristics of the eligible studies

| Study          | Region   | Centre(s) | Design          | Obesity % | Total   | Male | Age (yr) | Outcomes                                                                 | NOS score |
|----------------|----------|-----------|-----------------|-----------|---------|------|----------|---------------------------------------------------------------------------|-----------|
| Alkhateib [19] | USA      | Single    | Retrospective   | 60.76     | 158     | 61   | 57       | ICU admission                                                            | 7         |
| Argenziano [20]| USA      | Single    | Retrospective   | 41.85     | 1000    | 596  | 63       | 50–75 ICU admission                                                      | 7         |
| Bello-Chavolla [21] | Mexico  | Multiple  | Retrospective   | 16.42     | 177133  | 90582| 42.58    | Risk of COVID-19 infection Mortality ICU admission Need of IMV            | 7         |
| Buckner [22]   | USA      | Multiple  | Retrospective   | 47.31     | 105     | 53   | 69       | 23–97 Severe cases                                                       | 7         |
| Busetto [11]   | Italy    | Single    | Retrospective   | 31.52     | 92      | 57   | 70.5 ±13.3 | Mortality ICU admission Need of IMV                                    | 8         |
| Cai1 [23]      | China    | Single    | Retrospective   | NA        | 298     | 145  | 47       | 33–61 Severe cases                                                      | 7         |
| Cai2 [24]      | China    | Single    | Retrospective   | 10.70     | 383     | 183  | 48.4     | Severe cases                                                            | 7         |
| Caussy [25]    | France   | Single    | Retrospective   | 25        | 340     | NA   | NA       | Severe cases                                                            | 7         |
| Chand [26]     | USA      | Multiple  | Retrospective   | 54.33     | 300     | 182  | 57.8 ±12.2 | Mortality                                                              | 8         |
| Chao [27]      | USA      | Single    | Retrospective   | 26.09     | 46      | 31   | 13.1 ±0.4–19.3 | ICU admission                                                           | 7         |
| Cummings [29]  | USA      | Double    | Prospective     | 46.30     | 257     | 171  | 62       | 51–72 Mortality                                                         | 8         |
| Czernichow [28]| France   | Multiple  | Prospective     | 21.81     | 5795    | 3791 | NA       | Mortality                                                               | 8         |
| Docherty [30]  | UK       | Multiple  | Prospective     | 10.48     | 20133   | 12068| 73       | 58–82 Mortality                                                         | 8         |
| Duanmu [31]    | USA      | Single    | Retrospective   | 22        | 100     | 56   | 45       | 32–65 Hospitalisation                                                   | 7         |
| Escalera-Antezana [32] | Bolivia | Single    | Retrospective   | 5.61      | 107     | 55   | 43.9 ±17.6 | Mortality                                                              | 8         |
| Gao [33]       | China    | Multiple  | Retrospective   | 50        | 150     | 94   | 48       | Severe cases                                                            | 7         |
| Gerwen [34]    | USA      | Multiple  | Retrospective   | 28.95     | 3703    | 2049 | 56.8 ±18.2 | Mortality Need of IMV Hospitalisation                                  | 8         |
| Giannouchos [35]| Mexico   | Multiple  | Retrospective   | 16.7      | 236439  | 120347| 42.5 ±16.9 | Risk of COVID-19 infection Hospitalisation                              | 7         |
| Goyal1 [36]    | USA      | Single    | Retrospective   | 34.60     | 393     | 238  | 62.2     | 48.6–73.7 Need of IMV                                                    | 7         |
| Goyal2 [37]    | USA      | Double    | Retrospective   | 31.12     | 1687    | 1004 | 66.5     | 53.7–77.2 Mortality                                                     | 8         |
| Giracomelli [38]| Italy    | Single    | Prospective     | 16.31     | 233     | 161  | 61       | 50–72 Mortality                                                         | 8         |

