Anesthetic Considerations

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Hendrikus J. M. Lemmens, John M. Morton, Cindy M. Ku, and Stephanie B. Jones

Chapter Objectives

1. Provide the anesthesiologist with a practical approach to the problems that require special consideration in patients with severe obesity.
2. Identify comorbidities that require preoperative evaluation.
3. Evaluate anesthetic and analgesic options.
4. Discuss how obesity affects airway management and how bariatric surgery affects fluid management.
5. Review postoperative considerations.

Introduction

Anesthetic management of the patient with severe obesity (SO) presenting for bariatric surgery differs significantly from that of the normal-weight patient undergoing similar procedures. Well-planned and rational management of patients undergoing bariatric surgery requires detailed knowledge of how severe obesity affects anesthesia care. The mechanical effects of increased body mass index (BMI) as well as the physiological changes and associated comorbidities all impact safe management and decision-making by the anesthesiologist. The aim of this chapter is to provide a practical approach to the problems that require special consideration in patients with severe obesity.

H. J. M. Lemmens
Multispecialty Division, Department of Anesthesia, Stanford University School of Medicine, Stanford, CA, USA

J. M. Morton
Bariatric and Minimally Invasive Surgery Division, Yale School of Medicine, New Haven, CT, USA

C. M. Ku · S. B. Jones (✉)
Department of Anesthesia, Critical Care and Pain Medicine, Beth Israel Deaconess Medical Center, Boston, MA, USA
e-mail: sbjones@bidmc.harvard.edu

Preoperative Evaluation

A full assessment for medical conditions that can affect perioperative complications must be performed. Preoperative "clearance" by a primary care physician or allied health professional and surgical consultation notes may not include information pertinent to anesthesia care, and while electronic health records can be helpful in information sharing, errors and gaps in information may be perpetuated. Organ dysfunction identified in the preoperative evaluation should be thoroughly evaluated and optimized before proceeding with this elective surgery.

Respiratory Issues Relevant to Anesthesia Management

The effect of obesity on the respiratory system decreases the margin of safety of anesthetic agents and increases the risk of respiratory failure in the perioperative period [1]. Respiratory failure is a life-threatening complication after bariatric surgery, with a reported incidence of 1.35–8% [2, 3]. Risk factors that increase the likelihood of respiratory failure are congestive heart failure, open surgery, chronic renal failure, peripheral vascular disease, male gender, age >50 years, alcohol abuse, chronic lung disease, diabetes, and smoking [2]. The presence of metabolic syndrome significantly increases the odds of postoperative pulmonary adverse events [4, 5].

At baseline, subjects with severe obesity may be mildly hypoxemic, with higher respiratory rates and lower tidal volumes. The compliance of the respiratory system is reduced and work of breathing increased. Functional residual capacity (FRC) and expiratory reserve volume (ERV) decrease exponentially with increasing BMI, with the greatest rate of change in the overweight (BMI 25.0–29.9 kg/m^2) and mildly obese (BMI 30.0–34.9 kg/m^2). In sitting subjects with a BMI of 30 kg/m^2, FRC and ERV are 75 and 47%, respectively, of the values for a person with a BMI of 20 kg/m^2 [6]. In anes-

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thetized supine patients, the effect of BMI on FRC is more pronounced, and tidal volume is more likely to fall within closing capacity, promoting shunting [7]. In addition to the changes in respiratory mechanics and lung volumes, the prevalence of obstructive sleep apnea (OSA) in bariatric patients can be as high as 75% [8]. Of those with OSA and severe obesity, up to 20% may have obesity hypoventilation syndrome (OHS), which is characterized by daytime awake hypercapnia, hypoxemia, and elevated HCO_3^- [9]. It is important for anesthesiologists to recognize patients with OHS since it is associated with severe upper airway obstruction, restrictive lung disease, blunted central respiratory drive, pulmonary hypertension, and increased mortality. Before bariatric surgery, these patients should be referred to sleep medicine for polysomnography and positive airway pressure (PAP) titration. An echocardiogram should be performed to assess right ventricular function and pulmonary hypertension. Poor right ventricular function and high mean pulmonary artery pressures (>35 mmHg) are associated with an unacceptable anesthesia-related perioperative mortality risk. Perioperative precautions for OHS include prudent airway management, rapid emergence, monitoring for ventilatory impairment, and early resumption of PAP therapy.

