Obesity, as defined by the World Health Organization (WHO), is the “abnormal or excessive fat accumulation that may impair health.” Body mass index (BMI), weight in kilograms divided by the square of height in meters (kg/m²), has been the most commonly used scale of obesity. The WHO classifies weight by BMI into the following ranges:

- Normal weight: BMI > 18.5–24.9 kg/m²
- Overweight: BMI > 25–29.9 kg/m²
- Obesity: BMI > 30–39.9 kg/m²
- Severe (morbid) obesity BMI > 40 kg/m²

Other terms used in the description of BMI classes include severe obesity to include BMI over 35 kg/m² in the presence of comorbidities or super obese when BMI is above 50 kg/m². More valid measures of obesity have been proposed rather than the BMI. Waist to hip ratio, sagittal abdominal diameter, and dual energy x-ray absorptiometry may reflect body composition and distribution better than BMI (1).

Globally, the prevalence of obesity has significantly increased over the last decades. More than a third of the population of the United States are obese with severe or morbid obesity greater than 5%. Although the prevalence of obesity may have plateaued in some developed nations (2), authors note a projected faster rise in the prevalence of morbid obesity in the next decade (3). Therefore, care of the obese especially the morbidly obese has become part of all aspects of health care including critical care. The prevalence of obesity and morbid obesity in the intensive care population reflects the general population distribution (4,5).

**CELLULAR PATHOPHYSIOLOGY**

Obesity has been shown to be a state of chronic inflammation and hypercoagulopathy. White adipose tissue especially visceral adipose tissue is an active immunoendocrine organ. Adipocytes of the obese have up to a fourfold increase in the density of macrophages (6). Adipose tissue macrophages produce and secrete proinflammatory cytokines including but not limited to tumor necrosis factor alpha (TNF-alpha), interleukin-6, interleukin-8, and monocyte chemoattractant protein-1 (MCP-1) (7). The blood levels of these inflammatory proteins increase as adiposity rises (8). Adipocytes produce signaling molecules known as adipokines. Leptin, adiponectin, and plasminogen activator inhibitor-1 (PAI-1) are such molecules.

Leptin is an upregulator of cell-mediated immune response. Leptin is increased in obesity, and its proinflammatory properties have been linked to obesity-associated disease states such as cardiovascular disease, diabetes, and cancer (9).

Adiponectin is a protective, anti-inflammatory cytokine that is important in insulin-sensitization, antiatherogenesis, and anti-thrombus formation. Adiponectin is depressed in the obese patient contributing to the development of cardiovascular disease, metabolic syndrome, and venous thrombosis (10). PAI-1 increased in obesity causes hypercoagulable state by decreasing fibrinolysis and increasing platelet aggregation. Angiotensin levels are elevated in obesity increasing angiotensin II thus contributing to obesity-induced hypertension and toxic effects on the myocardium (11).

Adipose tissue inflammation disrupts the normal functions of the adipocytes and leads to dyslipidemia. This increase in circulating lipid levels leads to the heterotopic deposit of lipids within liver, pancreas, and heart. Local toxic effects of visceral fat deposits can induce organ pathology. Obesity especially central or abdominal obesity leads to changes in cellular, organ, and system levels. The pathophysiologic consequences of obesity involve all major organ systems. Diabetes mellitus, elevated fasting glucose, hypertension, and hyperlipidemia are associated with central obesity and collectively known as the metabolic syndrome or syndrome X. These conditions contribute to chronic morbidity in the obese. Cardiopulmonary concerns are the most often encountered by the intensivists (12). A summary of adipokines effects is given in Table 69.1.

**CARDIOVASCULAR CONSIDERATIONS IN THE MORBIDLY OBESE**

Cardiovascular diseases are common in obese individuals and manifest as ischemic heart disease, hypertension, and cardiac failure. Obesity has been observed to be an independent risk factor for the development of these conditions (13).