(Continued)
| Study          | Region           | Centre(s)       | Design       | Obesity n% | Total | Male | Age      | Outcomes                  | NOS score |
|---------------|------------------|-----------------|--------------|------------|-------|------|----------|----------------------------|------------|
| Hajifathalian [39] | USA              | Double Retrospective | 35.97        | 770        | 468   | 63.5 ± 17 | Mortality ICU admission Need of IMV | 8          |
| Halasz [40]    | Italy            | Single Retrospective | 19.83        | 242        | 194   | 64 56-71 | Mortality                      | 8          |
| Hamer [41]     | UK               | Multiple Prospective | 23.84        | 334 329    | 152 162 | NA   | Risk of COVID-19 infection | 7          |
| Hu [42]        | China            | Single Retrospective | 4.02         | 323        | 166   | 61 23-91 | Severe cases                  | 7          |
| Hur [43]       | USA              | Multiple Retrospective | 53.29        | 486        | 271   | 59 47-69 | Need of IMV                   | 7          |
| Jung [44]      | South Korea      | Multiple Retrospective | NA           | 18 940     | 7185  | 53.7 ± 13.8 | Risk of COVID-19 infection   | 7          |
| Kalligeros [45] | USA              | Single Retrospective | 47.57        | 103        | 63    | 60 50-72 | ICU admission Need of IMV    | 7          |
| Killerby [46]  | Atlanta          | Multiple Retrospective | 42.75        | 531        | 228   | 51.63 | Hospitalisation              | 7          |
| Kim [47]       | USA              | Multiple Retrospective | 46.33        | 2491       | 1326  | 62 50-75 | ICU admission                | 7          |
| Klang [48]     | USA              | Single Retrospective | 36.14        | 3406       | 1961  | 65.9  | Mortality                      | 8          |
| Lighter [49]   | USA              | Single Retrospective | 37.90        | 3615       | NA    | NA    | Hospitalisation ICU admission | 7          |
| Lodigiani [67] | Italy            | Single Retrospective | 23.97        | 388        | 264   | 66    | ICU admission                  | 7          |
| Lusignan [50]  | UK               | Multiple Retrospective | 21.70        | 3802       | 1612  | NA    | Risk of COVID-19 infection   | 7          |
| Monterio [51]  | USA              | Single Retrospective | 35.71        | 112        | 74    | 61 45-74 | Need of IMV                   | 7          |
| Nakeshbandi [52] | USA              | Single Retrospective | 42.66        | 504        | 263   | 68 ± 15 | Mortality Need of IMV       | 8          |
| Ong [53]       | Singapore        | Single Retrospective | NA           | 91         | 51    | 54.92 | Mortality ICU admission Need of IMV | 7          |
| Oriz-Brizuela [54] | Mexico         | Single Prospective | 21.68        | 309        | 183   | 43 33-54 | Hospitalisation ICU admission | 7          |
| Palaiodimos [55] | USA              | Single Retrospective | NA           | 200        | 98    | 64 50-73.5 | Mortality Need of IMV     | 8          |
| Parra-Bracamonte [56] | Mexico       | Multiple Retrospective | 19.92        | 142 690    | 79 280 | 45 34-57 | Mortality                      | 8          |
| Petrelli [57]  | USA              | Multiple Retrospective | 26.81        | 4103       | 2072  | 52 36-65 | Hospitalisation Severe cases | 7          |
| Price-Haywood [58] | USA            | Single Retrospective | 49.61        | 3481       | 1394  | 54    | Hospitalisation                | 7          |
| Shah [59]      | USA              | Multiple Retrospective | 66.48        | 522        | 347   | 63 50-72 | Mortality                      | 8          |
Data assessment

Two individual authors (Jiao Yang and ZhiYing Ma) independently extracted the following information: study design, age, gender, susceptibility to COVID-19, the severity of COVID-19 (need for hospitalisation, severe cases, need for intensive care unit (ICU) admission, need for invasive mechanical ventilation (IMV) and mortality). Severe COVID-19 was defined according to the American Thoracic Society guidelines.

Statistical analysis

RveMan5.3 (Cochrane Collaboration) was used to analyse data with associated odds ratios (OR) and corresponding 95% confidence intervals (CIs). The generic inverse variance approach was used for the meta-analysis. A \( P < 0.05 \) was identified as statistically significant. The \( I^2 \) statistic was used to assess the heterogeneity among the studies analysed. An \( I^2 > 50\% \) or \( P < 0.1 \) indicated heterogeneity, for which the random-effects model was utilised. Otherwise, the fixed-effects model was used. In addition, publication bias was evaluated through visual inspections of funnel plots, and the quality of eligible studies was assessed using the Newcastle-Ottawa Quality Assessment Scale.

Results

Study characteristics

A total of 50 studies [11, 19–67] that included 18 260 378 subjects were eligible for the meta-analysis. Out of these 50 studies, 44 were retrospective and 6 were prospective cohort studies. Twenty-five studies were conducted in the USA, 6 in China, 4 in Italy, 4 in the UK, 4 in Mexico, 3 in France and 1 in Brazil, Singapore, South Korea and Bolivia. The incidence of obesity, defined as BMI \( \geq 30 \), varied from 5.57\% to 68.48\% in this meta-analysis. Detailed search strategies and characteristics of eligible studies are presented in Fig. 1 and Table 1, respectively. The Newcastle–Ottawa Quality Assessment Scale scores for all included studies were equal to or more than 6, as shown in Table 1, which is acceptable for a meta-analysis.

Outcomes

Risk of COVID-19

Five studies involving 753 597 cases mentioned the association between obesity and the risk of SARS-CoV2 infection. We used the random-effects model for analysis due to a high heterogeneity (\( P < 0.00001 \) and \( I^2 = 92\% \)) between studies. This model suggested that obese subjects had a higher risk of SARS-CoV2 infection as compared to those without obesity (OR: 1.39; 95% CI 1.25–1.54; \( P < 0.00001 \) (Fig. 2).

