Physiological and Management Implications of Obesity in Critical Illness

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Abstract

Obesity is highly prevalent in the United States and is becoming increasingly common worldwide. The anatomic and physiological changes that occur in obese individuals may have an impact across the spectrum of critical illness. Obese patients may be more susceptible to hypoxemia and hypercapnia. During mechanical ventilation, elevated end-expiratory pressures may be required to improve lung compliance and to prevent ventilation–perfusion mismatch due to distal airway collapse. Several studies have shown an increased risk of organ dysfunction such as the acute respiratory distress syndrome and acute kidney injury in obese patients. Predisposition to ventricular hypertrophy and increases in blood volume should be considered in fluid management decisions. Obese patients have accelerated muscle losses in critical illness, making nutrition essential, although the optimal predictive equation to estimate nutritional needs or formulation for obese patients is not well established. Many common intensive care unit medications are not well studied in obese patients, necessitating understanding of pharmacokinetic concepts and consultation with pharmacists. Obesity is associated with higher risk of deep venous thrombosis and catheter-associated bloodstream infections, likely related to greater average catheter dwell times. Logistical issues such as blood pressure cuff sizing, ultrasound assistance for procedures, diminished quality of some imaging modalities, and capabilities of hospital equipment such as beds and lifts are important considerations. Despite the physiological alterations and logistical challenges involved, it is not clear whether obesity has an effect on mortality or long-term outcomes from critical illness. Effects may vary by type of critical illness, obesity severity, and obesity-associated comorbidities.

Keywords: obesity; physiology; artificial respiration; critical illness; patient outcome assessment

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Case

A 55-year-old male with a body mass index (BMI) of 38 kg/m^2 is admitted to the intensive care unit (ICU) with pneumonia and septic shock and is subsequently intubated for hypoxemic respiratory failure. Worsened hypoxemia and low static compliance immediately after intubation are improved by the application of a positive end-expiratory pressure (PEEP) of 12 cm H_2O. Large-bolus doses of opioids and benzodiazepines are required to achieve adequate sedation. The ICU course is complicated by a central venous catheter (CVC)-associated bloodstream infection. After 10 days of mechanical ventilation, the patient is successfully extubated. On Hospital Day 20, he is discharged to a rehabilitation facility. How did his obesity impact the pathophysiology, management, and outcome of his critical illness?

Introduction

Obesity is a highly prevalent condition in the United States and throughout the developed world. Although the U.S. prevalence has leveled somewhat in the past 10 years, two-thirds of adults have BMIs above the World Health Organization (WHO)–defined normal range (18.5–25 kg/m^2) and one-third are obese (BMI $\geq$ 30 kg/m^2) (1). Morbid obesity (BMI $\geq$ 40 kg/m^2)

has a prevalence of 6.3%. The critical care community has taken notice. With the prevalence of obesity in ICUs estimated at 25%, there have been multiple studies over the past 10–15 years aimed at exploring the gross and molecular pathophysiology, management, and outcomes particular to obese critically ill patients (2–4). In this concise review, we focus on pertinent physiological changes in obesity and studies that investigate the impact of these alterations on critical illness. Anticipation of challenges, optimal management, and understanding of how obesity impacts clinically relevant outcomes are stressed. Figure 1 summarizes relevant effects of obesity on three key organ systems.

A comprehensive textbook as well as an article series are available for more detailed review of these topics (5, 6). Care of obese burn patients, outside the scope of this review, has also been reviewed in detail elsewhere (7).

What Is Obesity?

Defining obesity is necessary because of the varied ways in which obesity is characterized in clinical studies. The WHO classification of obesity as a BMI equal to or greater than 30 kg/m^2 is the measure used in most critical care studies, in part due to its relative simplicity and the availability of height and weight measures in hospital records. The validity of BMI as an ideal metric of obesity has been questioned, because it does not account well for differences in body composition (e.g., nonfat solid mass, extra- and intracellular water mass, visceral vs. subcutaneous adipose mass) (8). Waist-to-hip ratio, sagittal abdominal diameter, and imaging studies such as computed tomography (CT) and dual-energy X-ray absorptiometry better reflect body composition. These measures have been increasingly used in outpatient cohorts and in some cases found to have stronger associations than BMI with clinical outcomes (9–12). Given the limited

