Body mass index does not impact survival in COVID-19 patients requiring veno-venous extracorporeal membrane oxygenation

Elizabeth K Powell,[1,2] Daniel J Haase,[1,3,2] Allison Lankford,[4,2]
Kimberly Boswell,[1,2] Emily Esposito,[1,2] Joseph Hamera,[1,2]
Siamak Dahi,[3] Eric Krause,[3] Gregory Bittle,[3]
Kristopher B Deatrick,[3] Bree Ann C Young,[3,5]
Samuel M Galvagno Jr[6,2] and Ali Tabatabai[7,2]

Abstract

Introduction: With the increased demand for veno-venous extracorporeal membrane oxygenation (VV ECMO) during the COVID-19 pandemic, guidelines for patient candidacy have often limited this modality for patients with a body mass index (BMI) less than 40 kg/m^{2}. We hypothesize that COVID-19 VV ECMO patients with at least class III obesity (BMI ≥ 40) have decreased in-hospital mortality when compared to non-COVID-19 and non-class III obese COVID-19 VV ECMO populations.

Methods: This is a single-center retrospective study of COVID-19 VV ECMO patients from January 1, 2014, to November 30, 2021. Our institution used BMI ≥ 40 as part of a multi-disciplinary VV ECMO candidate screening process in COVID-19 patients. BMI criteria were not considered for exclusion criteria in non-COVID-19 patients. Univariate and multivariable analyses were performed to assess in-hospital mortality differences.

Results: A total of 380 patients were included in our analysis: The COVID-19 group had a lower survival rate that was not statistically significant (65.7% vs.74.9%, *p* = .07). The median BMI between BMI ≥ 40 COVID-19 and non-COVID-19 patients was not different (44.5 vs 45.5, *p* = .2). There was no difference in survival between the groups (73.3% vs. 78.5%, *p* = .58), nor was there a difference in survival between the COVID-19 BMI ≥ 40 and BMI < 40 patients (73.3, 62.7, *p*= .29). Multivariable logistic regression with the outcome of in-hospital mortality was performed and BMI was not found to be significant (OR 0.99, 95% CI 0.89, 1.01; *p* = .92).

Conclusion: BMI ≥ 40 was not an independent risk factor for decreased in-hospital survival in this cohort of VV ECMO patients at a high-volume center. BMI should not be the sole factor when deciding VV ECMO candidacy in patients with COVID-19.

Keywords

Circulatory support, circulatory temporary support, extracorporeal membrane oxygenation, COVID-19, Acute Respiratory Distress Syndrome

[1]Department of Emergency Medicine, University of Maryland School of Medicine, Baltimore, MD, USA
[2]Program in Trauma R Adams Cowley Shock Trauma Center, University of Maryland School of Medicine, Baltimore, MD, USA
[3]Department of Surgery, University of Maryland School of Medicine, Baltimore, MD, USA
[4]Department of Obstetrics Gynecology and Reproductive Sciences, University of Maryland School of Medicine, Baltimore, MD, USA
[5]Department of Cardiac Surgery, University of Michigan, Ann Arbor, MI, USA

[6]Department of Anesthesiology, University of Maryland School of Medicine, Baltimore, MD, USA
[7]Department of Medicine Division of Pulmonary and Critical Care Medicine, University of Maryland School of Medicine, Baltimore, MD, USA

Corresponding author:
Elizabeth K. Powell, MD, Department of Emergency Medicine, University of Maryland School of Medicine, 22 South Greene St, Baltimore, MD 21201, USA.
Email: Elizabeth.powell@som.umaryland.edu

Introduction

The 2019 novel coronavirus outbreak started in Wuhan, China and rapidly spread worldwide causing the World Health Organization (WHO) to declare a global health emergency on January 20, 2020.[1] On March 11, 2020, a global pandemic was officially declared.[2] SARS-CoV-2 (COVID-19) commonly causes respiratory symptoms and in the most severe cases, acute respiratory distress syndrome (ARDS).[3] Some cases of COVID-19 ARDS require veno-venous extracorporeal membrane oxygenation (VV ECMO).[3] However, with increased severity of the pandemic, ECMO resources have become increasingly limited, and efforts to discern which patients derive the greatest benefit from this therapy have led to numerous inclusion and exclusion criteria that are often more stringent than criteria applied to non-COVID-19 ARDS.[4]