Severity of COVID-19

Hospital admission: We conducted a stratified analysis to assess the relationship between BMI ranges and the need for hospital admission in patients with COVID-19. Patients with a BMI 25–29.9, BMI \( \geq 30 \) and BMI \( \geq 35 \) had higher rates of hospital admission than those with a BMI <25 (OR: 2.09, 95% CI 1.22–3.60, \( P\):
1.35

and the need for IMV in patients with COVID-19. We compared a higher prevalence of severe cases than those with BMI < 30

BMI than those with mild disease (OR: 1.18, 95% CI 1.09–1.37, P: 0.4) than those with a healthy weight, as shown in Figure 3.

Severe cases: Ten studies reported on the association between BMI and severe cases of COVID-19. Four trials comprising 794 patients showed that those with severe diseases had a higher BMI than those with mild disease (OR: 1.18, 95% CI 1.09–1.27, P < 0.0001) (Fig. 3). In addition, patients with a BMI ≥ 30 had a higher prevalence of severe cases than those with BMI < 30 (OR: 3.74, 95% CI 1.18–11.87, P: 0.02) (Fig. 3).

ICU admission: Eleven studies evaluated the incidence of ICU care in COVID-19 patients. A stratified analysis on the association of the different BMI classes and the rate of ICU admission was conducted. Patients with COVID-19 with a BMI ≥30, BMI ≥35 and ≥40 had a higher probability of requiring ICU admission than those with a BMI < 30 (OR: 1.30, 95% CI 1.21–1.40, P < 0.00001; OR: 1.86, 95% CI 1.31–2.63, P: 0.005 and OR: 1.96, 95% CI 1.27–3.02, P: 0.002, respectively), as shown in Figure 4. However, patients with a BMI >25 or BMI 30–34.9 showed no significantly higher rate of ICU admission than those with a BMI < 25 or BMI <30 (OR: 3.10, 95% CI 0.76–12.61, P: 0.11 and OR: 1.44, 95% CI 0.74–2.81, P: 0.28, respectively) (Fig. 4).

IMV: Thirteen studies assessed the association between BMI and the need for IMV in patients with COVID-19. We compared the requirement of IMV in different BMI groups and found that the need for IMV was notably raised in patients with a BMI >25, BMI ≥30, BMI ≥35 and BMI ≥40 compared to those with a BMI <25 (OR: 1.40, 95% CI 1.13–1.73, P: 0.002; OR: 1.59, 95% CI 1.35–1.88, P < 0.00001; OR: 5.22, 95% CI 2.46–11.07, P < 0.0001 and OR: 1.97, 95% CI 1.24–3.12, P: 0.004, respectively) (Fig. 5).

Mortality

Fourteen studies investigated the association between different BMI categories and mortality. As shown in Figure 6, the mortality was significantly higher in patients with a BMI ≥30, BMI 35–39.9 and BMI ≥40 than those with a BMI < 30 (OR: 1.65, 95% CI 1.21–2.25, P: 0.001; OR: 1.91, 95% CI 1.04–3.49, P: 0.04 and OR: 1.71, 95% CI 1.32–2.22, P: < 0.0001, respectively). Nevertheless, patients with a BMI between 25 and 29.9 and a BMI between 30 and 34.9 did not have a statistically significant higher risk of mortality than those with a BMI <25 (OR: 1.10, 95% CI 0.84–1.45, P: 0.48 and OR: 1.38, 95% CI 0.94–2.04, P: 0.1) (Fig. 6).

Publication bias

The publication bias was assessed using a visual funnel plot. No obvious publication bias was found for the outcomes assessed ((a) risk of COVID-19; (b) hospital admission; (c) severe cases; (d) ICU admission; (e) need of IMV) as shown in Figure 7.

Discussion

Our study found obesity increased the prevalence of SARS-CoV2 infection and the severity of COVID-19 (as assessed by the need for hospitalisation, severe cases, need for ICU admission, need for IMV and mortality). Patients with overweight presented with a higher rate of hospitalisation and higher requirement of IMV. However, a non-linear association between BMI and the severity of COVID-19 was found. To our knowledge, this study is the largest meta-analysis conducted so far to comprehensively explore the association between obesity and COVID-19.

Yates et al. analysed UK biobank data and found that overweight and obese patients were at a higher risk of getting the SARS-CoV-2 in a dose–response manner. Compared to a healthy weight, overweight, obese and severely obese (BMI ≥35) subjects had a 1.31-, 1.55-, or 1.57-fold higher probability of SARS-CoV-2 positivity [68]. Chadeau-Hyam et al. reported that severe obesity is independently associated with the risk of obtaining COVID-19 with an odds ratio >1.05 by analysing the data from Public Health England [69]. In our meta-analysis, patients with a BMI ≥30 had a 1.39 times higher chance of having COVID-19 than those with a healthy weight, which was in line with previous studies.