The compromised respiratory status of the patient with obesity requires special precautions to prevent oxygen desaturation at induction of anesthesia, during surgery, and in the postoperative phase. After preoxygenation with 100% oxygen and complete denitrogenation, an anesthetized supine paralyzed SO patient's oxygen saturation decreases from 100% to 90% in about 2.5 min [10]. Premedication with anxiolytics or opioids depresses spontaneous ventilation and should be minimized. Preoxygenation techniques delaying the onset of hypoxia should be used: the 25° head-up position may add a minute to the safe apnea time [11], the use of supplemental oxygen or high flow oxygen decreases the rate of desaturation [12], and application of noninvasive positive airway pressure during induction of anesthesia can increase safe apnea time by 50% [13] while improving oxygenation during maintenance of anesthesia [14].

Immediately after induction of anesthesia, atelectasis develops mainly in the dependent areas of the lung. Atelectasis results in pulmonary shunting and hypoxemia. Release of inflammatory cytokines associated with atelectasis may contribute to postoperative ventilator-associated lung injury such as pneumonia and respiratory failure. In the patient with severe obesity, ventilatory strategies to prevent atelectasis may require recruitment maneuvers and positive end-expiratory pressure (PEEP) values higher than 10 cm H_2O. Although high PEEP levels combined with pneumoperitoneum will decrease venous return and can induce hypotension, PEEP levels up to 20 cm H_2O are generally tolerated in well-hydrated patients [15]. The trend toward maintaining preoperative normovolemia as part of enhanced recovery protocols will assist in that regard. Strategies such as reverse Trendelenburg positioning (when appropriate for the surgical procedure), periodic intraoperative lung recruitment, avoiding reabsorption atelectasis by keeping FiO2 <0.8, using less than 8 ml/kg of LBW for volume-controlled mechanical ventilation to avoid volutrauma, and utilizing incentive spirometry and noninvasive ventilation in the PACU may help prevent respiratory complications in the patient with obesity.

Cardiovascular Issues Relevant to Anesthesia Management

The increased tissue mass of the patient with severe obesity needs to be perfused, leading to an increased total blood volume. While the total blood volume is increased, on a per kg total body weight basis, blood volume is decreased. Blood volume per kg total body weight (TBW) decreases exponentially from 70 ml/kg TBW at a BMI of 22 kg/m^2 to 40 ml/kg TBW at a BMI of 65 kg/m^2 (Fig. 8.1) [16]. If 70 ml/kg TBW is used for blood volume calculation, blood volume is overestimated, and under-transfusion of blood products may occur when significant blood loss during surgery is encountered. The increased total blood volume of the patient with SO results in an increased cardiac output (CO). CO increases from 4 L/min at a BMI of 20 kg/m^2 to more than 6 L/min at BMIs greater than 40 kg/m^2. CO affects early pharmacokinetics, the front-end kinetics of drug distribution, and dilution in the first minutes after administration. An increased CO decreases the fraction of drug distributed to the brain and increases the rate of redistribution, which will result in lower

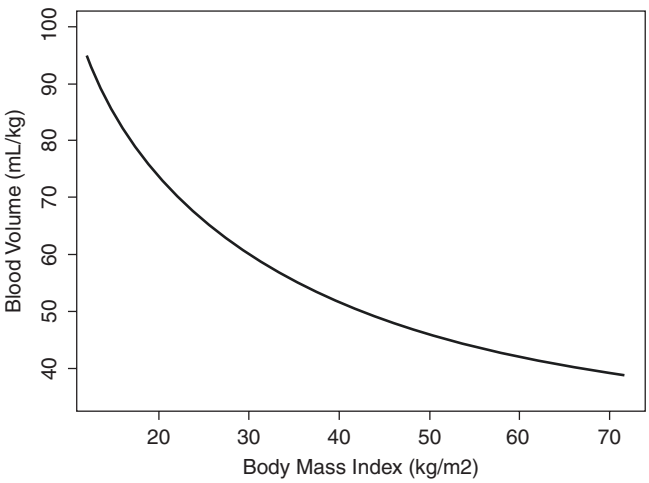

Fig. 8.1 Effect of BMI on blood volume in mL per kg TBW. Blood volume (mL per kg TBW) for a patient with a given BMI (BMI_p) can be calculated using the equation: $\frac{70}{\sqrt{\frac{BMIp}{22}}}$

concentrations, faster awakening, and increased dose requirement. This phenomenon has important implications for the induction dose of intravenous anesthetic agents.