The Extracorporeal Life Support Organization (ELSO) released interim guidelines for the selection of patients for ECMO in COVID-19[5] which included consideration of body mass index (BMI) during capacity limited situations. Subsequent guidelines from ELSO removed the specific consideration of BMI but significant comorbidities and individual institutional guidelines remained as part of evaluation consideration.[6] A BMI greater than or equal to 40 kg/m^2 (classified as class III obesity)[7,8] is still used at facilities including our own when evaluating patients for VV ECMO.[5] In COVID-19 patients not requiring VV ECMO, increasing BMI corresponds with increased risk of hospitalization, intensive care unit (ICU) admission, invasive mechanical ventilation, and increased mortality.[9,10] These findings might be partially explained at the cellular level with some studies that have shown enhanced viral entry, inadequate immune response and impaired viral clearance, and a pro-inflammatory response from adipose cells leading to cytokine storm in the obese patients with COVID-19.[11] Though not specifically conducted in the VV ECMO population, these studies suggest that critically ill, obese COVID-19 patients have poor outcomes due to their physiology.

The effects of BMI have been studied in the non-COVID-19 VV ECMO population. In previous studies, obesity was not associated with increased mortality in the VV ECMO population[12,13]; even some patients with BMIs greater than or equal to had favorable outcomes.[14] In one small cohort of COVID-19 patients requiring VV ECMO, obese patients were found to have improved outcomes though this study compared patients with BMIs above and below 30 kg/m^2.[15]

The aim of this study was to examine in-hospital mortality in obese COVID-19 and non-COVID-19 patients at a high-volume VV ECMO referral center. We hypothesized that COVID-19 VV ECMO patients with BMI ≥ 40 would have worse in-hospital mortality when compared to non-COVID-19 VV ECMO patients with a BMI ≥ 40. We also hypothesized that our BMI ≥ 40 COVID-19 VV ECMO patients would have greater in-hospital mortality when compared to the BMI < 40 COVID-19 VV ECMO population.

Methods

Study design

This is a single center, retrospective chart review. This study was approved by the University of Maryland School of Medicine Institutional Review Board (HP-00099397) and the need for written consent was waived.

Patient selection

Patients were evaluated between January 1, 2014, and November 30, 2021. All patients greater than or equal to 18 who were cannulated for peripheral VV ECMO were screened for inclusion. Patients placed on VV ECMO for trauma-related respiratory failure and patients with an alternate canulation strategy (veno-arterial, VVA, VAV) were excluded.

COVID-19 VV ECMO candidate selection

Our institution utilizes a multi-disciplinary approach for VV ECMO candidate selection. On each referral call, an intensivist from the Critical Care Resuscitation Unit (CCRU),[16] an intensivist from the Lung Rescue Unit (LRU),[17] and a cardiac surgeon discuss the case and apply institutional guidelines for selection. The Critical Care Resuscitation Unit is a receiving intensive care unit (ICU) for the R Adams Cowley Shock Trauma Center and the University of Maryland Medical Center and the Lung Rescue Unit is a dedicated VV ECMO ICU.

Since the beginning of the pandemic, BMI (<40 kg/m^2) has been used as part of the COVID-19 VV ECMO candidate screening process. Other screening guidelines included age ≤ 55, co-morbidities, end organ function, laboratory values, and ventilator settings and all guidelines were based on available literature.[5,6,18] Gender and race were not used as part of selection guidelines; however, this information was collected as part of our electronic medical record so available for a retrospective analysis. Physician discretion prevailed in borderline cases.

Data storage and analysis

Study data were collected and managed using REDCap electronic data capture tools hosted at the University of Maryland.[19,20] REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies, providing: 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources.

Survival was determined at hospital discharge. Centers for Disease Control and Prevention (CDC) and World Health Organization (WHO) definitions for body mass index were utilized.[7,8] Weight classes were used in our analysis including normal and overweight (BMI 18.5–29.9 kg/m^2), class I and class II obesity (BMI 30–39.9 kg/m^2), and class III obesity (BMI $\geq$ 40 kg/m^2). As described by Kon et al.,[14] class III obesity was further separated into BMI $\geq$ 50 kg/m^2 for analysis.

