Scientific Foundation SPIROSKI, Skopje, Republic of Macedonia
Open Access Macedonian Journal of Medical Sciences. 2021 Oct 20; 9(F):410-419.
https://doi.org/10.3889/oamjms.2021.6585
eISSN: 1857-9655
Category: *F - Review Articles*
Section: *Meta-analytic Review Article*

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Are Patients with Coronavirus Disease 2019 and Obesity at a Higher Risk of Hospital and Intensive Care Unit Admissions? A Systematic Review and Meta-analysis

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Edited by: Eli Djulejic
Citation: Wicaksana AL, Hertanti NS, Pramono RB, Hsu YY. Are Patients with Coronavirus Disease 2019 and Obesity at a Higher Risk of Hospital and Intensive Care Unit Admissions? A Systematic Review and Meta-analysis. Open Access Maced J Med Sci. 2021 Oct 20; 9(F):410-419. https://doi.org/10.3889/oamjms.2021.6585
Keywords: Coronavirus disease 2019; Hospital admission; Intensive care unit; Meta-regression; Mortality; Obesity; Severe obesity
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Received: 05-Jun-2021
Revised: 23-Aug-2021
Accepted: 10-Oct-2021

Funding: This research did not receive any financial support
Competing Interests: The authors have declared that no competing interests exist

Abstract

BACKGROUND: Obesity, common condition among patients with coronavirus disease 2019 (COVID-19), contributes to illness severity during hospitalization. To date, knowledge on the prevalence, risk of hospital and intensive care units (ICU) admissions and mortality is limited. Therefore, systematic review and meta-analysis were conducted using a preferred reporting items for systematic reviews and meta-analyses guideline.

AIM: The study aimed to address the prevalence, risk of hospital and ICU admissions and mortality among patients with COVID-19 and obesity.

METHODS: The Newcastle–Ottawa scale was used to assess the quality of a study. Primary outcomes were the prevalence and risk of hospitalization, and secondary outcomes were the risk of ICU admissions and mortality risk. Mantel–Haenszel with random effects was applied, and the effect measure was odds ratio (OR) with 95% confidence interval (CI).

RESULTS: Nine studies were included in the systematic review, and only four studies for meta-analysis. Among 29,776 patients with COVID-19, obesity was identified as the second-highest comorbidity. The prevalence rates of obesity and severe obesity among patients with COVID-19 were 26.1% and 15.5%, respectively. Obesity resulted in significantly increased risk of hospital admission (OR = 1.99, 95% CI = 1.12–3.53, p = 0.02) and ICU admission (OR = 1.77, 95% = CI 1.52–2.06, p < 0.00001). Severe obesity had a significantly increased risk of ICU admission (OR = 1.79, 95% CI = 1.42–2.25, p < 0.00001). The mortality rate of patients with COVID-19 and obesity was about 30.5% (438/1,434), and 19.7% (2,777/14,095) of them recovered from COVID-19.

CONCLUSION: Obesity poses as nearly twice the risk of hospital and ICU admissions, and severe obesity contributes to almost twice the risk of ICU admissions.

Introduction

Chronic diseases, such as hypertension, diabetes, heart, and pulmonary diseases, have been recognized and associated with the severity of coronavirus disease 2019 (COVID-19) [1], [2], [3]. Among all chronic conditions, obesity has been seldom identified as a risk factor of COVID-19 [3], [4], [5], [6]. The previous studies identified that obesity or the body mass index (BMI) is equal to or more than 30, was major risk factor for the severity of COVID- 19 [1], [7], [8]. The prevalence rate of obesity among patients with COVID-19 varies. Bello-Chavolla *et al.* [1] reported 20.7% patients with COVID-19 and obesity, whereas Richardson *et al*. [9] reported 41.7% patients with COVID- 19 and obesity. Other studies have also reported a different prevalence rate of obesity from 26.8% to 47.5% among patients COVID- 19 [2], [10], [11]. To date, COVID- 19 is spreading worldwide, especially in areas where obesity is mostly dominant, such as North American and European countries [3].

Obesity in patients with COVID-19 is associated with adverse outcomes [1], [12], [13] and affects patients' outcomes [2], [3], [7], [10], [11]. Patients with severe COVID-19 and obesity require more hospitalization [10], and some of them even need intensive care because of the nature of disease progression [3], [5], [7], [10], [12]. Furthermore, obesity contributes to the occupation of invasive mechanical ventilation [2], [3] and increases the risk of mortality of patients with COVID-19 [1], [13].

The effect of obesity on patients with COVID- 19 should be explored [3]. Health-care providers and policy makers must identify the risk level and outcomes related to COVID-19 [11]. However, the previous studies were limited in terms of particular areas/countries and number of participants, resulting in a wide range of outcomes of the risk level and causing difficulty in decision-making.