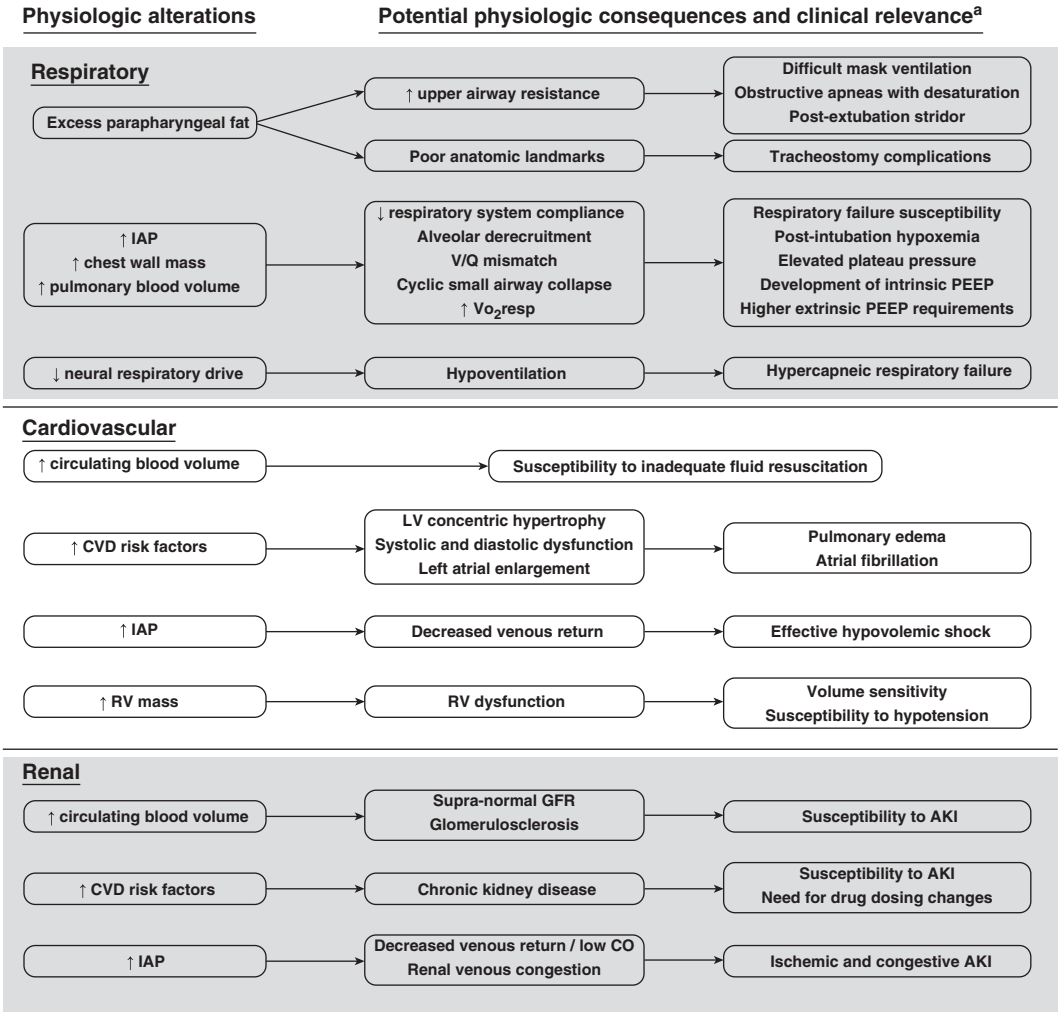

Figure 1. Obesity-related alterations in pulmonary, cardiovascular, and renal physiology and their potential relevance to critical illness. [a]The physiological consequences and clinical relevance are described as "potential" because they have been theorized but in some cases have conflicting evidence in human studies. See text for discussion of evidence. AKI = acute kidney injury; CO = cardiac output; CVD = cardiovascular disease; GFR = glomerular filtration rate; IAP = intraabdominal pressure; LV = left ventricle; PEEP = positive end-expiratory pressure; RV = right ventricle; $\dot{V}o_2$resp = oxygen consumption of the respiratory system; $\dot{V}/\dot{Q}$ = ventilation–perfusion.

number of critical care studies that have used non-BMI measures, most of the data reviewed here use BMI to define obesity. A number of these studies are focused specifically on severely obese populations, a distinction that is noted when possible.

Pulmonary System

Pulmonary Physiology

Obesity results in anatomic and physiological alterations to the face, neck, pharynx, lungs, and chest wall that may affect pulmonary system function in critically ill patients. Excess facial fat may compromise fit of a mask for ventilation, while parapharyngeal fat and consequent airway collapse increase upper airway resistance (13, 14). Studies of intubated morbidly obese patients have also shown increased total lung resistance compared with nonobese patients, although the increase in airway resistance may be due to low lung volumes rather than airway obstruction (15–17).

Excess abdominal fat increases abdominal pressure and displaces the diaphragm upward, combining with increased chest wall mass to raise baseline pleural pressure (15, 18–20). The most significant and consistent resultant change in pulmonary function is a decrease in expiratory reserve volume and functional residual capacity (FRC), while total lung capacity and spirometric values usually remain in the normal range (21). Reduced FRC may result in closure of peripheral dependent airways during tidal ventilation, particularly at high respiratory rates, and diminished lung compliance due to tidal ventilation below the lower inflection point of the inspiratory pressure–volume curve (18, 21–23). The combination of poor dependent ventilation with persistent dependent perfusion in some obese patients can result in baseline ventilation–perfusion ($\dot{V}/\dot{Q}$) mismatch and susceptibility to hypoxemia (22). These effects are magnified in the supine position (22, 24).