The primary outcome was in-hospital mortality. Our secondary outcome was patient in-hospital mortality in BMI $\geq$ 40 patients with and without COVID-19 on VV ECMO and COVID-19 patients that did and did not have a BMI $\geq$ 40. Parametric or nonparametric statistics were used based on the nature of the data. Normality was assessed with the Shapiro-Wilk test, and examination of stem-and-leaf as well as q-q plots. The student's t-test was used to assess differences with parametric continuous data and the Kruskal-Wallis and Wilcoxon rank sum tests were used to analyze nonparametric data. Normally distributed data were presented with mean and standard deviation (SD) while nonnormally distributed data was presented with median and quartiles (Q1-Q3). Chi square tests were used to analyze categorical data. All tests were two-tailed and a *p* value of < .05 was used to define statistical significance.

Logistic regression, with calculation of robust standard errors, was performed after variables were selected based on Akaike's information criterion (AIC) and commonly used patient information and selection guidelines from our institution. Regression diagnostics were performed including a link test to assure proper model specification and the Hosmer-Lemeshow chi-square goodness-of-fit test. Model fit (*p* = .49) and specification were confirmed. Deviance residuals and Pearson residuals as well as leverage and influence were also assessed to confirm the required assumptions for the logistic regression model. All tests were performed in Stata version 17 (StataCorp. 2021. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC) and GraphPad Prism 7.0 for Mac (GraphPad Software, La Jolla, CA).

Results

Demographics and characteristics

A total of 517 records were screened for inclusion criteria during the study period. There was a total of 380 patients: 105 patients were COVID-19 positive and 275 were COVID-19 negative (Table 1). The median total age was 43 with 64.2% being male with an overall BMI of 33.1 and overall survival rate of 72.4%. There was no difference in age or sex between the COVID-19 and non-COVID-19 groups. More COVID-19 VV ECMO patients were Hispanic (47.6% vs. 5.5%, *p* < .001) while more non-COVID-19 patients were Caucasian and African American. Non-COVID-19 patients had more asthma/chronic obstructive pulmonary disease (COPD) and substance abuse diagnoses. Each group had similar median BMIs (34.2 vs 32.6, *p* = .22). Both ECMO length in hours and hospital length of stay (LOS) in days was significantly longer in the COVID-19 VV ECMO group. The Sequential Organ Failure Assessment (SOFA) score was higher in the non-COVID-19 group (10.49 vs 11.33, *p* = .01) and the Respiratory ECMO Survival Prediction (RESP) score was lower in the non-COVID-19 group (4 vs 3, *p* < .001). The COVID-19 group appeared to have a lower survival rate that was not statistically significant (65.7% vs. 74.9%, *p* = .07).

Comparison of COVID-19 and non-COVID-19 VV ECMO patients with BMI $\geq$ *40* kg/m^2

Thirty patients in the COVID-19 group and 65 patients in the non-COVID-19 group had a BMI $\geq$ 40 (Table 2). COVID-19 patients were significantly younger (37 vs 44, *p* = .04), had significantly longer time on ECMO, longer hospital LOS, and higher RESP scores (5 vs 3, *p* = .01). The median BMI was not different between groups (44.5 vs 45.5, *p* = .2). There was no difference in survival between the groups (73.3% vs. 78.5%, *p* = .58).

A multivariable logistic regression was then performed with in-hospital mortality as the dependent variable. Only the RESP score was significant (OR 0.63, 95% CI 0.48, 0.82, *p* = .001) with a higher RESP score corresponding to improved survival.

Comparison of COVID-19 VV ECMO patients by BMI

There were 30 patients in the COVID-19 BMI $\geq$ 40 group and 75 patients in the COVID-19 BMI < 40 group (Table 2). Patients in the $\geq$ 40 group were significantly younger (37 vs 45, *p* = .002). There was no difference in sex, ECMO length, LOS, or SOFA score. RESP score was significantly higher in the $\geq$ 40 group (5 vs 4, *p* = .01). A higher proportion of patients with BMI $\geq$ 40 survived;

Table 1. Demographics and Characteristics of all VV ECMO, COVID-19 and non-COVID-19 patients. Percentages calculated as a proportion of the individual group. BMI Measurements expressed as kg/m^2.