A systematic review and meta-analysis to identify the prevalence of obesity, the risk of hospital and intensive care unit (ICU) admissions, and the mortality risk among patients with COVID-19 and obesity and severe obesity, was conducted. The study aimed to address the following questions: (a) Are patients with COVID-19, obesity, and severe obesity at a high risk of hospital admissions? (b) Are patients with COVID- 19, obesity, and severe obesity at a high risk of ICU admissions? (c) Are patients with COVID-19, obesity, and severe obesity at a high risk of mortality?

Methods

The systematic review and meta-analysis study were conducted and the guideline of the preferred reporting items for systematic reviews and meta-analyses (PRISMA) protocol [14] was applied for selecting the articles.

Eligibility criteria

The prevalence and risk of hospital admissions were determined as the primary outcomes, and the risk of ICU admission and mortality risk was identified as the secondary outcomes. The study design was limited to prospective and retrospective cohort or case control studies. Only published articles in 2020 and written in English were included in the study. The preprint articles did not included to minimize the bias and only peer-reviewed articles were involved. The targeted populations were classified as (1) all patients with COVID-19 and obesity (BMI ≥30) and (2) those who had COVID-19 and severe obesity (BMI ≥35). Commentaries, abstracts, news, editorials, and case reports were excluded from the study.

Search strategy

Science Direct, PubMed, Clinical Keys, and Google Scholar databases were used with two authors (N.S.H. and A.L.W.) were independently searched. Any different findings were communicated and consulted to the third author (R.B.P.). The medical subject heading (MeSH) terms (“COVID-19” OR “severe acute respiratory syndrome coronavirus 2”) AND “Obesity” AND “Hospital Admission” were used in all the databases from January 1, 2020, to May 10, 2020. Researchers searched and used MeSH terms in PubMed as standard terms, and then the terms were used in other databases to make sure the systematic search. The MeSH terms represent biomedical concepts in particular context as assigned label. Articles were selected using the Microsoft Excel spreadsheet and extracted by two authors (N.S.H. and A.L.W.). All the studies that fitted the inclusion criteria were included in the systematic review. From each study, following data were extracted as the number of patients COVID-19; median age; number of males; prevalence of obesity, diabetes, and hypertension; number of hospitalized patients with COVID-19; number of patients who suffered from COVID-19 and were admitted to the ICU; and number of survivors or nonsurvivors. Obesity (BMI ≥ 30) and severe obesity (BMI ≥ 35) were identified when data were available for comparison.

Risk of bias assessment

Newcastle–Ottawa quality assessment scale (NOS) was used to assess the quality of nonrandomized studies in meta-analysis. The NOS was available for case control and cohort studies [15]. For this review, scoring outcomes were classified into three categories, that is, low (<5 stars), moderate (5–7 stars), and high quality (more than 7 stars) [16]. Only studies with at least five stars (moderate level) were analyzed. Funnel plots and Egger’s regression test was utilized to assess publication bias. The publication bias was identified when the studies were asymmetrically distributed or when their concentration at the bottom of the funnel plots was high [17]. Egger’s regression test was performed to detect the asymmetry of the funnel plots. The absence of a significant outcome indicated there is no bias on the selected studies [18].

Data synthesis and analysis

Data were examined using Review Manager 5.3 [19] and comprehensive meta-analysis (CMA) version 3.0 (trial) [20]. The extracted data were classified into primary and secondary outcomes. They were assembled using the random effects of the Mantel– Haenszel model with OR as the effect measure with 95% CI. The Higgins I^2 statistic was utilized to check the heterogeneity among groups [21]. The heterogeneity outcomes were classified into low, moderate, and high when the I^2 was less than 25%, 25–75%, and more than 75%, respectively [16], [22]. Meta-regression with random effect was carried out to explore heterogeneity if the dataset was unavailable to run a sub-group analysis [23].

Results

Outcomes of characteristics of the included studies

At the initial steps, 246 studies were found in the four databases. After duplications were removed, 231 papers were retained for reviewing their abstracts and titles. Only nine studies met the eligibility criteria and were included for a full-text review. They also fitted the criteria for systematic review and provided primary (nine studies on the prevalence of obesity and three studies on the risk of hospital admissions) and secondary outcomes (four studies on the risk of ICU admissions and one study on the risk of mortality; (Table 1). Among the nine studies, only four [1], [2] [10], [11] were eligible for meta-analysis (Figure 1). After the quality was assessed, six and three studies were found to have high and moderate qualities (5–9 stars), respectively. All of the four studies that were included in the meta-analysis indicated a high quality of assessment (8–9 stars).