The relationship between the increase in blood pressure and the risk of cardiovascular disease is considered to be independent of other risk factors. The chances of myocardial infarction, heart failure, stroke, and kidney disease are all greater as a patient’s blood pressure increases. Obesity is also well recognized as a risk factor for ischemic heart disease. Many obese individuals also suffer from metabolic syndrome, which has a strong association with being a precursor to the development of diabetes, cardiovascular disease, and increased mortality rates from cardiovascular disorders. There is also a 5% to 7% risk of heart failure associated with each 1% increase in body mass (14).

**Pathophysiology**

There is an increase in stroke volume as weight increases resulting in higher cardiac output. Total blood volume also increases thought to be due to polycythemia and sodium retention from adipose-produced angiotensinogen thus increasing preload. These changes manifest clinically as arterial hypertension,
increased left ventricular mass, and hypertrophy. Both eccentric and concentric hypertrophy is seen in obese individuals. This can result in left ventricular and diastolic dysfunction with atrial enlargement. It is the complex interaction of hypertension, ischemic heart disease, and pulmonary hypertension that contribute to the development of global cardiac dysfunction and exacerbates congestive heart failure. This clinical situation is referred to as “obesity cardiomyopathy” (15).

**RESPIRATORY CONSIDERATIONS IN THE MORBIDLY OBSESE**

Morbidly obese patients have significant anatomic and pathophysiologic changes of the pulmonary system. Reduced lung volumes, increased work of breathing, respiratory muscle inefficiency, and alterations in control of breathing and gas exchange can complicate the care of the morbidly obese. Many factors are involved including, but not limited to, BMI, patient's age, duration of obesity, fat distribution (central or peripheral), and the strong association of certain sleep-related breathing disorders such as obstructive sleep apnea (OSA) and obesity hypoventilation syndrome (OHS) (16).

Morbidly obese patients have the lower functional residual capacity (FRC), expiratory reserve volume (ERV) and to a lesser extent total lung capacity (TLC). Forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), and maximum voluntary ventilation (MVV) are also reduced in the morbidly obese suggesting small airway remodeling and decrease in caliber. These changes are worsened by supine positioning, in which diaphragmatic movement is hampered by the increased abdominal pressure. The increased adipose tissue around the rib cage decreases chest wall compliance, which also reduces FRC. As the FRC decreases it approaches the closing capacity, which can lead to airway closure within the range of tidal breathing. Areas of the lung may be underventilated leading to intrapulmonary shunting and hypoxemia. Respiration can also be comprised by early airway closure resulting in air trapping and auto-PEEP, which increases work of breathing (17). This loss of FRC with resultant smaller airway collapse and atelectasis decreases pulmonary compliance. Increased blood volume within the pulmonary circulation also contributes to the diminished pulmonary compliance and is exponentially related to BMI. These changes result in increased work of breathing, which is compounded by decreased diameter of the upper airway caused by parapharyngeal fat (18).

As with nonobese individuals, lower lung segments in the obese are well perfused, but because of the closure of small airways in these areas, ventilation is shifted to the upper lung segments resulting in increased V/Q mismatch and hypoxemia. Chronic hypoxemia contributes to persistent increased pulmonary vascular resistance and right heart failure. The level of hypoxemia is worse in OHS. Respiratory muscle endurance is also decreased in the obese patient and to a greater degree in OHS with a marked increase in oxygen consumption of the respiratory muscles. This decline in respiratory muscle endurance leads to earlier fatigue and respiratory failure (18).

Obese patients require higher minute ventilation to match the oxygen consumption and metabolic demands, which result in increased respiratory rate and shallower volumes. In OHS, the neural drive fails resulting in hypercapnia and hypoxia. There is not a linear association between these respiratory changes and degree of obesity. However, the cumulative effect can result in lower pulmonary reserve and increase the risk of respiratory failure in obese patients (17).