The most prevalent comorbidity in bariatric patients is hypertension. Obesity may lead to abnormal cardiac function through pathways that are associated with or independent of hypertension. The mechanisms of decreased cardiac contractility associated with obesity independent of hypertension are related to metabolic dysregulation, but not completely understood. The increased body mass, metabolic syndrome, insulin resistance, type 2 diabetes, and physical inactivity all contribute to systolic and diastolic dysfunction even in otherwise healthy young obese subjects. This may eventually progress to left and/or right heart failure. The combination of super obesity (BMI > 50 kg/m^2) with hypertension and diabetes is associated with a twofold increased risk of death and adverse cardiac events in the perioperative phase [5]. Congestive heart failure, peripheral vascular disease, and chronic renal failure are predictive factors of increased in-hospital mortality after surgery. Obesity is also associated with an increased risk of atrial fibrillation and ventricular ectopy. Cardiac events can be a significant cause of 30-day mortality after bariatric surgery.

Pharmacological Considerations

Until recently, obese subjects have been routinely excluded from clinical trials to obtain regulatory approval for investigational drugs. This has resulted in package insert dosage recommendations based on total body weight, valid for normal-weight patients but not for the obese. Severe obesity alters the pharmacokinetics and drug response of anesthetic agents. In addition, the decreased pulmonary and cardiac reserve of the patient with SO significantly decreases the margin of safety of anesthetic agents. Incorrect dosing can increase the rate of perioperative complications.

Obesity is not only associated with an increase in tissue mass but also changes in body composition and tissue perfusion. Fat mass and lean body mass both increase, but the increase is not proportional. The percentage of lean body mass as a percentage of total body weight decreases as BMI increases (Fig. 8.2). The different ratio of lean body weight (LBW) to fat weight at different BMIs has a significant impact on drug distribution. Fat perfusion is also altered at different BMIs. At low BMIs, fat is relatively well perfused; at high BMIs fat is poorly perfused. Because of the different ratio of fat to lean body weight at different BMIs and changes in fat perfusion, the effect of obesity on drug distribution into the different tissues is poorly understood.

The increased CO of the patient with SO increases the dose requirements of induction agents, but not to the level of total body weight. In patients with normal cardiac function, CO is highly correlated to lean body weight, more so than total body weight or other variables. Therefore, lean body weight and CO are more appropriate dosing scalars than total body weight. Total body weight dosing of induction agents will result in overdosing and side effects such as hypotension.

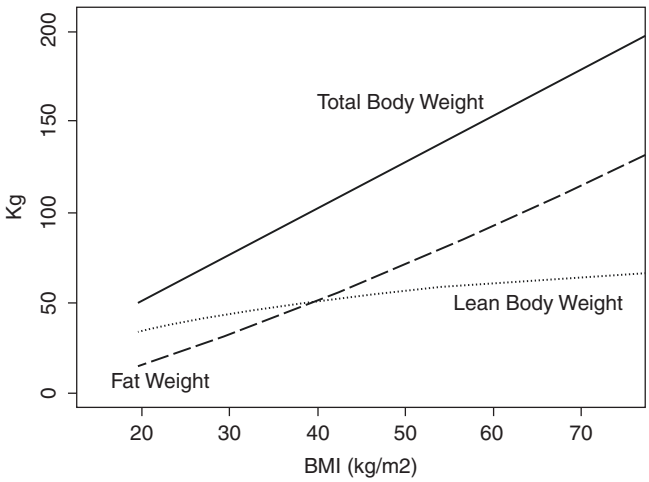

Fig. 8.2 Changes in body composition for a typical frame 160-cm-tall female who increases her BMI. Lean body weight was calculated using the equations published by Janmahasatian et al. [17]. Fat weight was calculated by subtracting lean body weight from total body weight

Numerous pharmacokinetic studies have shown that clearance, the most relevant pharmacokinetic parameter for maintenance dosing, is linearly related to lean body weight but not total body weight. This implies that lean body weight is the appropriate dosing scalar, not only for determining induction and loading doses but also for maintenance doses. Recommended dosing scalars for several anesthetic agents are summarized in Table 8.1.