Obesity was the most prevalent condition in inpatients with COVID-19 aged 18–49 years in a study conducted by Garg et al. [70], which suggests that obesity may increase the hospitalisation rate of patients with COVID-19. A prospective study in New York revealed that an increase in BMI (e.g. BMI ≥40 with 2.6 odds) in patients with COVID-19 was strongly associated with hospital admission [71]. In our meta-analysis, the odds ratios for hospitalisation rate were 2.09, 2.45 and 2.63 for patients with a BMI of 25–29.9, ≥30 and ≥35, respectively. This suggests that a higher BMI predicts a higher hospitalisation rate for patients with COVID-19. However, no significant association between patients with a BMI 30–34.9 and hospital admission was found, which may be attributed to the limited number of eligible studies reporting on this BMI group.

A study conducted in China reported that there were no patients with underweight who developed severe COVID-19, and that obese patients progressed to severe cases (39% in the obese group, 29.3% in the overweight group and 19.2% in the healthy weight group) [23]. An observational study revealed that severely ill patients had a higher BMI (mean, 24.78 vs. 23.20) than patients with non-severe disease [72]. This indicated that a higher BMI increased the chance of COVID-19 severity. Here, we found that BMI was a major influential factor for COVID-19 progression to severity (OR: 1.18). In addition, obese patients

![Fig. 2. Forrest plot depicting the risk of COVID-19.](https://doi.org/10.1017/S0950268820003027)
Fig. 3. Forrest plot showing the severity of COVID-19: (a) BMI 25-29.9 and hospital admission, (b) BMI ≥ 30 and hospital admission, (c) BMI 30-34.9 and hospital admission, (d) BMI ≥ 35 and hospital admission, (e) BMI and severe cases, (f) BMI ≥ 30 and severe cases.
were 3.74 times more likely to get severe COVID-19 than those with BMI < 30. These data together indicate that obesity or a high BMI increases the chance of severe cases.

A large international multicentre study showed that the mean BMI of critically ill patients was 28.1, and the overall prevalence of obesity was 37.5% [73]. Cai et al. also reported that patients with a BMI ≥ 24 (OR = 1.258, \( P = 0.005 \)) were more likely to be admitted to the ICU [74]. However, we failed to find a positive association between overweight and the risk of ICU admission. However, patients with BMI ≥30 and BMI ≥35 showed a 1.30- and
1.86-fold odds of requiring ICU admission compared to those with a BMI <30. Therefore, there might be a positive correlation between the severity of obesity and the risk of ICU admission. Surprisingly, patients with BMI 30–34.9 presented no significant risk of ICU admission compared to those with BMI <30, which should be confirmed in future studies.

Simonnet et al. reported data from the Lille University centre, showing that severe obesity (BMI ≥35) was associated with a higher requirement for mechanical ventilation compared to patients with a healthy weight (81.8% vs. 41.9%) [60]. In Singapore, Ong et al. found that a BMI ≥25 was significantly associated with mechanical ventilation (OR 1.16) [53]. Moreover, Chetboun et al. reported that the relationship between BMI and the risk of the need for IMV was linear, and the odds were 3.06-fold higher in patients with a BMI ≥40 [73]. In our meta-analysis, the odds of IMV risk in patients with BMI ≥25 and BMI ≥30 were 1.40 and 1.59 times higher than those with BMI <25 and BMI <30. For severely obese patients (BMI ≥35) diagnosed with COVID-19, the odds of requiring IMV were 5.22. However, for morbidly obese patients (BMI ≥40), the odds were 1.97. It appears that no significant linear relationship exists between higher BMI and the requirement of IMV, which is in contrast to previous studies [73].

A retrospective analysis of 112 patients with COVID-19 showed that 88.2% of non-survivors had a BMI ≥25 compared to 18.8% of survivors [75]. Asare et al. showed that 733 of 1930 deaths from COVID-19 were contributed to obesity alone in patients without reported comorbid conditions such as hypertension and cardiovascular disease [76]. On the contrary, no difference in the mortality rates was found between those with obesity and the non-obesity arm [77]. In the study, patients with a BMI between 25 and 29.9 had no significant higher risk of mortality compared to those with a BMI <25. However, the odds ratio of mortality in patients with COVID-19 with a BMI ≥30, BMI 35–39.9 and BMI ≥40

Fig. 5. Forrest plot showing the severity of COVID-19: (a) BMI ≥25 and need for IMV, (b) BMI ≥30 and need for IMV, (c) BMI ≥35 and need for IMV, (d) BMI ≥35 and need for IMV, (e) BMI ≥40 and need for IMV.

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were 1.65, 1.91 and 1.71, respectively. This suggests a positive relationship between obesity and mortality in patients with COVID-19. Surprisingly, patients with a BMI between 30 and 34.9 did not have a higher mortality risk.