Obstructive sleep apnea syndrome (OSAS) is more prevalent in the morbidly obese than OHS and is often underdiagnosed. This can lead to difficulties in the management of morbidly obese patients in stressed situations such as perioperative or in acute disease states where OSAS pathophysiology may not be recognized. OSAS is associated with increased risk of postoperative cardiac events, respiratory failure, and intensive care admissions. OSAS is associated with difficult mask ventilation and intubation. OSAS patients are more susceptible to sedation effect of hypnotics and opioids. OSAS is also associated with increased overall mortality (19). Use of empiric positive airway pressure in patients who are high risk for OSA but undiagnosed may be of use in the management of the morbidly obese for perioperative care, acute respiratory failure, and bridge after extubation (20–22). In patients with OHS, noninvasive continuous positive airway pressure may improve upper airway patency, increase FRC, offset auto-PEEP, augment respiratory muscles, and oxygenation. However, the additional inspiratory component of bilevel positive airway pressure helps ameliorate the hypercapnia of OHS. Noninvasive positive pressure ventilation (NIPPV) does not appear to impact the need for endotracheal intubation in acute hypoxic respiratory failure due to ARDS in this population, however so close monitoring of these patients is warranted preferably in an intensive care setting where difficult airways can be managed if intubation is warranted (16).

It is still a debatable issue whether or not morbid obesity should be considered a risk factor for difficult airway management especially in the elective situation such as in the operating room. More important was consideration of Mallampati score of 3 or greater, previous documented difficult airway, limited mouth opening or cervical mobility, and history of OSA. There is also some data to suggest that patients intubated in the intensive care unit are more likely to have difficult airways and complications related to intubation than those patients in an operating room setting (23). Whether or not morbid obesity is considered a risk factor for intubation, issues related specifically to the patient's BMI that impact airway management should be considered.

Less cardiopulmonary reserve in the morbidly obese from pathophysiologic changes described previously results in more
rapid desaturation during intubation. Supine positioning increases V/Q mismatch thereby worsening hypoxemia. Obesity alters upper airway anatomy. Increased fat deposition in pharyngeal tissues increases the likelihood of pharyngeal wall collapse and also decreases the cross-sectional area of the upper trachea. These changes, as well as increased airway resistance from decreased pulmonary and chest wall compliance, makes bag mask ventilation more difficult. Obese patients have increased the risk of aspiration pneumonia resulting from increased intrathoracic pressure (IAP) and increase in gastric volumes (23).

The key to maximizing intubation success and decreasing complications is preparation if possible with the following important points preoxygenation, positioning, and resources. Preoxygenation with 100% oxygen by mask or by NIPPV with the patient in the 30- to 45-degree head up or reverse Trendelenburg position. This positioning helps unload the abdominal contents from the diaphragm. Before induction of sedation, the obese patient should be placed in a ramped position. In the ramped position, blankets or commercially available tools or beds are used to elevate the head and torso such that the external auditory meatus and the sternum are horizontally aligned. Essential equipment and personnel should be gathered. The exact list of equipment needed may vary slightly depending on the intubating individual’s preference, but endotracheal tubes with stylets, functioning suction, a bag-valve device connected to an oxygen source, laryngoscope (direct or video) and blades, oral/nasal airways, and a device to detect end-tidal carbon dioxide are essential. Continued oxygen delivery via high-flow nasal cannula during laryngoscopy may extend safe apnea time. All providers who are responsible for intubation of critically ill morbidly obese should be familiar with an accepted difficult airway guideline (Table 69.2) (24–27).

Obesity is associated with more severe asthma and increased risk of adult respiratory distress syndrome (ARDS). Recent viral pandemics such as H1N1 showed obesity as a risk factor for ARDS and multi-system organ failure, However, BMI alone is not associated with increased mortality from ARDS (28). Morbidly obese patients often require longer ventilatory support in their normal weight counterpart. The mechanically ventilated morbidly obese patient presents the critical care physician with unique challenges. There is no clear optimum mode of ventilation in the critically ill, mechanically ventilated morbidly obese patient. Much of the literature on ventilation in this population is from elective surgical patients undergoing bariatric surgery. Positioning the patient in a 70-degree sitting position rather than a semi-Fowler position where the head of the bed is at 30 to 45 degrees has been reported to improve expiratory flow and decrease auto-PEEP (29). Recent studies suggest that intensivists underestimate appropriate PEEP needed to optimize end-expiratory lung volumes in the intubated morbidly obese patient. Utilization of pressure–volume curve to determine lower inflection point (where alveoli collapse) or utilization of esophageal balloon manometry as a surrogate for transpleural pressure may be a better guide to determining the optimal level of PEEP in these patients. Some authors suggest routine recruitment maneuvers shortly after intubation (i.e., PEEP 30 cm H2O for 30 seconds) in addition to PEEP guided by transpleural pressure monitoring or equivalent (30). If estimating, empiric PEEP of 10 to 15 cm H2O has been suggested as optimal for the morbidly obese mechanically ventilated patient (31). Ideal body weight should be used to determine tidal volume and monitoring of acid–base status as a guide to appropriate minute ventilation.