Obesity also is associated with alterations in work of breathing. Kress and colleagues demonstrated that morbidly obese patients (mean BMI, 53 kg/m^2) had a 60% higher resting oxygen consumption (V_{O_2}) than normal weight patients (25). Whereas oxygen required to conduct respiratory work was negligible in normal weight patients, nearly half of the higher resting V_{O_2} in obese patients was due to the oxygen cost of breathing. Neural respiratory drive increases in obese patients to compensate for increased ventilatory load and respiratory muscle inefficiency (26). In obesity hypoventilation syndrome (OHS) this compensatory mechanism fails and neural drive drops with resultant hypercapnia and hypoxemia (27).

The degree to which each obese individual manifests these respiratory system changes varies and is not entirely dependent on obesity severity. However, it is not difficult to see that a variety of pulmonary physiological changes may limit pulmonary reserve and potentially place critically ill obese patients at risk for airway management difficulties, respiratory failure, and challenges with ventilator management.

Airway Management

Despite the described physiological alterations in obesity, the clinical usefulness of BMI to predict intubation difficulty remains questionable. Several large studies have demonstrated an association of BMI with difficult mask ventilation and intubation in the operating room (28–31). The magnitude of this increased risk, however, is small. For example, a study of more than 90,000 Danish patients undergoing intubation for surgery showed that the frequency of difficult intubation was 5.2% in the overall population and 6.4% in those with a BMI equal to or greater than 35 kg/m^2 (30). Modified Mallampati class III or IV and previous difficult intubation each had much stronger associations with difficult intubation. In studies of ICU populations, difficult intubation rates have ranged from 6.6 to 15% (32–35). Limited evidence from one relatively small ICU study (n = 206) showed that severely obese (BMI $\geq$ 35 kg/m^2) patients had a higher risk of difficult tracheal intubation than nonobese patients (15 vs. 6%, respectively; $P = 0.04$) (35).

Of significant concern is the susceptibility of obese patients to developing hypoxemia during intubation. The increased pleural pressure associated with obesity renders such patients subject to profound atelectasis and $\dot{V}/\dot{Q}$ mismatch while supine, sedated, and (in some cases) paralyzed (36). Juvin and colleagues found that severely obese (BMI $\geq$ 35 kg/m^2) patients undergoing surgery had significantly lower nadir values of Sp_{O_2} (oxygen saturation as determined by pulse oximetry) during intubation compared with normal and overweight patients, despite similar preoxygenation durations and Sp_{O_2} values (29). This susceptibility to hypoxemia may have more significance in critical care populations, where the overall incidence of severe hypoxemia ($Sp_{O_2} < 80\%$) during intubation is 20–25% (32, 33, 37). Studies are lacking to clearly demonstrate the role of obesity in periintubation hypoxemia in this setting, given many other potential contributing factors. It may still be useful, however, for critical care clinicians to understand management strategies to prevent hypoxemia, largely tested in surgical populations. A 30° reverse Trendelenburg or a 25° head-up position has each been shown to improve preoxygenation Pa_{O_2} and safe apnea time in morbidly obese patients (38, 39). Futier and colleagues conducted a randomized controlled trial showing that use of noninvasive ventilation (NIV) during preoxygenation of obese patients improved Pa_{O_2} before, at the time of, and after intubation, and that addition of a recruitment maneuver after intubation resulted in even higher Pa_{O_2} (40).

Several studies have demonstrated that obesity is associated with higher tracheostomy complication rates (41–43). One study of 427 critically ill patients undergoing surgical tracheostomy noted a 25% rate of complications (10% serious, such as tube obstruction or extratracheal placement) in morbidly obese patients compared with 14% (2% serious) in those with BMI less than 40 kg/m^2 (41). In contrast, a large (n > 3,000, one-third obese, 8% morbidly obese) single-center study showed a complication rate so low (<1%) with percutaneous dilatational tracheostomy that an association between obesity and complications could not even be assessed (44). The authors postulated that the introduction of standard use of extralong tracheostomy tubes in obese patients may have contributed to their low complication rate. Although the population of patients undergoing bedside tracheostomy is likely to be, by proceduralist selection, lower risk than those undergoing operative procedures, this study demonstrates that obese patients with acceptable anatomic

landmarks may be reasonable candidates for a percutaneous approach.