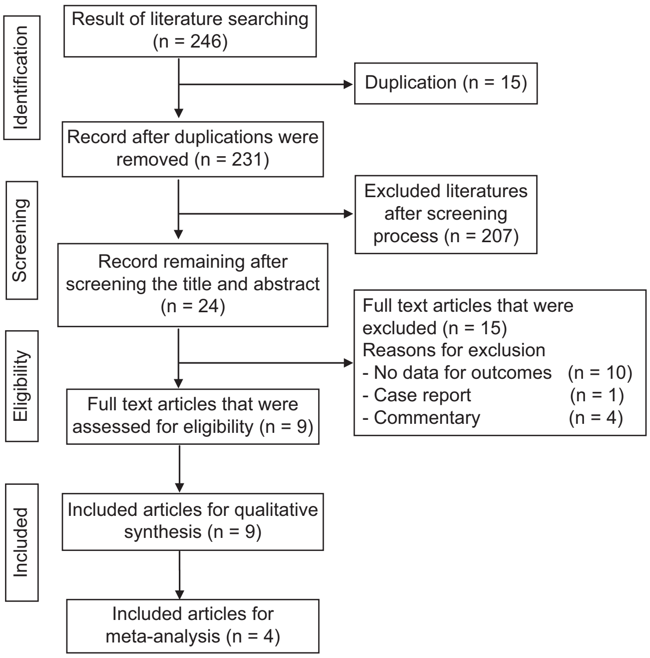

Figure 1: The PRISMA flow chart of the included studies

The total number of patients who had COVID-19 was reported from the nine included studies was 29,776. The median age was between 52 and 72 years, and males were predominant. Obesity was identified as the second-highest comorbidity among patients with COVID-19 (Table 2). All the studies were from American and European countries. Among the nine studies, two studies did not provide the complete information of the participants with COVID-19 [24]. Relevant data were requested from the researchers of the nine studies for further analysis, but no response was received. For this reason, only the available data in the studies were examined.

Prevalence of obesity

The prevalence of obesity among patients with COVID-19 was reported between 20.2% and 47.6% from the nine studies (Table 2). The five studies provided information on the prevalence of severe obesity among patients with COVID-19 from 13.9% to 28.2% (Table 3).

The information about the number of patients with obesity and severe obesity among patients with COVID-19 is presented in Table 3. The pooled prevalence of obesity among patients with COVID-19 from the nine studies was 26.1% (7,759/29,776). By comparison, the pooled prevalence of severe obesity among the patients with COVID-19 from the five included studies was 15.5% (1,516/9,799).

Risk of hospital admissions

The rates of hospital admissions among patients with COVID-19 were between 36.8% and 100%. Five [2], [3], [9], [24], [25] out of the nine studies showed a hospital admission of 100% among the patients with COVID-19 because their study participants were mainly hospitalized patients with COVID-19. The total number of the hospitalized patients with COVID-19 was 17,997 from all the nine studies (Table 2).

Only three [1], [10], [11] out of the nine studies provided the information on obesity among the hospitalized patients with COVID-19. Among 9,372 hospitalized patients with COVID-19, 2896 (30.9%) had obesity. Obesity was the second-highest comorbidity following hypertension. Obesity in patients with COVID- 19 resulted in a significantly increased risk of hospital admission with OR = 1.99 (95% CI = 1.12–3.53, p = 0.02, $Tau^2 = 0.25$, $I^2 = 99\%$), compared with patients with COVID-19 but without obesity (Figure 2).

Only one study [10] provided data about severe obesity among the patients with COVID-19. A total of 233 (17.5%) and 362 (15.8%) patients with COVID-19 and severe obesity were hospitalized and nonhospitalized, respectively.

Table 1: Studies providing data related to outcomes (n = 9)

Study	Obesity prevalence		Hospital admission		ICU admission		Mortality risk	
	BMI ≥ 30	BMI ≥ 35	BMI ≥ 30	BMI ≥ 35	BMI ≥ 30	BMI ≥ 35	BMI ≥ 30	BMI ≥ 35
Bello-Chavola *et al.* [1]	X		X		X		X	
Cummings, *et al.* [24]	X	X						
Petrillli, *et al.* [11]	X		X		X			
McMichael, *et al.* [25]	X							
Garg, *et al.* [25]	X							
Simonnet, *et al.* [3]	X	X						
Lighter, *et al.* [10]	X	X	X	X	X	X		
Richardson, *et al.* [9]	X	X						
Kalligeros, *et al.* [2]	X	X			X	X		

X: Data were available, BMI: Body mass index, ICU: Intensive care unit.