	All patients (n= 380)	COVID-19 Patients (n= 105)	Non-COVID-19 patients (n= 275)	p value
Age- median (Q1-Q3)	43 (32-52.5)	43 (34-49)	43 (31-54)	0.97
Gender-male (n, %)	244 (64.2)	74 (70.5)	170 (61.8)	0.12
Race				
Caucasian (n, %)	134 (35.3)	14 (13.3)	120 (43.6)	<0.001
Hispanic (n, %)	65 (17.1)	50 (47.6)	15 (5.5)	<0.001
African American (n, %)	146 (38.4)	31 (29.5)	115 (41.8)	0.03
Other (n, %)	35 (9.2)	10 (9.6)	25 (9.1)	0.90
Comorbidities				
Smoker (n, %)	4 (1.1)	4 (3.8)	0	—
Asthma/COPD (n, %)	79 (20.8)	9 (8.6)	70 (25.5)	<0.001
DM (n, %)	62 (16.3)	18 (17.1)	44 (16)	0.79
CHF (n, %)	18 (4.7)	0	18 (6.5)	—
CAD (n, %)	23 (6.1)	0	23 (8.3)	—
Cancer/malignancy (n, %)	19 (5)	0	19 (6.9)	—
Liver disease/failure (n, %)	26 (6.8)	0	26 (9.5)	—
Substance abuse (n, %)	66 (17.4)	2 (1.9)	64 (23.3)	<0.001
Perniatal (n, %)	15 (3.9)	4 (3.8)	11 (4)	0.93
HIV (n, %)	9 (2.4)	0	9 (3.3)	–
BMI- median (Q1-Q3)	33.1 (26.95-39.98)	34.2 (28.7-40.43)	32.6 (26.3-38.9)	0.22
ECMO length in hours- median (Q1-Q3)	408 (216-744)	838 (528-1499)	312 (191-552)	<0.001
Hospital LOS in days-median (Q1-Q3)	35 (20-57)	51 (32-82)	30 (17-51)	<0.001
SOFA- mean (SD)	11.09 (3)	10.49 (2)	11.33 (3)	0.01
RESP- median (Q1-Q3)	3 (1-5)	4 (2-5)	3 (0-5)	<0.001
Survivors (n, %)	275 (72.4)	69 (65.7)	206 (74.9)	0.07

Abbreviations: Body mass index, BMI; Congestive heart failure, CHF; Chronic obstructive pulmonary disease, COPD; Coronary artery disease, CAD; Diabetes mellitus, DM; Extracorporeal membrane oxygenation, ECMO; Human immunodeficiency virus, HIV; Length of stay, LOS; Respiratory ECMO survival prediction, RESP; Sequential organ failure assessment, SOFA

however, this was not statistically significant (73.3 vs 62.7, p = .29).

Multivariable logistic regression was performed with mortality as the dependent variable. Female sex was found to correlate with improved survival (OR 0.12, 95% CI 0.03, 0.66, p= 0.014). BMI was not found to be significantly associated with mortality (OR 0.99, 95% CI 0.89, 1.01, p = .92).

Survival analysis in the COVID-19 population was performed based on BMI (Figure 1). Patients with a BMI 18.5 to 29.9 had a survival rate of 61.3% (19/31). Patients with a BMI 30 to 39.9 had a 63.4% survival (26/41). Patients with a BMI ≥ 40 were split into 2 groups to further evaluate findings from Kon et al.[14]: BMI 40-49.9 (survival 78.6%, 22/28) and BMI ≥ 50 (survival 40%, 2/5). There was no statistical difference between the groups (p = .27). A Kaplan-Meier survival curve was then constructed with the described groups which did not demonstrate a mortality difference

between the groups (Figure 2) (Mantel-Cox log-rank test 0.418).