The mechanism behind the finding that overweight or obesity may aggravate COVID-19 remains to be elucidated. Possible mechanisms have been presented in previous studies. Zieglet et al. reported that angiotensin-converting enzyme 2 (ACE2)

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**Fig. 6.** Forrest plot showing mortality caused by COVID-19: (a) BMI 25–29.9 and mortality, (b) BMI ≥ 30 and mortality, (c) BMI 30–34.9 and mortality, (d) BMI 35–39.9 and mortality, (e) BMI ≥ 40 and mortality.
facilitates cellular entry of SARS-CoV-2 [78]. Higher concentrations of ACE2 are not only expressed on lung tissues [79, 80], such as bronchial smooth muscle cells and alveolar epithelium, but also on extrapulmonary tissues, specifically the heart, kidney, ileum, jejunum and adipose tissues [79, 81]. The ACE2 gene-expression profile was assessed in the HCCDB gene-expression database, demonstrating that ACE2 gene expression was higher in human subcutaneous and visceral adipose tissue than in human lung tissue [82], indicating excess adiposity may induce higher susceptibility of SARS-CoV-2 infection and higher infection severity in patients with COVID-19. Moreover, studies show that obesity disrupts the immune system, limiting its capacity to deal with a new virus like SARS-CoV-2 [83]. In severe cases, patients may have a cytokine storm, characterised by the overproduction of IL-6,
TNF-α, monocyte chemoattractant protein-1 and leptin, resulting in an increased risk of vascular hyperpermeability and multiorgan failure [84, 85]. Besides, respiratory physiology is altered in patients with obesity, resulting in decreased functional residual capacity and expiratory reserve volume, leading to subsequent ventilation–perfusion abnormalities and hypoxaemia [86, 87]. In addition, obesity has been associated with a high risk of developing venous thromboembolism [88], which is frequently reported in COVID-19 cases and is correlated with a poor prognosis [89].

There are some limitations of this study that should be noted. First, most studies included here were retrospective and were conducted in the USA. Additional prospective studies from other countries should be performed to validate the results presented here. Second, patients suffering from a SARS-CoV2 infection with BMI 30–34.9 presented no significant differences in hospitalisation rates, the need for ICU admission, or mortality compared with those without obesity. This might be attributed to the few eligible studies for this group of patients, and further studies are required to confirm these data. Third, we may have included some studies from this meta-analysis that reported outcomes related to obesity without mentioning the terms (obesity or overweight or body mass index). Last, experimental parameters such as C-reactive protein, interleukin-6, and coagulation index were not evaluated in this study.

In conclusion, obesity might increase the risk of SARS-CoV2 infection and aggravate the severity of COVID-19.

Conflict of interest. None declared.

Data availability statement. The data that support the findings of this study are openly available in at http://doi.org/10.1017/S0950268820003027.