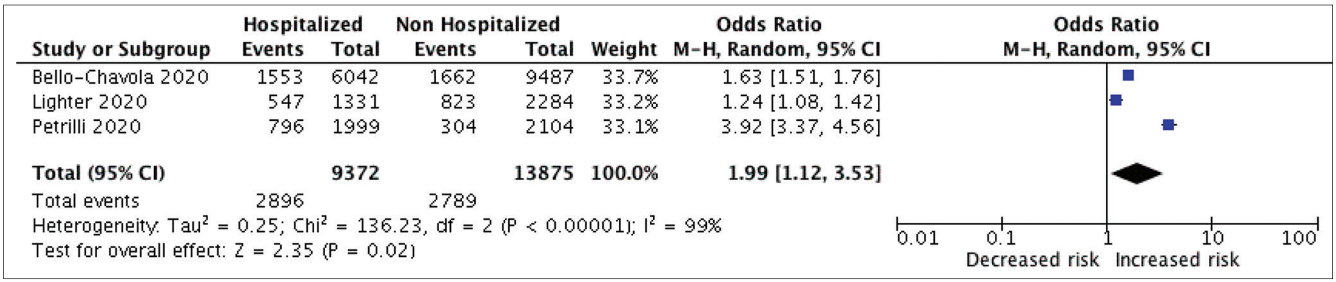

Figure 2: Forest plots of studies exploring the risk of hospital admissions among patients with COVID-19 and obesity (BMI ≥ 30). BMI: Body mass index, CI: Confidence interval.

Table 2: General characteristics of the included studies for systematic review

Authors	N of participants	Median of age	Males n (%)	Obesity n (%)	DM n (%)	HT n (%)	Hospitalization n (%)	ICU admission n (%)	NOS
Bello-Chavola, *et al.* [1]	15,529	NR[a]	8,977 (57.8)	3,215 (20.7)	2,831 (18.2)	3,370 (21.7)	6,042 (38.9)	676 (4.4)	High
Cummings, *et al.* [24]	257[b]	62	170 (66.1)	119 (46.3)	92 (35.8)	162 (63)	1,150 (100)	257 (22.3)	High
Petrillli, *et al.* [11]	4,103	52	2072 (50.5)	1100 (26.8)	614 (15)	1235 (30.1)	1,999 (48.7)	650 (15.8)	High
McMichael, *et al.* [38]	167	72	55 (32.9)	37 (22.2)	38 (22.8)	74 (44.3)	66 (39.5)	NR	Moderate
Garg, *et al.* [25]	178[c]	NR	NR	73 (41)	47 (26.4)	79 (44.4)	1482 (100)	NR	Moderate
Simonnet, *et al.* [3]	124	60	90 (72.6)	59 (47.6)	28 (22.6)	60 (48.4)	124 (100)	124 (100)	High
Lighter, *et al.* [10]	3,615	NR	NR	1,370 (37.9)	NR	NR	1331 (36.8)	431 (11.9)	High
Richardson, *et al.* [9]	5,700	63	3,437 (60.3)	1,737 (41.7)	1,808 (33.8)	3,026 (56.6)	5,700 (100)	1,281 (22.5)	Moderate
Kalligeros, *et al.* [2]	103	60	63 (61.2)	49 (47.5)	38 (36.8)	66 (64.1)	103 (100)	44 (42.7)	High
Total	29,776		14,864	7759	5496	8072	17,997	3,463	

[a]The authors did not report the median of the total number of participants, but the mean age was 46.55±15.51. [b]The authors reported 1,150 patients with COVID-19 admitted to hospital; however, only 257 data of the patients were available. [c]The authors reported 1,482 patients with COVID-19 admitted to hospital; however, only 178 data of patients were available. DM: diabetes mellitus, HT: Hypertension, ICU: Intensive care unit, N: Number, NOS: Newcastle–Ottawa quality assessment scale, NR: not reported.

Risk of ICU admissions

Of the nine studies, seven [1], [2], [3], [9], [10], [11], [24] reported the data about ICU admissions, with a total of 3,463 patients with COVID- 19. Approximately 4.4–100% patients had COVID-19 and were admitted to the ICU. Simonnet *et al.* [3] showed that 100% of the patients with COVID- 19 were admitted to ICU, because all of the study participants were recruited from the ICU (Table 2).