When preparing to extubate the morbidly obese patient, one must take into consideration the underlying lung mechanics. Decreasing PEEP to 5 cm H2O or use of T-piece during weaning may result in loss of recruited end-expiratory volume. Keeping PEEP above the level of lower inflection point during weaning may prevent derecruitment. Postextubation bridging with NIPPV at the same level of PEEP used during weaning should be considered. NIPPV helps overcome upper airway resistance, decreases respiratory muscle fatigue and prevents atelectasis (32). Keeping the patient in a more upright position will also help optimize lung mechanics (Table 69.3).

TABLE 69.2 Summary of Endotracheal Intubation Concerns in Morbidly Obese Patients

- Pulmonary aspiration of gastric contents
- Difficult mask ventilation and tracheal intubation
- Rapid development of hypoxemia after apnea
- Pulmonary atelectasis
- Hemodynamic instability
- Decreased ability to deal with the physiologic responses to stressful situations (i.e., hypoglycemia, hypertension, cardiac failure, arrhythmias, and myocardial ischemia)
- Delayed recovery
- Postoperative respiratory dysfunction
- Deep venous thrombosis

TABLE 69.3 Vital Measures to Prevent or Reduce the Severity and Duration of Atelectasis in the Obese Patient

- Place patients in the semirecumbent position and, if possible, out of bed in a chair as tolerated, as this maneuver may increase functional residual capacity.
- Provide effective analgesia, which will allow early and effective mobilization, cough, and excellent tolerance to physiotherapy.
- Institute aggressive incentive spirometry.
- During the first 3 postoperative days, deliver humidified “supplemental oxygen,” but avoid inspired fractions higher than 0.8. Supplemental humidified oxygen will not reduce atelectasis, but will facilitate respiratory secretion clearance, and will prevent hypoxemic episodes in efforts to improve the host’s defenses against bacterial infections.
- During surgery or postoperatively in intubated patients, instituting positive end-expiratory pressure is probably effective in increasing functional residual capacity via recruitment of atelectatic regions of the lung. Applying vital capacity maneuvers (also known as recruitment maneuvers) may also reduce the incidence and/or severity of atelectasis while improving the quality and effective time of alveoli recruitment.
- Noninvasive positive pressure ventilation can be used to avoid intubation in selected patients.

IMPORTANCE OF COUPLED CARDIORESPIRATORY FUNCTION

It is vital to maintain the best possible ventilation/perfusion (V/Q) balance because V/Q mismatch is a prominent mechanism that can trigger respiratory and subsequent cardiac dysfunction in the morbidly obese patient. In mechanically ventilated, morbidly obese patients, airway pressure may be elevated. Additionally, morbid obesity is associated with volume and pressure overload. Volume load conditions may fluctuate according to patient positioning. For example, changing position from the “physiologically ideal” reverse Trendelenburg...
to the supine position can significantly increase venous blood return to the heart and, as a result, augment cardiac output, pulmonary capillary wedge pressure, and mean pulmonary artery pressure, potentially increasing the risk of acute heart failure; one would expect this maneuver to increase airway pressure as well due to the increased weight of the chest. Compression of the inferior vena cava may reduce venous return to the heart, and is thus a possible mechanism of hypotension. This can be avoided by placing a wedge under the patient. Considering that the reverse Trendelenburg position or semi-Fowler position significantly improves cardiac and respiratory performance, it should be maintained unless there is a particular contraindication (33).