Discussion

ECMO in the obese population

In this cohort of COVID-19 and non-COVID-19 VV ECMO patients at a high-volume ECMO referral center, BMI ≥ 40 was not associated with worse in-hospital mortality. Prior to the pandemic, regardless of VV ECMO indication, obesity was not considered a contra-indication to VV ECMO,[12,21] and even patients with a BMI greater than 50 demonstrated similar outcomes compared to non-obese VV ECMO patients.[14] Whereas obesity can pose challenges for the ECMO management team, including cannulation, prone positioning, and ventilator management, these challenges have not trans-lated to poor outcomes.[22] Prior to the pandemic, VV

Table 2. Comparison of COVID-19 and non-COVID-19 VV ECMO Patients of Various Body Mass Indices. *BMI measurements expressed as* kg/m^2

	COVID-19 patients BMI ≥ 40 (n= 30)	Non-COVID-19 patients BMI ≥ 40 (n= 65)	COVID-19 patients BMI < 40 (n = 75)	p value* COVID/Non	p value** COVID BMIs
Age- median (Q1-Q3)	37 (29–43)	44 (31–53)	45 (37–51)	0.04	0.002
Gender- male (n, %)	19 (63.3)	33 (50.8)	55 (73.3)	0.26	0.31
BMI- median (Q1-Q3)	44.5 (41.6–48.63)	45.5 (42.1–50.5)	31.9 (26.81–35.2)	0.20	<0.001
ECMO length in hours- median (Q1-Q3)	791.5 (552–1416)	336 (216-552)	838 (480–1536)	<0.001	0.92
Hospital LOS in days- median (Q1-Q3)	52 (38–85)	35 (18–50)	50 (30-76)	<0.001	0.41
SOFA- mean (SD)	10.77 (2)	11.49 (4)	10.37 (2)	0.50	0.89
RESP- median (Q1-Q3)	5 (4–6)	3 (1-5)	4 (2–5)	0.01	0.01
Survivors (n, %)	22 (73.3)	51 (78.5)	47 (62.7)	0.58	0.29

*p Value COVID/Non compared the COVID-19 Patients BMI ≥ 40 with Non-COVID-19 Patients BMI ≥ 40
**p Value COVID BMIs compared COVID-19 Patients BMI ≥ 40 with COVID-19 Patients BMI < 40
Abbreviations: Body mass index, BMI (measured in Kg/m2); Extracorporeal membrane oxygenation, ECMO; Length of stay, LOS; Respiratory ECMO survival prediction, RESP; Sequential organ failure assessment, SOFA
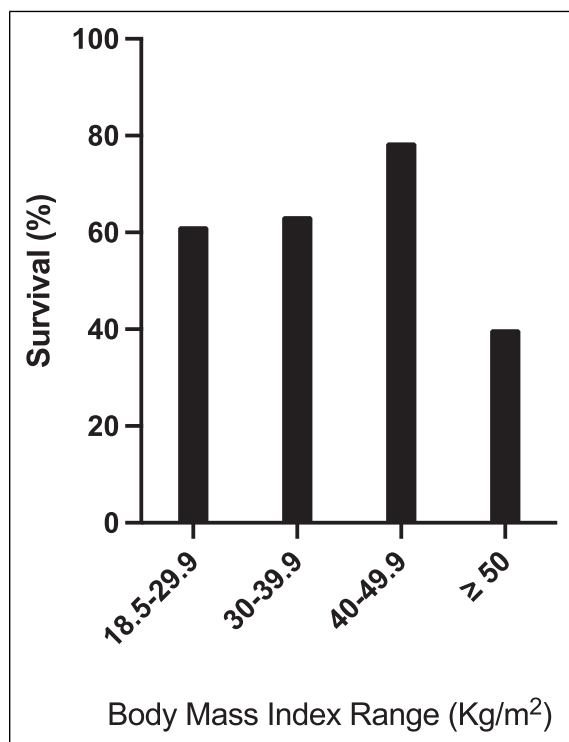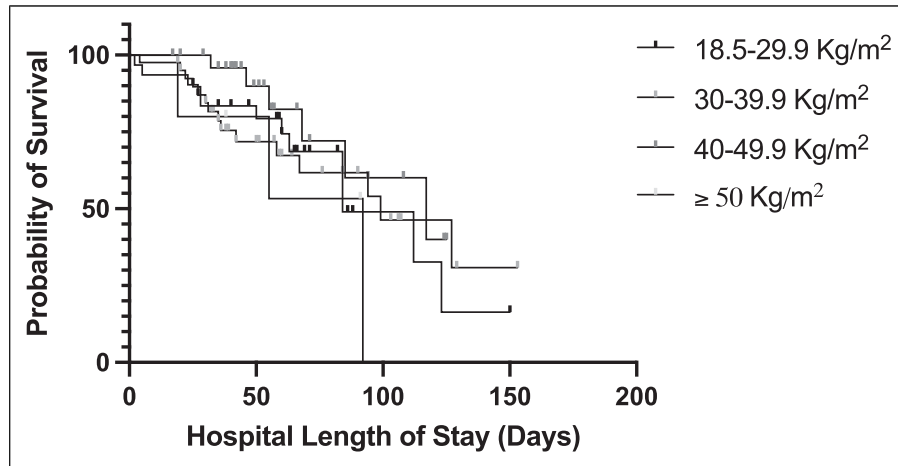