Table 3: Number of patients who had COVID-19 with obesity and severe obesity

Study	BMI ≥ 30 (obesity)		BMI ≥ 35 (severe obesity)	
	n (%)	Total patients	n (%)	Total patients
Bello-Chavola, *et al.* [1]	3,215 (20.7)	15,529	–	–
Cummings, *et al.* [24]	119 (46.3)	257	68 (26.5)	257
Petrillli, *et al.* [11]	1,100 (26.8)	4,103	–	–
McMichael, *et al.* [38]	37 (22.2)	167	–	–
Garg, *et al.* [25]	73 (41.1)	178	–	–
Simonnet, *et al.* [3]	59 (47.6)	124	35 (28.2)	124
Lighter, *et al.* [10]	1,370 (37.9)	3,615	595 (16.5)	3,615
Richardson, *et al.* [9]	1,737 (41.7)	5,700	791 (13.9)	5,700
Kalligeros, *et al.* [2]	49 (47.5)	103	27 (26.2)	103
Prevalence (%)	7,759, 26.06%	29,776	1,516, 15.47%	9,799

BMI: Body mass index

Four studies [1], [2], [10], [11] provided information on patients with COVID-19 and obesity for meta-analysis. Of the 1,801 patients with COVID-19 who were admitted to the ICU, 692 had COVID-19 and obesity (38.4%). Obesity was still the second-highest comorbidity among COVID-19 patients, following hypertension. The patients with COVID-19 and obesity had a significantly increased risk of ICU admissions with OR = 1.77 (95% CI = 1.52–2.06, $p < 0.00001$, $Tau^2 = 0.01$, $I^2 = 45\%$, Figure 3) compared with that of the patients with COVID-19 but without obesity.

The information on patients who had COVID- 19 and severe obesity and were admitted to the ICU was only available from two studies [2], [10] for meta-analysis. Of 475 patients with COVID- 19 who were admitted to the ICU, 120 had severe obesity (25.3%). In comparison with patients with COVID-19 but without severe obesity, those with severe obesity had a significantly increased risk of ICU admission (OR 1.79, 95% CI 1.42-2.25, $p < 0.00001$, $Tau^2 = 0.00$, $I^2 = 0\%$, Figure 4).

Mortality risk

Only one study [1] provided information about the mortality rate of patients with COVID-19 and obesity but did not have data on severe obesity. Of 14,095 COVID-19 survivors, 2,777 (19.7%) had obesity. However, of the 1,434 patients who died of COVID- 19, 438 (30.5%) had obesity.

Meta-regression outcomes

Meta-regression was applied to explore the high heterogeneity in meta-analysis outcomes. I^2 of the risk of hospital admissions among patients with COVID- 19 and obesity patients indicated a high heterogeneity. The CMA, however, could not be utilized for the analysis because of limited number of studies included in meta-regression.

The meta-regression of heterogeneity was conducted to explore the heterogeneity by using the design (retrospective vs. prospective) and location (USA vs. Mexico) as covariates. However, meta- regression was only performed for the design covariate, and it was not doable for location covariate because of the limited numbers of studies (n = 2). The outcomes of meta-regression showed $\beta = -0.235$

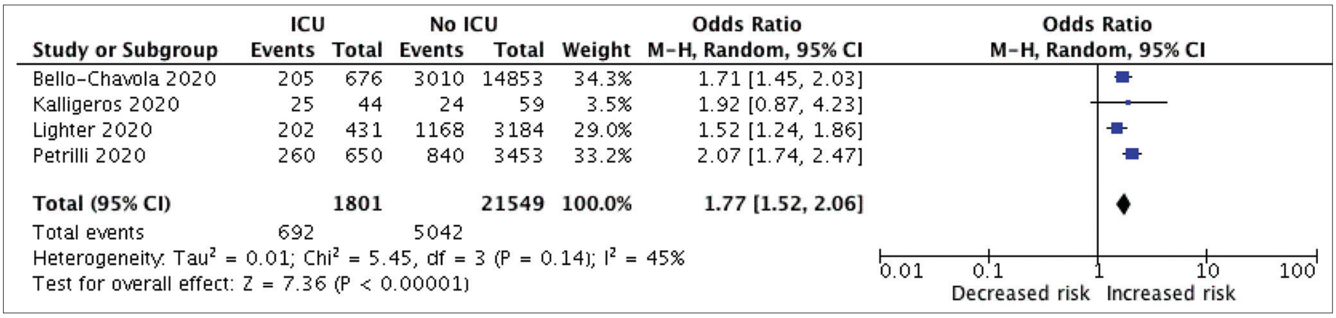

Figure 3: Forest plots of studies exploring the risk of ICU admissions among patients with COVID-19 and obese (BMI ≥ 30). BMI: Body mass index, CI: Confidence interval, ICU: Intensive care unit