References
1. Zhu N et al. (2020) A novel coronavirus from patients with pneumonia in China, 2019. New England Journal of Medicine 382, 727–733.
2. World Health Organization. WHO Coronavirus Disease (COVID-19) Dashboard. https://covid19.who.int (Accessed 8 November 2020).
3. Palaiodimos I. et al. (2020) Diabetes is associated with increased risk for in-hospital mortality in patients with COVID-19: a systematic review and meta-analysis comprising 18,506 patients. Hormones (Athens). Published online: 29 Oct 2020. doi: 10.1007/s42000-020-00246-2.
4. Zheng Z. et al. (2020) Risk factors of critical & mortal COVID-19 cases: a systematic literature review and meta-analysis. Journal of Infection 81, e16–e25.
5. Zhou F. et al. (2020) Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. The Lancet 395, 1054–1062.
6. Nancy C. et al. (2020) Preliminary estimates of the prevalence of underlying health conditions among patients with coronavirus disease 2019 – United States, February 12–March 28, 2020. Morbidity and Mortality Weekly Report 69, 382–386.
7. Huttunen R and Syrjanen J (2013) Obesity and the risk and outcome of infection. International Journal of Obesity (Lond) 37, 333–340.
8. Malavazos AE. et al. (2020) Targeting the adipose tissue in COVID-19. Obesity (Silver Spring) 28, 1178–1179.
9. Seravalle G GG (2017) Obesity and hypertension. Pharmacological Research 122, 1–7.
10. Van Kerkhove MD et al. (2011) Risk factors for severe outcomes following 2009 influenza A (H1N1) infection: a global pooled analysis. PLOS Medicine 8, e1000153.
11. Busetto L. et al. (2020) Obesity and COVID-19: an Italian snapshot. Obesity (Silver Spring) 28, 1600–1605.
12. Peng YD et al. (2020) Clinical characteristics and outcomes of 112 cardiovascular disease patients infected by 2019-nCoV. Zhonghua Xin Xue Guang Bing Za Zhi 48, E004.
13. Dreher M et al. (2020) The characteristics of 50 hospitalized COVID-19 patients with and without ARDS. Deutsches Arzteblatt International 117, 271–278.
14. Foldi M et al. (2020) Obesity is a risk factor for developing critical condition in COVID-19 patients: a systematic review and meta-analysis. Obesity Reviews 21, e13095.
15. Malik VS et al. (2020) Higher body mass index is an important risk factor in COVID-19 patients: a systematic review and meta-analysis. Environmental Science and Pollution Research 27, 42115–42123.
16. Pranata R et al. (2020) Body mass index and outcome in patients with COVID-19: a dose-response meta-analysis. Diabetes & Metabolism. Published online: 29 Jul 2020. doi: 10.1016/j.diabet.2020.07.005.
17. Yang J et al. (2020) Obesity aggravates COVID-19: a systematic review and meta-analysis. Journal of Medical Virology. Published online: 30 Jun 2020. doi: 10.1002/jmv.26237.
18. World Health Organization. Prevalence of obesity among adults, BMI ≥ 30, age-standardized estimates by WHO region. https://apps.who.int/gho/data/viewmainREGION2480A?lang=en (Accessed 1 November 2020).
19. Alkhatib AL et al. (2020) BMI is associated with coronavirus disease 2019 intensive care unit admission in African Americans. Obesity (Silver Spring) 28, 1795–1801.
20. Argenziano MG et al. (2020) Characterization and clinical course of 1000 patients with coronavirus disease 2019 in New York: retrospective case series. British Medical Journal 369, m1996.
21. Bello-Chavolla OY et al. (2020) Predicting mortality due to SARS-CoV-2: a mechanistic score relating obesity and diabetes to COVID-19 outcomes in Mexico. Journal of Clinical Endocrinology & Metabolism 105, dgga346.
22. Buckner FS et al. (2020) Clinical features and outcomes of 105 hospitalized patients with COVID-19 in Seattle, Washington. Clinical Infectious Diseases 71, 2167–2173.
23. Cai Q et al. (2020) Obesity and COVID-19 severity in a designated hospital in Shenzhen, China. Diabetes Care 43, 1392–1398.
24. Cai Q et al. (2020) COVID-19 in a designated infectious diseases hospital outside Hubei Province, China. Allergy 75, 1742–1752.
25. Causse C et al. (2020) Prevalence of obesity among adult inpatients with COVID-19 in France. The Lancet Diabetes & Endocrinology 8, 562–564.
26. Chand S et al. (2020) COVID-19-associated critical illness-report of the first 300 patients admitted to intensive care units at a New York City Medical Center. Journal of Intensive Care Medicine 35, 963–970.
27. Chao JY et al. (2020) Clinical characteristics and outcomes of hospitalized and critically ill children and adolescents with coronavirus disease 2019 at a tertiary care medical center in New York City. Journal of Pediatrics 223, 14–19.e12.
28. Czernecki S et al. (2020) Obesity doubles mortality in patients hospitalized for SARS-CoV-2 in Paris hospitals, France: a cohort study on 5795 patients. Obesity (Silver Spring). Published online: 20 Aug 2020. doi: 10.1002/oby.23014.
29. Cummings MJ et al. (2020) Epidemiology, clinical course, and outcomes of critically ill adults with COVID-19 in New York city: a prospective cohort study. The Lancet 395, 1763–1770.
30. Docherty AE et al. (2020) Features of 20,133 UK patients in hospital with Covid-19 using the ISARIC WHO clinical characterisation protocol: prospective observational cohort study. British Medical Journal 369, m1985.
31. Duanna Y et al. (2020) Characteristics of emergency department patients With COVID-19 at a single site in Northern California: clinical observations and public health implications. Academic Emergency Medicine 27, 505–509.
32. Escalera-Antezena J et al. (2020) Risk factors for mortality in patients with coronavirus disease 2019 (COVID-19) in Bolivia: an analysis of the first 107 confirmed cases. Le Infezioni in Medicina 28, 238–242.
33. Gao F et al. (2020) Obesity is a risk factor for greater COVID-19 severity. Diabetes Care 43, e72–e74.
34. van Gerwerken M et al. (2020) Risk factors and outcomes of COVID-19 in New York City: a retrospective cohort study. Journal of Medical Virology. Published online: 24 Jul 2020. doi: 10.1002/jmv.26337.

35. Giannouchos TV et al. (2020) Characteristics and risk factors for COVID-19 diagnosis and adverse outcomes in Mexico: an analysis of 89,756 laboratory-confirmed COVID-19 cases. European Respiratory Journal. doi: 10.1183/13993003.02144-2020.

36. Goyal P et al. (2020) Clinical characteristics of Covid-19 in New York City. New England Journal of Medicine 11, 2372–2374.

37. Goyal P et al. (2020) Obesity and COVID-19 in New York City – a retrospective cohort study. Annals of Internal Medicine 173, 855–858.

38. Giacomelli A et al. (2020) 30-day mortality in patients hospitalized with COVID-19 during the first wave of the Italian epidemic: a prospective cohort study. Pharmacological Research 158, 104931.

39. Hajifathalian K et al. (2020) Obesity is associated with worse outcomes in COVID-19: analysis of early data from New York City. Obesity (Silver Spring) 28, 1606–1612.

40. Halasz G et al. (2020) Obesity, overweight and survival in critically ill patients with SARS-CoV-2 pneumonia: is there an obesity paradox? Preliminary results from Italy. European Journal of Preventive Cardiology. Published online: 7 Jul 2020. doi: 10.1177/2047487320939675.