Figure 1. Survival Across a Range of Body Mass Indices in COVID-19 Patients. Survival reported as percentage of total for each body mass index category. Body mass index range divided as: normal and overweight (BMI 18.5–29.9 kg/m^2), class I and class II obesity (BMI 30–39.9 kg/m^2), and class III obesity (BMI ≥ 40 kg/m^2). Class III obesity was further separated into BMI ≥ 50 kg/m^2 for analysis.

ECMO was shown to be safe and effective in the obese population and at our institution, prior to COVID-19, BMI was not included in our selection guidelines. With the rise in severe ARDS COVID-19 cases, additional guidelines were established to aide in the evaluation of VV ECMO candidates and based on the anticipated care challenges with obese patients, BMI criteria was added as a criterion.[5]

Although obesity has been identified as a risk factor for worse outcomes in COVID-19,[23-25] This study may add to an existing body of literature that supports the "obesity paradox" in critically ill patients. In some studies, obese patients have been shown to have equivocal, or even improved outcomes compared to non-obese patients,[26,27] whereas others have questioned the validity of this observation when appropriate statistical controls were implemented.[28] Whereas obesity places patients at risk for hypertension, diabetes, heart disease, and other disease in the normal population, the reasons why obesity in critically ill patients is associated with lower mortality in the critically ill is not fully understood.[27,29] Potential explanations for the obesity paradox in critically ill patients may be related to anti-inflammation, higher energy reserves, greater endotoxin neutralization, increased adrenal steroid synthesis, renin-angiotensin system activation, cardioprotective metabolic effects, and prevention of muscle wasting in the obese.[30]

Our results are in contradistinction to a recently published study of over 35,000 patients hospitalized with COVID-19 in the Netherlands published by Kooistra et al.[31] In the Dutch study, patients with COVID-19-related respiratory failure had worse mortality. Other studies that have examined outcomes in COVID-19 patients who require mechanical ventilation, concluding that although higher driving pressures and

Figure 2. Kaplan-meier survival curve across a range of body mass indices in COVID-19 patients. Body mass index range divided as: normal and overweight (BMI 18.5-29.9 kg/m^2), class I and class II obesity (BMI 30-39.9 kg/m^2), and class III obesity (BMI ≥ 40 kg/m^2). Class III obesity was further separated into BMI ≥ 50 kg/m^2 for analysis. There was no survival difference observed between body mass index groups (Mantel-Cox log-rank test 0.418).

positive end-expiratory pressure was required in obese patients, mortality was not worse.[32] Regardless of the observations found in our study, obesity is associated with increased risk for organ failures such as acute kidney injury, infection, and may require adjustments for drug dosing and nutrition prescriptions.[29] Despite the challenges associated with performing procedures, diagnostic tests, and other logistical problems, the results of our study do not support withholding VV ECMO therapy for BMI ≥ 40 patients and support the current ELSO guidelines which removed obesity as a specific consideration in resource limited situations.[6] Additional data from larger, multi-institutional studies is needed to confirm or refute our results.