Induction Agents

Thiopental

Although thiopental is part of the World Health Organization's "Essential Drugs List," it is currently unavailable in the United States. Nevertheless, thiopental is an ideal anesthetic induction agent with arguably less side effects than propofol. Immediately after intravenous (IV) administration, thiopental distributes to highly perfused tissues such as the brain, lung, liver, heart, kidney, gut, and pancreas. After an anesthetic induction dose, redistribution into the muscle depletes thiopental from the brain and terminates the anesthetic effect within 5–10 min. The increased CO associated with severe obesity has a significant effect on the thiopental dose requirement. After a thiopental induction dose of 250 mg, the higher CO of a patient with severe obesity results in peak arterial concentrations up to 50% lower than those of

Table 8.1 Recommended dosing scalars for morbidly obese patients

	Dosing scalar	Comments
Induction agents		
Thiopental	LBW	
Propofol	LBW	For continuous infusion or maintenance dosing TBW
Etomidate	LBW	Use in septic patients is controversial; may cause adrenal suppression
Opioids		
Fentanyl	LBW	Titrate to effect
Alfentanil	LBW	
Sufentanil	LBW	
Remifentanil	LBW	TBW dosing may result in significant hypotension and/or bradycardia
Muscle relaxants		
Succinylcholine	TBW	The incidence of myalgia is low in morbidly obese patients
Rocuronium	LBW/ IBW	IBW dosing results in shorter duration of action
Vecuronium	LBW/ IBW	
Cisatracurium	LBW/ IBW	
Atracurium	LBW/ IBW	Fast administration may result in histamine release

LBW lean body weight, *TBW* total body weight, *IBW* ideal body weight

a lean subject. Thiopental dose adjusted according to lean body mass or increased CO results in the same peak plasma concentration as for a normal size person.

Propofol

In current practice, propofol is the induction agent of choice for obese patients. CO has a significant effect on peak plasma concentration and duration of effect. After a bolus dose for induction of anesthesia, propofol's peak plasma concentration is inversely related to CO. In addition, a higher CO is associated with a faster wake-up time. For COs of 8.5, 5.5, and 2.5 L/min, recovery of consciousness is predicted to occur at 2.9, 8.6, and 18.7 min, respectively. CO does not affect onset time. LBW is a more appropriate weight-based scalar than TBW for propofol induction of general anesthesia in patients with SO [18]. Patients in whom anesthesia was induced with propofol dose based on LBW required similar doses of propofol and had similar times to loss of consciousness compared to nonobese control patients given propofol based on TBW.

Etomidate

Etomidate is less likely to cause a significant decrease in blood pressure than thiopental or propofol. Thus, in patients with significant heart disease or hemodynamically unstable patients, anesthetic induction with etomidate may be a better choice. The pharmacology of etomidate in obese patients has not been studied, but an induction dose based on lean body mass and CO can be justified given the pharmacokinetic and pharmacodynamic similarities of etomidate, thiopental, and propofol.

Etomidate transiently suppresses corticosteroid synthesis in the adrenal cortex by reversibly inhibiting 11-beta-hydroxylase. This suppressant effect on steroid synthesis is probably clinically insignificant after a single dose used for induction of anesthesia. However, in patients with sepsis, the use of etomidate for induction of anesthesia is controversial. Other side effects are pain at injection, myoclonus, and a high incidence of postoperative nausea and vomiting.