41. Hamer M et al. (2020) Overweight, obesity, and risk of hospitalization for COVID-19: a community-based cohort study of adults in the United Kingdom. Proceedings of the National Academy of Sciences of the United States of America 117, 21011–21013.

42. Hu L et al. (2020) Risk factors associated with clinical outcomes in 323 COVID-19 hospitalized patients in Wuhan, China. Clinical Infectious Diseases. Published online: 3 May 2020. doi: 10.1093/cid/ciaa539.

43. Hur K et al. (2020) Factors associated with intubation and prolonged intubation in hospitalized patients with COVID-19. Otolaryngology Head and Neck Surgery 163, 170–178.

44. Jung CY et al. (2020) Association between body mass index and risk of COVID-19: a nationwide case-control study in South Korea. Clinical Infectious Diseases. Published online: 25 Aug 2020. doi: 10.1093/cid/ciaa1257.

45. Kalligeros M et al. (2020) Association of obesity with disease severity among patients with coronavirus disease 2019. Obesity (Silver Spring) 28, 1200–1204.

46. Killeher ME et al. (2020) Characteristics associated with hospitalization among patients with COVID-19 – metropolitan Atlanta, Georgia, March–April 2020. Morbidity and Mortality Weekly Report 69, 790–794.

47. Kim L et al. (2020) Risk factors for intensive care unit admission and in-hospital mortality among hospitalized adults identified through the U.S. Coronavirus disease 2019 (COVID-19)-associated hospitalization surveillance network (COVID-NET). Clinical Infectious Diseases. Published online: 16 July 2020. doi: 10.1093/cid/ciaa1012.

48. Klang E et al. (2020) Severe obesity as an independent risk factor for COVID-19 mortality in hospitalized patients younger than 50. Obesity (Silver Spring) 28, 1595–1599.

49. Lighter J et al. (2020) Obesity in patients younger than 60 years is a risk factor for COVID-19 hospital admission. Clinical Infectious Diseases 71, 896–897.

50. Lusignan SD et al. (2020) Risk factors for SARS-CoV-2 among patients in the Oxford Royal College of general practitioners research and surveillance centre primary care network: a cross-sectional study. The Lancet Infectious Diseases 20, 1034–1042.

51. Monteiro ACC et al. (2020) Obesity and smoking as risk factors for invasive mechanical ventilation in COVID-19 respiratory failure – a retrospective, observational cohort study. MediRxiv. Published online: 14 Aug 2020. doi: 10.1101/2020.08.12.20173849.

52. Nakeshandi M et al. (2020) The impact of obesity on COVID-19 complications: a retrospective cohort study. International Journal of Obesity 44, 1832–1837.

53. Ong SWX et al. (2020) Association of higher body mass index (BMI) with severe coronavirus disease 2019 (COVID-19) in younger patients. Clinical Infectious Diseases. Published online: 8 May 2020. doi: 10.1093/cid/ciaa548.

54. Ortiz-Brizuela E et al. (2020) Clinical and epidemiological characteristics of patients diagnosed with Covid-19 in a tertiary care center in Mexico City: a prospective cohort study. Revista de Investigación Clinical 72, 165–177.

55. Palaiodimos L et al. (2020) Severe obesity, increasing age and male sex are independently associated with worse in-hospital outcomes, and higher in-hospital mortality, in a cohort of patients with COVID-19 in the Bronx, New York. Metabolism: Clinical and Experimental 108, 154262.

56. Parra-Bracamonte GM et al. (2020) Clinical characteristics and risk factors for mortality of patients with COVID-19 in a large dataset from Mexico. Annals of Epidemiology. Published online: 14 Aug 2020. doi: 10.1016/j.annepidem.2020.08.005.

57. Petrelli C et al. (2020) Factors associated with hospitalization and critical illness among 4,103 patients with Covid-19 disease in New York city. Medicine. Published online: 11 April 2020. doi: 10.1101/2020.04.08.20057794.

58. Price-Haywood EG et al. (2020) Hospitalization and mortality among black patients and white patients with Covid-19. New England Journal of Medicine 382, 2534–2543.

59. Shah P et al. (2020) Demographics, comorbidities and outcomes in hospitalized Covid-19 patients in rural southwest Georgia. Annals of Medicine 52, 354–360.

60. Simonnet A et al. (2020) High prevalence of obesity in severe acute respiratory syndrome Coronavirus-2 (SARS-CoV-2) requiring invasive mechanical ventilation. Obesity (Silver Spring) 28, 1195–1199.

61. Soares RCM et al. (2020) Risk factors for hospitalization and mortality due to COVID-19 in Espirito Santo State, Brazil. American Journal of Tropical Medicine and Hygiene 103, 1184–1190.

62. Suleyman G et al. (2020) Clinical characteristics and morbidity associated with coronavirus disease 2019 in a series of patients in metropolitan Detroit. JAMA Network Open, e2012270.