**RENAL CONSIDERATIONS**

Morbid obesity is a risk factor for chronic kidney disease (CKD). Comorbidities such as hypertension and diabetes contribute to decrease in kidney function as well as the increased glomerular filtration rate (GFR) from morbid obesity itself. Obesity-related glomerulopathy is manifested as glomerulosclerosis, and secondary focal and segmental glomerulosclerosis. CKD is a risk factor for acute kidney injury (AKI). The critically ill morbidly obese patient who has increased GFR might mask underlying renal insufficiency predisposing these patients to AKI from inappropriate drug dosing, exposure to nephrotoxins such as IV contrast dye, overestimation of intravascular volume, and failure to recognize abdominal compartment syndrome (ACS) (34).

AKI increases mortality in the critically ill morbidly obese patient. Strategies to avoid AKI in the critically ill morbidly obese patient include recognition of the risk of underlying kidney pathology. Class III obesity and above have been shown to be an independent risk factor in developing AKI in the perioperative population. Obtaining euvoolemia while maintaining renal perfusion pressure with minimum vasopressors is a logical goal. Management of dynamic fluid responsiveness should avoid suspected nephrotoxins, such as starch based colloids (35).

**GASTROINTESTINAL CONSIDERATIONS**

There is an increased prevalence of gastroesophageal reflux in the morbidly obese. Coupled with increased gastric volume, increased IAP and decreased lower esophageal sphincter, the obese patient is at risk for aspiration during critical illness and endotracheal intubation. Several studies have shown an association between increases in BMI and intra-abdominal hypertension (defined as IAP >12 mmHg). This baseline increase in IAP can predispose obese individuals to develop ACS. ACS occurs when the IAP exceeds 20 mmHg with evidence of organ dysfunction, such as oliguria, decreased cardiac output from impedance on venous return, decreased pulmonary compliance, increased intracranial pressure, and lactic acidosis. Disorders such as ascites, intra-abdominal hemorrhage, visceral edema, bowel distension, or large abdominal tumors can lead to ACS. Treatment is usually focused on the cause (i.e., paracentesis for massive ascites) and sometimes may require surgical decompression.

Nonalcoholic fatty liver disease (NAFLD) is more prevalent in the obese patient. The NAFLD covers a spectrum of disease, from asymptomatic elevations of alanine transaminase to steatosis with lobular inflammation and ballooning degeneration, termed nonalcoholic steatohepatitis (NASH) to liver fibrosis and cirrhosis. Some patients diagnosed with NAFLD may have NASH or cirrhosis, which could lead to complications, particularly prolonged drug metabolism and relative immune suppression of liver disease, and worse outcomes in the intensive care unit (36).

**DRUG DOSING**

The distribution, metabolism, protein binding, and clearance of many drugs are altered by the physiologic changes associated with obesity as reviewed in the previous sections. Also, obesity-associated comorbidities may substantially influence the pharmacokinetic properties of a drug. Although data on effects of morbid obesity on pharmacokinetics is increasing, there is still a paucity of well-powered studies. This clinician should be aware of weight-based dosing is complicated by which value one uses: ideal body weight, adjusted body weight, or actual body weight. Many drugs used in the intensive care setting can be titrated to obvious effect such as vasoactive medications. Although sedation and pain medications can also be titrated to effect, the lipophilic nature of commonly used benzodiazepines may prolong elimination of these drugs. Sedation and opiates in the nonintubated seriously ill morbidly obese patient requires heightened awareness as this population may have undiagnosed sleep-disordered breathing and may have increased hypercapnia and hypoxia (37). Some drugs can be monitored in steady state by drug levels or laboratory values. However, often it is imperative to have adequate initial or loading dosing for many drugs in the critically ill. For example, underdosing antimicrobials by providers has been shown to be common in the morbidly obese which may lead to treatment failure and resistance (38). Drugs with narrow therapeutic windows such as anticoagulants should be monitored closely. Consultation with critical care pharmacists and development of protocols can help achieve early adequate dosing (39).

**VENOUS THROMBOEMBOLISM**

Obesity is a risk factor for venous thromboembolic disease. Literature suggests relative risk for deep vein thrombosis (DVT) of 2.50 in obese versus nonobese patients and relative risk for pulmonary embolus (PE) of 2.21 (40).