Respiratory Failure and Mechanical Ventilation

Epidemiologic data implicating obesity as an independent risk factor for acute respiratory failure are limited. Studies in surgical populations have failed to consistently identify an increase in postoperative pulmonary complications in obese patients (45). However, higher BMI has shown associations with increased risk of moderate and severe acute respiratory distress syndrome (ARDS) in at-risk ICU patients and with primary graft dysfunction after lung transplantation (46, 47). There are several potential explanations for these findings, although data delineating mechanisms are lacking. Obese patients may have been at risk for misclassification as ARDS cases due to interpretation of excess soft tissue and basilar atelectasis as bilateral infiltrates. However, Gong and colleagues reported that increased frequency of $Pa_{O_2}/FI_{O_2} < 200$, rather than radiographic findings, was the criterion driving the higher ARDS incidence in obese patients (46). The underlying predisposition of obese patients to hypoxemia could result in a lower Pa_{O_2}/FI_{O_2} compared with normal weight patients in the setting of a similar insult to the lungs. In addition, reduced FRC with tidal ventilation near the lower inflection point of the pressure–volume curve could predispose obese patients to the atelectrauma that has been shown in ventilated animal models (48).

In addition to lung injury, acute hypercapnic respiratory failure in patients with OHS is well described even if incidence rates and risk factors are not firmly established (49). A recent cohort study showed that OHS patients with acute ventilatory failure who could be trialed on NIV had similar intubation rates and adjusted mortality rates compared with COPD patients with ventilatory failure, a population in which the benefits of NIV are well documented (50). It is important to distinguish acute ventilatory failure from a chronic, compensated respiratory acidosis in patients with OHS. Baseline Pa_{CO_2} may be quite high, so an elevated Pa_{CO_2} should not be the sole basis for acute NIV or intubation. Patients with OHS may adapt to compromised ventilation by regularly sleeping in a sitting or semi-recumbent position. Therefore, providers must be aware of potential respiratory decompensation or failure to wean from mechanical ventilation in such patients if they are kept supine.

Intubated obese patients warrant special consideration in selecting mechanical ventilation parameters, particularly regarding tidal volume (V_T) and PEEP. Predicted body weight (based on height and sex, as in ARDSNet studies) should be used for normalizing V_T when a low tidal volume strategy is indicated (21, 51, 52). Because obese patients may have elevated baseline pleural pressure (18), it is possible that transpulmonary pressure, alveolar stretch, and consequent volutrauma are reduced even in the setting of elevated plateau pressure. There are no outcome data, however, validating a liberalization of plateau pressure goals in obese patients with ARDS. Pending additional studies, such patients should continue to be managed according to a standard ARDSNet protocol (52).

The selection of appropriate PEEP may have beneficial effects on two phenomena of concern in ventilated obese subjects: (*1*) alveolar derecruitment, and (*2*) expiratory flow limitation with consequent intrinsic PEEP (PEEPi). Pelosi and colleagues showed that in morbidly obese (mean BMI, 51 kg/m^2) surgical patients, PEEP of 10 cm H_2O compared with zero PEEP significantly improved lung and chest wall compliance and end-expiratory lung volume, while modestly improving average Pa_{O_2} (from 110 to 130 mm Hg), whereas the effects of increased PEEP in nonobese patients were comparatively limited (16).

Koutsoukou and colleagues found that 10 of 15 morbidly obese (mean BMI, 56 kg/m^2) postoperative patients exhibited expiratory flow limitation and increased PEEPi at zero PEEP (53). Extrinsic PEEP titrated to a range of 4–16 cm H_2O abolished expiratory flow limitation and minimized PEEPi, but had no effect on oxygenation. These studies were not designed to test outcomes, and a zero PEEP strategy is seldom used in critically ill populations, particularly those with ARDS. However, the observations still serve to highlight physiological factors in ventilated obese patients that may make them particularly PEEP-responsive.

Small nonrandomized studies have compared outcomes in obese versus nonobese patients with ARDS treated with prone positioning, with conflicting results (54, 55). However, study subjects in the PROSEVA randomized clinical trial, which showed a mortality benefit of prone positioning in severe ARDS, had an average BMI of 28–29 kg/m^2, with ample numbers of subjects in the obese range (56). Given the limited data specific to prone positioning of morbidly obese patients, clinical judgment must guide whether logistical challenges and concerns such as intraabdominal hypertension from extrinsic abdominal compression outweigh the potential benefits.

Does obesity prolong mechanical ventilation or increase the risk of extubation failure? Meta-analyses are conflicting, with lack of risk adjustment and significant study heterogeneity making definitive conclusions difficult (2, 57). In a study published after these meta-analyses, O'Brien and colleagues performed a risk-adjusted analysis that also accounted for the competing risk of death and found evidence that obese medical ICU patients had a shorter time to successful extubation than those with a BMI less than 25 kg/m^2 (58). No difference in reintubation rates was seen, consistent with the findings of Frat and colleagues (35). Although the O'Brien study (n = 508) was smaller than most of those included in the meta-analyses, its methodological rigor combined with the conflicting results of prior studies cast doubt on the notion that obesity is an independent risk factor for prolonged mechanical ventilation or extubation failure. Evidence that prophylactic postextubation NIV may specifically benefit obese ICU patients is limited to a study using historical controls (59), although this strategy may be effective for patients with hypercapnia and chronic respiratory disorders (60).