63. Williamson EJ et al. (2020) Factors associated with COVID-19-related death using OpenSAFELY. Nature 584, 430–436.

64. Wu J et al. (2020) Early antiviral treatment contributes to alleviate the severity and improve the prognosis of patients with novel coronavirus disease COVID-19. Journal of International Medicine 288, 128–138.

65. Zachariah P et al. (2020) Epidemiology, clinical features, and disease severity in patients with Coronavirus disease 2019 (COVID-19) in a children’s hospital in New York City, New York. JAMA Pediatrics 174, e202430.

66. Zheng KJ et al. (2020) Letter to the editor: Obesity as a risk factor for greater severity of COVID-19 in patients with metabolic associated fatty liver disease. Metabolism: Clinical and Experimental 108, 154244.

67. Lodigiani C et al. (2020) Venous and arterial thromboembolic complications in COVID-19 patients admitted to an academic hospital in Milan, Italy. Thrombosis Research 191, 9–14.

68. Yates T et al. (2020) Obesity and risk of COVID-19 – analysis of UK biobank data. International Journal of Epidemiology. Published online: 20 Aug 2020. doi: 10.1093/ije/dyaa134.

69. Garg S et al. (2020) Hospitalization rates and characteristics of patients hospitalized with laboratory-confirmed coronavirus disease 2019 – COVID. Morbidity Mortality Weekly Report 69, 458–464.

70. Petrelli C et al. (2020) Factors associated with hospital admission and critical illness among 5279 people with coronavirus disease 2019 in New York City: a prospective cohort study. British Medical Journal 369, m1996.

71. Chen QQ et al. (2020) Clinical characteristics of 145 patients with coronavirus disease 2019 (COVID-19) in Taizhou. Infection 48, 543–551.

72. Chetboun M et al. (2020) Association of body mass index and other metabolic risk factors with pneumonia outcomes in critically ill patients with coronavirus disease-19: an international multicenter retrospective cohort study. SSRN Electronic Journal.

73. Cai SH et al. (2020) Association between obesity and clinical prognosis in patients infected with SARS-CoV-2. Infectious Diseases of Poverty 9, 80.

74. Peng Y et al. (2020) Clinical characteristics and outcomes of 112 cardiovascular disease patients infected by 2019 -nCoV. Zhonghua Xin Xue Guan Bing Za Zhi 48, 450–455.
76. Asare S et al. (2020) Higher obesity trends Among African Americans are associated with increased mortality in infected COVID-19 patients within the city of Detroit. SN Comprehensive Clinical Medicine. Published online: 30 June 2020. doi: 10.1007/s42399-020-00385-y.

77. Moriconi D et al. (2020) Obesity prolongs the hospital stay in patients affected by COVID-19 and may impact on SARS-CoV-2 shedding. Obesity Research & Clinical Practice 14, 205–209.

78. Ziegler CGK et al. (2020) SARS-CoV-2 receptor ACE2 is an interferon-stimulated gene in human airway epithelial cells and is detected in specific cell subsets across tissues. Cell 181, 1016–1035.

79. Zou X et al. (2020) Single-cell RNA-seq data analysis on the receptor ACE2 expression reveals the potential risk of different human organs vulnerable to 2019-nCoV infection. Frontiers of Medicine 14, 185–192.

80. Verdecchia P et al. (2020) The pivotal link between ACE2 deficiency and SARS-CoV-2 infection. European Journal of International Medicine 76, 14–20.

81. Hamming I et al. (2004) Issue distribution of ACE2 protein, the functional receptor for SARS coronavirus. A first step in understanding SARS pathogenesis. Journal of Pathology 203, 631–637.

82. Al-Benna S (2020) Association of high level gene expression of ACE2 in adipose tissue with mortality of COVID-19 infection in obese patients. Obesity Medicine 19, 100283.

83. Milner JJ et al. (2012) The impact of obesity on the immune response to infection. Proceedings of the Nutrition Society 71, 298–306.

84. Jose RJ et al. (2020) COVID-19 cytokine storm: the interplay between inflammation and coagulation. Lancet Respiratory Medicine 8, e46–e47.

85. van der Voort PHJ et al. (2020) Leptin levels in SARS-CoV-2 infection related respiratory failure: a cross-sectional study and a pathophysiological framework on the role of fat tissue. Heliyon 6, e04696.

86. Bahammam AS SEA-J (2012) Managing acute respiratory decompensation in the morbidly obese. Respirology (Carlton, Vic.) 17, 759–771.

87. Zammit C et al. (2010) Obesity and respiratory diseases. International Journal of General Medicine 3, 335–343.

88. Lorenzet R et al. (2012) Thrombosis and obesity: cellular bases. Thrombosis Research 129, 285–289.

89. Kyriakoulis KG, et al. (2020) Venous thromboembolism in the era of COVID-19. Phlebology: The Journal of Venous Disease. Published online: 10 Sep 2020. doi: 10.1177/0268355520955083.