There are several proposed mechanisms for the increased risk of VTE in obese patients in the intensive care unit. Because of limitations of body habitus, these patients are often less ambulatory and assisted mobilization in the hospital may also be limited. Also, prophylactic measures may be inadequate. Compression devices are less likely to fit properly, and the limited data on appropriate pharmacologic prophylaxis dosing in the obese may result in subtherapeutic levels. Increased procedural complications exist in this patient population, and limited intravenous access may increase the duration of central access, which can lead to thrombosis.

Diagnosis of VTE may also be compromised. Studies have shown that clinical signs of a DVT are often absent. Entities
involved in critical illness such as peripheral edema–decreased sensorium, surgical dressing, and adiposity further impair clinical signs of DVT (41).

The best regimen for thromboprophylaxis in this high-risk group is not single armed. The risk of bleeding should be balanced with the risk of thrombosis. In patients with low risk of bleeding, chemoprophylaxis should be used in conjunction with mechanical prophylactic devices such as intermittent pneumatic compression boots. If the bleeding risk is high, mechanical prophylactic devices should be used until chemoprophylaxis can be instituted. Prophylactic inferior vena cava filters can be considered, but not recommended for primary prophylaxis. Unfractionated or low–molecular-weight heparins are both viable options though precise dosing regimens and duration of dosage have emerged largely from uncontrolled trials. There are reports in the bariatric literature that 40 mg of enoxaparin every 12 hours may provide better thromboprophylaxis than 30 mg every 12 hours. Weight-based dosing of 0.5 mg/kg with weights over 150 kg following thromboprophylaxis than 30 mg every 12 hours. Weight-based dosing of 0.5 mg/kg with weights over 150 kg following anti-factor Xa levels after the third dose with the goal of 0.2 to 0.5 IU/mL is suggested by many authors (42).

OUTCOMES

There is no consensus whether obesity confers a survival advantage or disadvantage in critical illness. This disparity may reflect the difficulty in defining obesity only based on a measure of weight and not the complex tissue and system effect of adiposity. Obese patients present the entire critical care team with obstacles to overcome. From acute illness and resuscitation to mobilization and rehabilitation; the morbidly obese critically ill patient requires an understanding of the pathophysiology at a cellular, tissue, and system level.

Key Points

- Obesity is a worldwide epidemic in which the morbidly obese is rapidly increasing.
- In the morbidly obese, adipose tissue is immunologically active and through a multitude of inflammatory pathways causes pathology on cellular, tissue, and system levels.
- Changes to the cardiopulmonary system, lead to little reserve during critical illness. Obese patients have increased blood volume.
- Increase in body mass leads to increased oxygen demand, and results in chronic stress on myocardium coupled with increase in arterial resistance can lead to left ventricular systolic and diastolic dysfunction.
- FRC is chronically decreased in the morbidly obese leading to V/Q mismatch and hypoxia. This coupled with decreased excursion of diaphragms and decreased chest wall compliance can lead to rapid desaturation during critical illness and intubation.
- Anatomical alterations from fat deposits of the upper airway and increased resistance from narrowed trachea and bronchioles can be additive, making the morbidly obese patient a “difficulty airway.”
- Intensivists underestimate the amount of peep to recruit collapsed alveoli in the ventilated morbidly obese. Levels of at least 10 cm H2O should be a started point.
- Consideration of extubating to NIPPV even in recent thoracic and bowel surgery should be strongly considered. There has been no evidence that NIPPV in postoperative patient disrupts anastomosis except for possibly the pharyngeal and oral surgeries.
- Drug dosing in the morbidly obese is complex and maybe unique in each patient. Underdosing antibiotics and anticoagulation has been shown to be as serious a problem as overdosing. Expert consultation with critical care pharmacist is imperative.
- Many morbidly obese patients are malnourished both macro and micronutrients. Adequate protein should be given.
- Morbidly obese patients should not be ridiculed, or disparaged.
- Equipment should be made available to morbidly obese patient that can safely handle extreme weight safely.
References