Cardiovascular System

Blood volume and cardiac output increase in obese patients in response both to the need to perfuse additional mass and to increased baseline oxygen consumption (61, 62). Increased preload results in eccentric left ventricular (LV) hypertrophy, and concomitant hypertension may contribute to concentric hypertrophy (63). LV systolic and diastolic dysfunction, left atrial enlargement, and new-onset

atrial fibrillation are more common in obese individuals even after accounting for obesity-associated comorbidities such as hypertension and diabetes (64, 65). Overweight and obese individuals have greater right ventricular (RV) mass and modestly lower RV ejection fraction independent of cardiovascular risk factors and LV function (66). Such changes to the RV as well as elevated pulmonary vascular resistance may be more common in those with concomitant obstructive sleep apnea and are well described in OHS (67, 68).

Few studies have examined the risk obesity poses to cardiovascular dysfunction during critical illness. Evidence suggests that obesity is not associated with the risk of Sequential Organ Failure Assessment–defined cardiovascular failure (SOFA score $>$ 2), although these studies did not adjust for confounders (69, 70). It is possible, although not well studied, that the baseline alterations in cardiac anatomy and function described previously may make obese patients more susceptible to ICU complications such as atrial fibrillation, pulmonary edema, and RV dysfunction. Two studies demonstrated lower fluid resuscitation volumes, when indexed to BMI, in obese sepsis and trauma patients (71, 72). Fluids were indexed to BMI because use of unindexed administered fluid volumes does not account for increased circulating blood volume and therefore may overestimate the adequacy of fluid resuscitation in obese patients. However, blood volume increases in a nonlinear, plateauing fashion as BMI increases (62). In obese patients, therefore, administered fluid volumes indexed to BMI in a linear fashion are *underestimates* of the adequacy of fluid resuscitation with respect to blood volume.

Although Winfield and colleagues did show evidence of slower resolution of metabolic acidosis in morbidly obese trauma patients, it remains unclear whether there is systematic underresuscitation of obese patients and, most importantly, if protocolized resuscitation accounting for BMI-associated changes in blood volume would make an impact on outcomes (73).

Renal System

Obesity is an established risk factor for chronic kidney disease (CKD), due both to associated comorbidities and to glomerular lesions potentially related to a supranormal glomerular filtration rate (GFR) (74, 75). Obesity has also been identified as a risk factor for acute kidney injury (AKI) in trauma, ARDS, and general ICU populations (76–78). Some of these studies controlled for CKD, hypertension, and diabetes, leading to hypotheses that additional obesity-associated factors may increase risk. As circulating inflammatory mediators have been associated with AKI risk, adipose production of these mediators, as well as adipokines such as leptin, in response to acute illness could contribute to the obesity-AKI link (77, 79–81).

In addition, intraabdominal hypertension may cause renal dysfunction from both venous congestion and poor arterial perfusion. Obese ICU patients are at increased risk for elevated intraabdominal pressure (IAP) (82, 83). IAP is elevated at baseline, however, in otherwise healthy morbidly obese patients ($\sim$9–14 mm Hg) (84). Therefore it is not clear that a given elevated IAP in the setting of critical illness will have the same damaging physiological effects in obese as nonobese patients. As per guidelines for all patients, abdominal compartment syndrome in obese patients depends on the combination of elevated IAP and consistent clinical findings (85).

The limitations of current consensus criteria for AKI should be kept in mind when interpreting studies of obese patients (86). The indexing of urine output criteria to weight may misclassify obese patients as having AKI. For example, a 120-kg patient meets AKI criteria if urine output is less than 60 ml/hour for at least 6 hours. Creatinine-defined AKI may be more valid in this population, having demonstrated an association with increased mortality among obese patients with ARDS (77). In addition, common GFR estimating equations may be inaccurate in obese patients even when properly applied to those with stable renal function (87–89). The Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation may yield the best results in obese patients (90).

Nutrition

Optimal nutritional therapy in critically ill obese patients remains controversial. Compared with lean patients, protein losses from the catabolic state of critical illness may be accelerated in obese patients because they are more likely to use muscle as fuel (91, 92). Nutrition therapy can mitigate this catabolism, although not entirely. As in all critically ill patients, enteral nutrition should begin within 24–48 hours of ICU admission unless contraindications exist, and enteral is preferred over parenteral feeding (93). Optimal caloric prescription in obese patients is unclear. Predictive equations for energy expenditure are especially imprecise in obese critically ill patients, although no data suggest that using indirect calorimetry improves outcomes (94–96). Hypocaloric high-protein feeding has been suggested as a nutrition strategy in obese critically ill patients to simultaneously reduce protein catabolism and hyperglycemia while promoting steady weight loss, although clinical trial data are lacking (97, 98). The large-scale ARDS Network trial of early (first 6 d) trophic versus full enteral feedings found no differences in mortality, ventilator-free days, infectious complications, or long-term outcomes, with similar findings when stratified by BMI categories (99–101). However, contradictory evidence from a multicenter observational study suggests that obese critically ill patients may benefit from increased calories (102), and a randomized clinical trial on this topic is ongoing (Identifier NCT01206166; ClinicalTrials.gov).