Dexmedetomidine

Dexmedetomidine is used as a sedative agent with both anxiolytic and analgesic effects. Dexmedetomidine is a selective alpha-2 adrenergic receptor agonist. Respiratory depression is minimal, but dexmedetomidine potentiates the respiratory depressant effect of opioids and benzodiazepines. The short distribution half-life (8 min) and relatively short elimination half-life (2 h) make it suitable for titration by continuous infusion. The sympatholytic effect of dexmedetomidine decreases norepinephrine release and will decrease arterial blood pressure and heart rate. This may result in severe hypotension in hypovolemic patients and severe bradycardia in patients with heart block. Another side effect is dry mouth, which when used during fiber-optic intubation is an advantage. Postoperatively, dexmedetomidine reduces shivering. During open gastric bypass surgery when used instead of fentanyl to supplement desflurane, a loading dose of dexmedetomidine, 0.5 mcg/kg, given over 10 min followed by an infusion of 0.4 mcg/kg/h, resulted in significantly lower arterial blood pressure and heart rate, shorter time to tracheal extubation, lower pain scores, and less use of morphine and antiemetics in the postanesthesia care unit (PACU). A systematic review of 30 studies with intraoperative use of dexmedetomidine showed a decrease in morphine consumption, lower pain scores, and lower rates of PONV [19]. For adjunctive use during laparoscopic bariatric surgery, a lower infusion rate (0.2 mcg/kg/min) is recommended to reduce the risk of cardiovascular side effects.

Opioids

Compared to fentanyl and its analogues alfentanil, sufentanil, and remifentanil, the longer-acting opioids morphine and hydromorphone are not potent enough to effectively

block somatic and autonomic responses during surgery. In addition, the drowsiness and sleepiness at emergence associated with morphine and hydromorphone administration are unwanted in the morbidly obese. Therefore, their use during surgery is best avoided. If necessary, morphine should be dosed with IBW [20] and titrated to effect with close respiratory monitoring, as opioid-related adverse events remain a significant complication in SO patients [21].

Fentanyl

Fentanyl has a fast onset of effect (5 min) and effectively blocks somatic and autonomic responses during surgery. Fentanyl is probably the most commonly used opioid during bariatric surgery. The higher CO in patients with obesity will result in significantly lower fentanyl concentrations in the early phase of distribution. Pharmacokinetic parameters of normal size persons will overpredict measured fentanyl concentrations in patients with obesity. The clearance of fentanyl is higher in patients with obesity and increases nonlinearly with increasing TBW, but linearly with lean body weight (LBW). These data suggest loading and maintenance doses of fentanyl should be based on LBW. However, obesity increases the probability of respiratory depression in the perioperative period, and fentanyl and other opioid administration should be carefully titrated according to individual patient's need.

Sufentanil

Sufentanil is highly lipophilic and has an onset time of approximately 5 min. Like fentanyl, pharmacokinetic parameters of normal size persons will overpredict measured sufentanil concentrations in patients with severe obesity.

Alfentanil

Alfentanil has a fast-onset time of approximately 1 min. The higher CO in patients with obesity will result in significantly lower alfentanil concentrations in the early phase of distribution. Alfentanil is less lipid soluble than fentanyl or sufentanil and has a smaller volume of distribution. No data on the effects of obesity on the pharmacokinetics of alfentanil have been published.

Remifentanil

Remifentanil's physicochemical properties result in a rapid-onset time of approximately 1 min. Bolus administration in awake patients may result in severe bradycardia, hypotension, and muscle rigidity. Plasma and tissue esterases rapidly hydrolyze remifentanil, resulting in an extraordinary high clearance (3 L/min) unaffected by hepatic or renal insufficiency. The fast-onset time and high clearance make remifentanil especially suitable for administration by continuous infusion. Volumes and clearances not normalized for weight are similar in obese and nonobese patients and do not correlate with TBW, but correlate significantly with LBW. Therefore, in the patient with obesity, dosing of remifentanil based on TBW will result in concentrations higher than those needed for clinical purposes and an increased incidence of side effects such as hypotension and bradycardia. Remifentanil dosing based on LBW will result in plasma concentrations similar to those in normal-weight subjects when dosed according to TBW. After discontinuation of administration, drug effects terminate rapidly, within 5–10 min. Therefore, when postoperative pain is anticipated, alternative analgesics should be administered prior to remifentanil's discontinuation. Remifentanil may also induce postoperative hyperalgesia, requiring higher than normal dosages of longer-acting opioids to effectively treat pain, putting the patient with severe obesity at higher risk of opioid complications such as respiratory depression.