Limitations

This is a retrospective, observational single center study. Applicability to other institutions may be limited. We may have observed a selection bias in patients with morbid obesity cannulated for VV ECMO. Specifically, when examining BMI ≥ 40 COVID-19 and BMI < 40 COVID-19 patients on VV ECMO, the BMI ≥ 40 group was younger with higher RESP scores. This indicates that BMI ≥ 40 COVID-19 patients are predicted to have better outcomes compared to their BMI < 40 COVID-19 counterparts. We also had a fewer number of BMI ≥ 40 COVID-19 patients on VV ECMO so we may have screened for healthier and younger BMI ≥ 40 patients overall though non-selected patients were not examined as part of this study.

Also, our study was not larger enough to employ additional statistics to examine the potential for an obesity paradox without the risk of overfitting models.

Larger studies comparing BMI ≥ 40 patients with similar risk stratification scores for outcomes is required to confirm our findings.

Conclusions

Our large, retrospective, single-center study demonstrated that COVID-19 VV ECMO patients with a BMI ≥ 40 have similar mortality rates compared to non-COVID-19 VV ECMO patients with a BMI ≥ 40 and COVID-19 VV ECMO patients with a BMI < 40. The COVID-19 BMI ≥ 40 patients had other screening characteristics indicating that they may have had a higher chance of survival compared to their non-COVID-19 and COVID-19 BMI < 40 counterparts. Developing accurate screening tools and identifying patients who would most benefit from VV ECMO is important, especially in resource limited situations. Our study indicates that obesity in the COVID-19 population should not be used in isolation when selecting or declining patients for VV ECMO.

ORCID iDs

Elizabeth K Powell https://orcid.org/0000-0003-1258-5272
Daniel J Haase https://orcid.org/0000-0001-8950-1933

Samuel M Galvagno ⓘ https://orcid.org/0000-0001-5563-4092

Ali Tabatabai ⓘ https://orcid.org/0000-0002-5325-4907

References

1. Wee SLMD, Hernández JC. *WHO declares global emergency as Wuhan coronavirus spreads*. New York, NY: nytimes, 2020, Available from: https://www.nytimes.com/2020/01/30/health/coronavirus-world-health-organization.html.

2. Hu Y, Sun J, Dai Z, et al. Prevalence and severity of corona virus disease 2019 (COVID-19): a systematic review and meta-analysis. *J Clin Virol* 2020; 127(104371): 1–7.

3. Welker C, Huang J, Gil IJN, et al. Acute respiratory distress syndrome update, with coronavirus disease 2019 focus. *J Cardiothorac Vasc Anesth* 2021; 36(4): 1188–1195.

4. Seethala R, Keller SP. Extracorporeal membrane oxygenation resource planning in the setting of pandemic respiratory illness. *Ann Am Thorac Soc* 2020; 17(7): 800–803.

5. Shekar K, Badulak J, Peek G, et al. Extracorporeal life support organization coronavirus disease 2019 interim guidelines: a consensus document from an international group of interdisciplinary extracorporeal membrane oxygenation providers. *ASAIO J* 2020; 66(7): 707–721.

6. Badulak J, Antonini MV, Stead CM, et al. Extracorporeal membrane oxygenation for COVID-19: updated 2021 guidelines from the extracorporeal life support organization. *ASAIO J* 2021; 67(5): 485–495.

7. Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organ Tech Rep Ser.* 2000; 894(i-xii): 1–253.

8. Prevention CfDCa. *Body Mass Index*, Atlanta, GA: CDC, 2022. Available from: https://www.cdc.gov/healthyweight/assessing/bmi/index.html.

9. Yang Y, Wang L, Liu J, et al. Obesity or increased body mass index and the risk of severe outcomes in patients with COVID-19: a protocol for systematic review and meta-analysis. *Medicine (Baltimore)* 2022; 101(1): e28499.

10. 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. *Diabetes Metab Syndr* 2020; 14(6): 1897–1904.

11. Demeulemeester F, de Punder K, van Heijningen M, et al. Obesity as a risk factor for severe Covid-19 and complications: a review. *Cells* 2021; 10(4): 933

12. Galvagno SM, Jr., Pelekhaty S, Cornachione CR, et al. Does Weight Matter? Outcomes in Adult Patients on Venovenous Extracorporeal Membrane Oxygenation When Stratified by Obesity Class. *Anesth Analg* 2020; 131(3): 754–761.