Pharmacology

Accounting for obesity when dosing medications in the ICU is challenging. Because data to guide drug dosing in obesity are often limited, the clinician must be familiar with medications that require heightened awareness. For simplicity, it is useful to consider whether a drug (*1*) has weight-based dosing, (*2*) is lipophilic, (*3*) can be titrated to a rapidly clinically observable effect or serum concentration, or (*4*) has a narrow therapeutic window (Table 1).

Weight-based dosing regimens are usually based on studies that excluded the extremes of weight, and in many cases no specification is made regarding the use of actual body weight, ideal body weight (determined by height and sex), or adjusted

Table 1. Pharmacologic considerations in critically ill obese patients

Drug Characteristic	Potential Relevance	Examples
Weight-based dosing	Actual vs. ideal vs. adjusted weight (may differ for load vs. maintenance, may not be well studied in obese)	Vancomycin Low molecular weight heparins
Lipophilic	Higher loading doses Longer elimination $t_{1/2}$	Benzodiazepines Propofol
Renal metabolism	↑ Clearance (supranormal GFR) ↓ Clearance (CKD)	Vancomycin
Hepatic metabolism	↓ Clearance (fatty liver disease)	Phenytoin
Rapidly observable clinical effect or testable drug level	After estimating loading and maintenance dosing, titrate to effect or level	Sedatives Opioids Vasopressors Aminoglycosides
Narrow therapeutic window	Close monitoring of drug levels and dose-related adverse reactions	Low molecular weight heparins Phenytoin Digoxin

Definition of abbreviations: CKD = chronic kidney disease; GFR = glomerular filtration rate; $t_{1/2}$ = half-life.
Shown are drug characteristics that affect dosing strategies in critically ill obese patients.

body weight (most commonly, ideal + 0.4 [actual − ideal]) (5). Different considerations apply to bolus/loading versus maintenance dosing. Highly lipophilic drugs have increased volumes of distribution in patients with excess adipose tissue, and therefore may require higher bolus doses to rapidly achieve therapeutic plasma concentrations than might be predicted by ideal body weight (103). Hydrophilic medications such as nondepolarizing neuromuscular blockers do not distribute significantly to adipose, so dosing by ideal body weight may be more appropriate (4). Lipophilicity ranges widely, however, and myriad other factors influence dosing. Higher blood volume in obese patients may increase bolus dose requirements even for hydrophilic medications, while maintenance dosing of lipophilic medications must account for the potential for prolonged elimination half-life given the depot effect of adipose. Medication clearance, the major determinant of maintenance dosing, may be increased by a supranormal GFR or decreased if obesity-associated renal disease or fatty liver disease is present.

Comprehensive reviews can be found elsewhere, but several common ICU medications serve as useful examples (4, 5, 104). Vasopressors and sedatives can be rapidly titrated to effect and therefore may require less specific consideration of obesity in initial dosing. Given the potential for extended sedative elimination half-life, however, it is prudent to adhere to dose titration or interruption protocols to prevent unnecessarily prolonged sedation. Anticoagulants are a concern because of their relatively narrow therapeutic window. Intravenous unfractionated heparin is not well distributed in adipose, and dosing by adjusted body weight to account for increased blood volume has been suggested (5, 104). One systematic review of low molecular weight heparins concluded that actual body weight should be used for therapeutic dosing, with monitoring of anti-Xa activity in those weighing more than 190 kg, as well as an increase in prophylactic dosing for morbidly obese patients (105). It should be noted that the studies on which this review was based, however, were not well powered to detect clinically significant bleeding complications in the obese subgroup. Ultimately, the complexity that obesity adds to drug dosing highlights the need to understand fundamental pharmacokinetic concepts and to involve a pharmacist whenever possible.

Complications and Logistics

Venous Thromboembolism

Obesity is a risk factor for venous thromboembolism (106–108). Decreased mobility and thrombophilia from changes in circulating coagulation factors in obese patients may be responsible for this finding, as may inadequate dosing of prophylactic anticoagulants (109, 110). As with all ICU patients, heightened clinical suspicion of venous thromboembolism is needed given the difficulty in detecting classic signs of leg swelling and erythema (111, 112). In addition, ultrasound evaluation of deep vein compressibility may be more technically challenging in morbidly obese patients because of excess soft tissue, and CT can be limited both in image quality and capacity of scanners to accommodate weight and size (*see below*, Logistics).