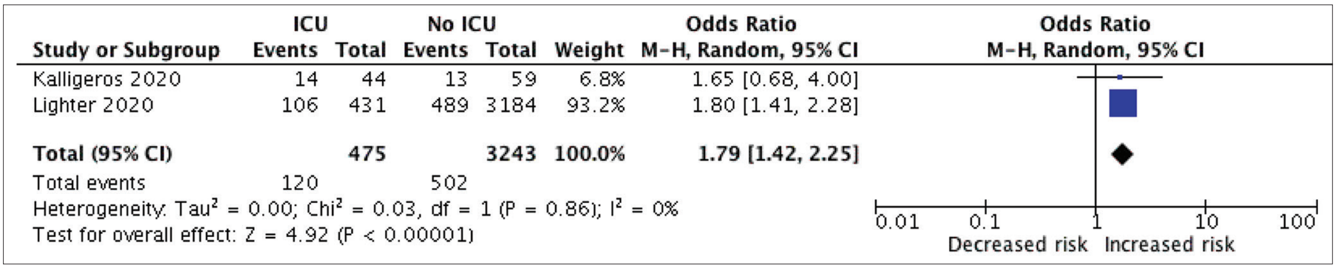

Figure 4: Forest plots of studies exploring the risk of ICU admissions among patients with COVID-19 and severe obese (BMI ≥ 35). BMI: Body mass index, CI: Confidence interval, ICU: Intensive care unit

and standard error = 0.110 (Q = 4.53, df = 1, 95% CI = –0.452 to –0.018, p = 0.034); the goodness-of-fit outcomes were Tau^2 = 0.000, Tau = 0.000, and I^2 = 0% (Q = 0.92, df = 2, p = 0.631), and the proportions of variances were Tau^2 = 0.0101, Tau = 0.1007, I^2 = 44.9%, and R^2 analog = 1 (Q = 5.45, df = 3, p = 0.142). These results indicated that the covariate of the retrospective design significantly contributed to a decrease of 0.235 units in the risk of ICU admissions among patients with COVID- 19 and obesity.

Bias assessment

The funnel plots indicated a symmetrical shape and a non-higher concentration at the bottom of the funnel plots (Additional file: Figure S1-3). Furthermore, Egger's regression yielded intercept = 9.845, 95% CI = –248.312 to 268.001, df = 1, p = 0.713 for hospital admission and intercept = -0.067, 95% CI -9.022 to -9.067, df = 2, p = 0.977 for ICU admissions among patients with obesity. These findings showed that the funnel plot had no asymmetry. The analysis on the publication bias of the risk of ICU admissions among patients with severe obesity was inapplicable because a minimum of three studies was not achieved.

Discussion

This study addressed the prevalence, risk of hospital and ICU admissions, and risk of mortality among patients with COVID-19, obesity, and severe obesity using available published data. To our best knowledge, this study was the first to extensively perform a systematic review and meta-analysis and address the aforementioned questions, particularly for severe obesity. Our findings revealed that 26.1% and 15.5% of patients with COVID-19 had obesity and severe obesity, respectively. The risk of hospital and ICU admissions of the patients with COVID-19 and obesity was twice higher that of the patients without obesity. Furthermore, COVID-19 patients with severe obesity had almost twice risks of ICU admission than non-severe obese COVID-19 patients.

The previous studies had limitations on the regional report and some reported small cases of COVID-19. The current study presented a pooled data of obesity and severe obesity on COVID-19 patients. The previous study showed a pooled prevalence of obesity was about 33.9%, relatively higher than these findings [26]. Furthermore, obesity was identified as the second-highest prevalence of comorbidity among COVID- 19, particularly in American and European countries. This finding was different from previous results that highlighted diabetes as the second- largest comorbidity among patients with COVID- 19 [16], [27], [28], [29]. The previous studies rarely assessed obesity among patients with COVID-19. Thus, this finding might reflect the basic characteristics of the population [16], especially in areas with a high prevalence of obesity.

Obesity and severe obesity in patients with COVID-19 were associated with poor outcomes, namely, hospital admission, ICU admission, and mortality. The current meta-analyses indicated that patients with COVID-19 and obesity had almost twice the risk of hospital admissions. These results were in accordance with other meta-analysis, in which identified the OR about 1.3–2.3 [30], [31], [32]. Obesity and severe obesity significantly increased the risk of ICU admissions among patients with COVID-19 with moderate heterogeneity, by 77% and 79%, respectively. The outcome of twice risks of ICU admissions among patients with COVID- 19 and obesity was similar with the previous meta-analysis (OR 1.3–2.3) [30], [31], [32]. BMI ≥30 and a history of heart diseases are independently associated with the use of invasive mechanical ventilation [2], [31], [32]. The mechanism of obesity contributing to the severity level of COVID- 19 is recommended [2]. Obesity caused multistranded pathophysiology, such as hyperactivation, increased interleukin-6 (IL-6) concentration, inflammation, and presence of other comorbidities [33]. Abdominal obesity leads to impaired lung ventilation and reduced oxygen saturation [7], [34]. A study on pulmonary function has shown that patients with obesity have restrictive and decreased lung volumes [35]. Some studies have indicated that patients with COVID-19 and severe obesity are subjected to long-term invasive mechanical ventilation [3], [7].