13. Merritt-Genore H, Lyden E, Ryan T, et al. The effect of patient obesity on extracorporeal membrane oxygenator outcomes and ventilator dependency. *J Card Surg* 2020; 35(6): 1283–1286.

14. Kon ZN, Dahi S, Evans CF, et al. Class III obesity is not a contraindication to venovenous extracorporeal membrane oxygenation support. *Ann Thorac Surg* 2015; 100(5): 1855–1860.

15. Daviet F, Guilloux P, Hraiech S, et al. Impact of obesity on survival in COVID-19 ARDS patients receiving ECMO: results from an ambispective observational cohort. *Ann Intensive Care* 2021; 11(1): 157–167.

16. Scalea TM, Rubinson L, Tran Q, et al. Critical care resuscitation unit: an innovative solution to expedite transfer of patients with time-sensitive critical illness. *J Am Coll Surg* 2016; 222(4): 614–621.

17. Menaker J, Dolly K, Rector R, et al. The lung rescue unit-Does a dedicated intensive care unit for venovenous extracorporeal membrane oxygenation improve survival to discharge? *J Trauma Acute Care Surg* 2017; 83(3): 438–442.

18. Bartlett RH, Ogino MT, Brodie D, et al. Initial ELSO guidance document: ECMO for COVID-19 patients with severe cardiopulmonary failure. *ASAIO J* 2020; 66(5): 472–474.

19. Harris PA, Taylor R, Thielke R, et al. Research electronic data capture (REDCap)–a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009; 42(2): 377–381.

20. Harris PA, Taylor R, Minor BL, et al. The REDCap consortium: building an international community of software platform partners. *J Biomed Inform* 2019; 95: 1–24.

21. Zaidi SAA, Saleem K. Obesity as a risk factor for failure to wean from ECMO: a systematic review and meta-analysis. *Can Respir J* 2021; 2021: 1–9.

22. Javidfar J, Zaaqoq AM, Yamashita MH, et al. Venovenous extracorporeal membrane oxygenation in obese patients. *JTCVS Tech* 2021; 10: 335–348.

23. Martin-Del-Campo F, Ruvalcaba-Contreras N, Velazquez-Vidaurri AL, et al. Morbid obesity is associated with mortality and acute kidney injury in hospitalized patients with COVID-19. *Clin Nutr ESPEN* 2021; 45: 200–205.

24. Sidhu G, Samson R, Nedunchezian SH, et al. COVID 19 in-hospital mortality, body mass index and obesity related conditions. *J Diabetes Complications* 2021; 35(12): 1–3.

25. Bushman D, Davidson A, Pathela P, et al. Risk factors for death among hospitalized patients aged 21-64 years diagnosed with COVID-19-New York City, march 13-april 9, 2020. *J Racial Ethn Health Disparities* 2021: 1–16. Online ahead of Print.

26. Acharya P, Upadhyay L, Qavi A, et al. The paradox prevails: outcomes are better in critically ill obese patients regardless of the comorbidity burden. *J Crit Care* 2019; 53: 25–31.

27. Falls C, Melander S. Obesity in the critical care setting. *Nurs Clin North Am* 2021; 56(4): 573–581.

28. Decruyenaere A, Steen J, Colpaert K, et al. The obesity paradox in critically ill patients: a causal learning

approach to a casual finding. *Crit Care* 2020; 24(1): 485–496.

29. Schetz M, De Jong A, Deane AM, et al. Obesity in the critically ill: a narrative review. *Intensive Care Med* 2019; 45(6): 757–769.

30. Karampela I, Chrysanthopoulou E, Christodoulatos GS, et al. Is there an obesity paradox in critical illness? epidemiologic and metabolic considerations. *Curr Obes Rep* 2020; 9(3): 231–244.

31. Kooistra EJ, Brinkman S, van der Voort PHJ, et al. Body mass index and mortality in coronavirus disease 2019 and other diseases: A cohort study in 35,506 ICU patients. *Crit Care Med* 2022; 50(1): e1–e10.

32. Schavemaker R, Schultz MJ, Lagrand WK, et al. Associations of body mass index with ventilation management and clinical outcomes in invasively ventilated patients with ards related to COVID-19-insights from the provent-COVID Study. *J Clin Med* 2021; 10(6): 1–14.