Pressure Ulcers

Reports on risk of pressure ulcers associated with obesity are conflicting. Increased risk has been noted in obese nursing home and hospitalized patients (113, 114). In contrast, increased BMI was associated in a dose-dependent manner with lower pressure ulcer risk in a study of hospitalized elderly patients (115). Frat and colleagues reported pressure ulcers in 15% of obese versus 16% of normal weight mechanically ventilated patients, although the study was under-powered (35). It may be that in a resource-rich environment such as the ICU, the challenge of regularly mobilizing obese patients can be overcome more easily than in other settings, and that the cushioning effect of excess soft tissue may counteract the negative effects of excess weight (115). Given the conflicting data, obese patients should be risk-stratified in a similar fashion to nonobese patients, using validated tools such as the Braden Scale (116).

Nosocomial Infections

There are several reasons why obese patients might be at higher risk of nosocomial infection: difficulty obtaining peripheral

intravenous access with resultant increased use of CVCs, weight-related skin breakdown and soft tissue infection, and alterations in immune function. The few published studies addressing infection risk have shown conflicting results about whether obesity conferred an elevated risk of bloodstream infection or pneumonia (69, 117, 118). It is notable that in the study by Bochicchio and colleagues showing that obese patients (BMI $\geqslant$ 30 kg/m^2) more than doubled the risk of catheter-associated infections and nosocomial pneumonia, such patients also had much longer durations of CVCs, urinary catheters, and mechanical ventilation (117). In obese patients, placement of CVCs at the femoral site may increase the risk of bloodstream infection compared with the jugular site (119).

Logistics

Noninvasive blood pressure measurements have shown inaccuracies in critically ill obese patients, although these findings are not clearly different from those in nonobese patients (120). To prevent erroneously high readings due to small cuff size, the cuff bladder should be at least 80% of arm circumference in length, with a width at least 50% of upper arm length (5).

Table 2. Systematic reviews and meta-analyses of outcomes in critically ill obese patients

Authors (year); (Ref. No.)	Exposure	Outcomes	Effect of Obesity (95% CL)	Heterogeneity*
Akinnusi *et al.* (2008); (2)	BMI $\geqslant$ 30 kg/m^2 vs. $<$ 30 kg/m^2	ICU mortality	RR 1.0 (0.86, 1.16)	Substantial (I^2 = 75.6%)
		Hospital mortality	RR 0.83 (0.74, 0.92)	Moderate (I^2 = 56.4%)
		Duration of mechanical ventilation	1.48 (0.07, 2.89) more days	Moderate (I^2 = 60.1%)
		ICU length of stay	1.08 (0.27, 1.88) more days	High (I^2 = 98.8%)
Hogue *et al.* (2009); (57)	BMI categories (kg/m^2):	ICU mortality	No significant differences for any weight category vs. normal†	Moderate–substantial (I^2 = 50–80%)
	• Underweight ($<$18.5)	Hospital mortality		
	• Normal weight (18.5–24.9)	Obese vs. normal	RR 0.76 (0.59, 0.92)	High (not specified)‡
	• Overweight (25–29.9)	Morbidly obese vs. normal	RR 0.83 (0.66, 1.04)	High (I^2 = 93%)
	• Obese (30–39.9)	Length of mechanical ventilation	No significant differences for any weight category vs. normal†	Low–substantial (I^2 = 10–74%)
	• Morbidly obese ($\geqslant$40)	ICU length of stay		
		Overweight or obese vs. normal	No significant difference†	Low (I^2 $<$ 40%)
		Morbidly obese vs. normal	0.77 (–0.14, 2.03) more days	Low (I^2 $<$ 40%)
		Hospital length of stay		
		Overweight or obese vs. normal	No significant difference†	Low (I^2 $<$ 13%)
		Morbidly obese vs. normal	1.36 (–2.08, 5.52) more days	Low (I^2 $<$ 13%)
Oliveros and Villamor (2008); (123)	BMI categories (kg/m^2):	Mortality§		
	• Underweight ($<$18.5)	Overweight vs. normal	OR 0.91 (0.84, 0.98)	Low (I^2 = 29.6%)
	• Normal weight (18.5–24.9)	Obese vs. normal	OR 0.82 (0.68, 0.98)	Substantial (I^2 = 63.2%)
	• Overweight (25–29.9)	Morbidly obese vs. normal	OR 0.94 (0.82, 1.07)	Low (I^2 = 24.0%)
	• Obese (30–39.9)			
	• Morbidly obese ($\geqslant$40)	ICU length of stay		
		Overweight vs. normal	0.17 (0.08, 0.26) more days	Low (I^2 = 0%)
		Obese vs. normal	0.10 (–0.54, 0.74) more days	Low (I^2 = 0%)
		Morbidly obese vs. normal	1.10 (0.84, 1.37) more days	Low (I^2 = 0%)