Obesity is associated with increased IL-6 [7], [33] and C-reactive protein contents [7]. Any abnormal secretion of interferon, adipokines, and cytokines (i.e. tumor necrotic factor alpha) result in a chronic low-grade inflammation. This condition potentially impairs the immune system by dysregulating the expression of tissue leukocyte [3], [7], [36]. Obesity and metabolic syndrome increase type 2 inflammation that impacts the lung parenchyma and bronchi [37], [38]. Obesity can stimulate insulin resistance and decrease beta-cell function. Consequently, insulin must be administered during a severe infection, thereby impairing host defense and leading to immunological deficit. In addition, obesity exacerbates the thrombosis that corresponds to pro-thrombotic disseminated intravascular coagulopathy and venous thromboembolism in patients with COVID- 19 [7].

The heterogeneity outcome of the risk of hospital admissions of patients with COVID-19 and obesity was high. Furthermore, meta-regression could not be performed to explore heterogeneity because of the limited number of studies included for analysis [20]. We acknowledged that the unexplained heterogeneity of these results might affect the inconsistency across the studies [22], [23]. Thus, further studies on hospital admissions among patients with COVID-19 and obesity should be performed to investigate such inconsistencies. Only Lighter *et al*. [10] reported the data about the risk of hospitalization among patients with COVID-19 and severe obese, with OR = 2.2 (95% CI = 1.7– 2.9, p < 0.0001). Another study has identified that BMI >40 contributes to 6.2 times (95% CI = 4.2– 9.3) of the hospitalization risk [11]. The retrospective design covariate significantly helped decrease the risk of ICU admissions among the patients with COVID- 19 and obesity by 0.235 units. The covariate of the retrospective design resulted in R^2 analog = 1, which indicated that the covariate of the retrospective design could explain all variances [20].

Strength and limitation of the study

This systematic review and meta-analysis had several limitations related to the nature of the study. The studies for meta-analysis were limited, although the nine included studies considered of a large number of patients with obesity or severe obesity as participants. The risk of hospital and ICU admissions among patients with COVID-19 and obesity might be underestimated because the accessibilities of hospital beds or ICU units are restricted. The high heterogeneity on the risk of hospital admission among patients with COVID-19 and obesity is also unexplained. Subgroup analysis is not workable because of the limited data and numbers of included studies. Furthermore, this study did not identify the risk of hospital admissions among patients with COVID-19 severe obesity because of limited data. Few studies have provided data about the survivorship of patients with COVID-19 and obesity or severe obesity. Thus, future research related to the survivorship of these patients should be conducted.

Conclusion

This systematic review identified that the prevalence rates of obesity and severe obesity were 26% and 15% among patients with COVID- 19, respectively. Patients with COVID-19 and obesity had twice the risks of hospital and ICU admissions compared with those of patients with COVID-19 but without obesity. Remarkably, patients with COVID-19 and severe obesity also showed approximately twice the risks for ICU admission compared with those of patients with COVID-19. Populations and health-care providers should notice and be aware of the high risk of hospital and ICU admissions among patients with COVID-19, obesity, and severe obesity.

This review provides valuable information on the high risk of hospital and ICU admissions for patients with COVID-19, obesity, and severe obesity. Health-care providers should intensively monitor the health outcomes these groups of patient. In addition, patients with obesity or severe obesity and their families should be aware of their risks of the severity of COVID-19 and minimize contact with other patients with COVID- 19. Health-care providers should also provide valid education on COVID-19 prevention and raise the awareness related to a high risk among patients with COVID-19 and obesity or severe obesity.

Supplementary Information

Additional file 1: Supplementary methods, PRISMA checklist. Figure S1, Funnel plots of the included studies on the risk of hospital admissions among patients with COVID-19 and obesity. Figure S2, Funnel plots of the included studies on the risk of ICU admissions among patients with COVID-19 and obesity. Figure S3, Funnel plots of the included studies on the risk of ICU admissions among patients with COVID-19 and severe obesity.