Definition of abbreviations: CL = confidence limits; BMI = body mass index; ICU = intensive care unit; OR = odds ratio; RR = relative risk.
Shown is a summary of systematic reviews and meta-analyses of outcomes in critically ill obese patients, with a focus on mortality and length of mechanical ventilation and hospitalization.
*Heterogeneity categories are based on those from the Cochrane Handbook (131); "High" is used in place of "Considerable" (the term used in the Cochrane Handbook) to make evident that this degree of heterogeneity is greater than "Substantial."
†The systematic review by Hogue and colleagues presented these results in graphical form but did not specify precise point estimates and confidence limits.
‡Although I^2 is not specifically stated for this comparison, the text indicates that all I^2 values for hospital mortality were between 86 and 93%.
§The systematic review by Oliveros and Villamor did not specify whether hospital mortality, ICU mortality, or both were used to perform the meta-analysis.

Placement of CVCs in obese patients can be challenging. A large abdominal pannus may interfere with femoral site sterility during placement and maintenance. Ultrasound guidance may be particularly helpful to overcome difficulties identifying anatomic landmarks or to facilitate the placement of peripheral catheters instead.

Interpretation of chest X-rays may be limited by soft tissue attenuation, giving the lung fields a hazy appearance even if no parenchymal process is present. The prevalence of dependent atelectasis and pulmonary edema also makes examination of plain films in obese patients challenging. CT imaging can be quite useful, although image noise and cropping can degrade quality (5). CT scanners also have limitations on table weight and aperture diameter (121). Good transthoracic echocardiographic windows can be difficult to obtain through excess chest wall soft tissue, occasionally necessitating a transesophageal approach.

Bariatric-capable beds and lifts can help in the care of obese patients. Such specialized equipment may help with the challenging task of transportation and associated transfers to and from examination tables. Some beds have the capability to be placed in a chair position to facilitate reconditioning efforts after surgery and critical illness without the need to transfer the patient. Specialized training may help as well—one pilot study showed decreased pressure ulcer and employee injury incidence and reduced overall costs after creation of a dedicated two-person lift team for moving patients weighing more than 90 kg at risk for pressure ulcers (122).

Outcomes

Many studies have investigated whether the mortality increase associated with obesity in the general population translates into worse outcomes from critical illness. Three systematic reviews (Table 2) concluded that obesity was associated with either similar or lower risk of death compared with normal weight (2, 57, 123). The substantial study heterogeneity found in these reviews is reason for caution in interpreting the results, and is itself instructive—obesity's impact on outcomes may depend on the population under consideration. For example, in medical ICU populations where comorbidities such as malignancy and chronic obstructive pulmonary disease are common, weight loss may be a marker for more advanced disease such that lower BMIs are associated with poor outcomes (124, 125). Controlling for such confounding is difficult without highly detailed medical history data. Trauma, in contrast, affects a younger average population with fewer comorbidities, such that the detrimental physiological changes and logistical challenges in obese patients might outweigh the effect of any correlation with less advanced chronic disease.

Other explanations have been put forth for the so-called "obesity paradox"—a term describing similar or improved survival for obese ICU patients despite associated comorbidities. Adipose may serve beneficial roles during critical illness as a source of nutrition, a storage depot for harmful circulating metabolites, or a counterbalance to excess inflammation as evidenced by the phenotypic switch of adipose macrophages to an antiinflammatory subtype in chronic critical illness (3, 126–128). Such mechanisms may underlie the findings of Prescott and colleagues that obesity and overweight were associated with decreased 1-year mortality compared with normal weight in severe sepsis patients (129). As described previously (Respiratory Failure and Mechanical Ventilation), higher baseline pleural pressure might protect obese patients from ventilator-induced lung injury when managed at similar plateau pressures as nonobese patients.

Despite contradictory data, practitioners may assume a link between obesity and mortality. In a survey of providers' predictions about outcomes in sepsis, obese patients were on average assigned a 4.3% higher likelihood of dying than normal weight patients given a variety of otherwise identical clinical scenarios (130). Survey respondents also predicted significantly higher likelihood that surviving obese patients would have problems with self-care at 6 months. Although loss of muscle mass and deconditioning affect all critically ill patients, obese patients may face added challenges in regaining enough strength to lift excess body weight to perform activities of daily living.

Conclusions

Obese critically ill patients present unique challenges. Physiological changes, differences in risk of organ dysfunction and complications, drug dosing alterations, and logistical issues must be understood to provide the best possible care. There is no standard "obese patient," however—obesity is just one factor among many to be considered, and many standard practices do not require modification for obese patients. How obesity affects outcomes from critical illness remains unclear, although the balance of evidence does not point to increased mortality. Further study of both the harmful and beneficial effects of obesity in critical illness has the potential to improve care for obese patients and may ultimately promote a better global understanding of ICU pathophysiology. ■

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