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Supplementary

Table of Contents

Supplementary Methods: PRISMA checklist

Section/topic	#	Checklist item	Reported on page #
		TITLE	
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
		ABSTRACT	
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	1
		INTRODUCTION	
Rationale	3	Describe the rationale for the review in the context of what is already known.	2
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	3
		METHODS	
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	N/A
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	3
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	4
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	3-4
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	4
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	3-4
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	4
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	5
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	5

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	5
		RESULTS	
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	5-6,20
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	5-6,18
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	9
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	6-8
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	6-8, 21-23
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	9
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	8-9
		DISCUSSION	
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	9-11
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	11-12
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	12
		FUNDING	
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	Title page #2

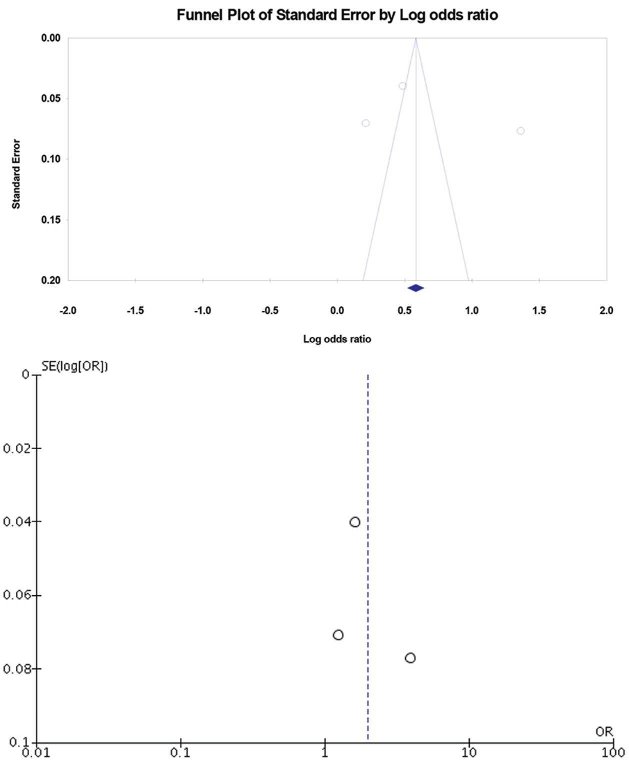

Figure S1: Funnel plots of the included studies on the risk of hospital admissions among patients with COVID-19 and obesity

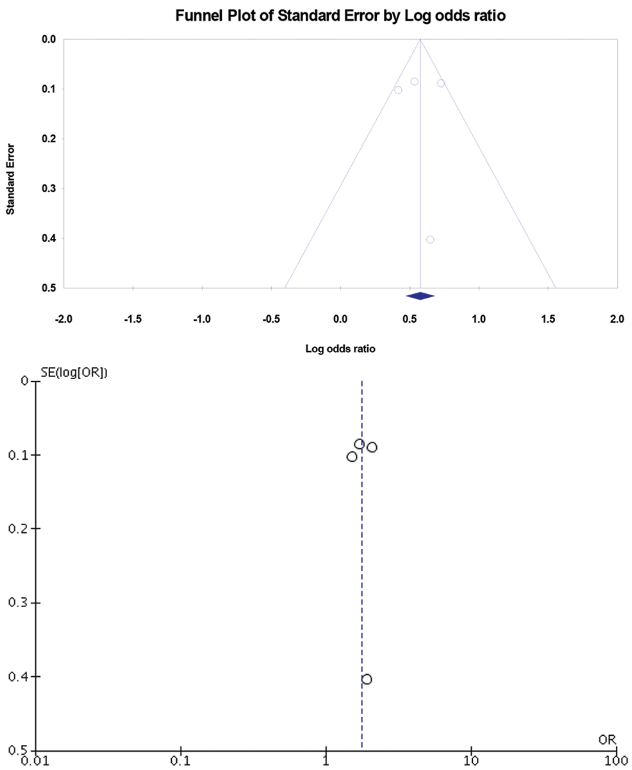

Figure S2: Funnel plots of the included studies on the risk of ICU admissions among patients with COVID-19 and obesity

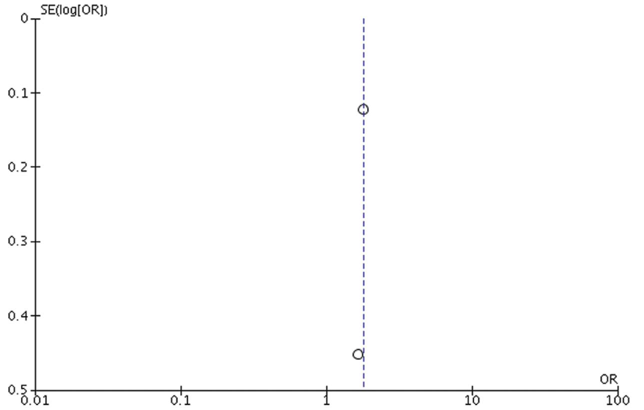

Figure S3: Funnel plots of the included studies on the risk of ICU admissions among patients with COVID-19 and severe obesity