Inhaled Anesthetics

Isoflurane

The solubility of inhaled anesthetic agents in fat and the increased fat mass of the patient with obesity would theoretically result in an increased anesthetic uptake, especially with more fat-soluble anesthetics such as isoflurane. However, blood flow per kg of fat tissue decreases significantly with increasing BMI, therefore limiting uptake. In addition, the time constants (the time to reach 63% of equilibrium) for equilibrium with fat are long (2110 and 1350 min for isoflurane and desflurane, respectively). The decreased fat perfusion and relatively long time constants will diminish the effect of the increased fat mass on the uptake of inhalational agents. During routine clinical practice, the effect of BMI on the uptake of desflurane and the more lipid-soluble isoflurane is clinically insignificant.

The concern that isoflurane prolongs emergence from anesthesia in patients with obesity due to its lipid solubility could also not be substantiated. Obese and nonobese patients emerged from anesthesia at similar times (7 min) after 0.6 MAC isoflurane administration for procedures lasting 2–4 h. After termination of isoflurane administration, the time to extubation can be decreased significantly by increasing alveolar ventilation using an isocapnic hyperpnea method [22].

Desflurane

The effect of BMI on desflurane uptake is insignificant, and obese and nonobese patients emerge from anesthesia equally rapidly (4 min) after 0.6 MAC desflurane administration for procedures lasting 2–4 h. Several studies in patients with obesity have compared desflurane and sevoflurane with variable results, finding either a faster awakening with desflurane or no difference [23, 24].

Sevoflurane

Sevoflurane appears to provide a slightly more rapid uptake and elimination of anesthetic in patients with severe obesity than does isoflurane. Fluoride, a metabolite of sevoflurane, in concentrations greater than 50 mmol/L, can be nephrotoxic. In addition, sevoflurane is degraded to compound A by carbon dioxide absorbers containing a strong base such as barium hydroxide lime or to a lesser extent by soda lime. Reductions in fresh gas flow as well as an increase in temperature in the gas mixture will increase compound A concentrations. Albuminuria, glycosuria, and enzymuria are associated with inhaled doses of compound A greater than 160 ppm/h. In the few studies in patients with renal impairment, no evidence of further worsening of renal function could be demonstrated after sevoflurane administration. However, the safety of sevoflurane in patients with impaired renal function is unclear.

Neuromuscular Blocking Agents

Succinylcholine

Succinylcholine is a depolarizing muscle relaxant. It is a nicotinic acetylcholine receptor agonist causing fasciculations followed by flaccid paralysis via depolarization of the motor end plate. Succinylcholine has the fastest onset and shortest duration of action of all muscle relaxants—excellent properties to achieve intubation of the trachea rapidly. If difficulty is encountered managing the airway of the patient, return of neuromuscular function and spontaneous ventilation will occur within 5–7 min. Maximum effect and duration of action are determined by the extracellular fluid volume and elimination by the plasma enzyme butyrylcholinesterase (also known as pseudocholinesterase). Extracellular fluid volume and activity of butyrylcholinesterase both increase with increasing BMI. Therefore, patients with severe obesity have larger succinylcholine requirements than normal size patients. Succinylcholine, 1 mg/kg total body weight, will result in complete neuromuscular blockade and excellent intubation conditions in the obese. Lower doses are associated with poor intubating conditions due to incomplete neuromuscular block. Succinylcholine use is associated with increases in potassium and myalgia. The incidence of succinylcholine-induced myalgia is low in morbidly obese patients.

Rocuronium

Rocuronium is a nondepolarizing muscle relaxant that can be used as an alternative to succinylcholine for rapid sequence intubation. A dose of 1.2 mg/kg ideal body weight (IBW) provides excellent or good intubating conditions 60 s after administration. However, the time to reappearance of T1 is 52 min. Rocuronium maintenance dosing based on lean body weight has not been studied, but dosing on the basis of ideal body weight is appropriate. Maximum effect and recovery times of rocuronium and all other muscle relaxants are highly variable; therefore, continuous monitoring of the degree of neuromuscular blockade is recommended. The use of rocuronium for rapid sequence intubation has become more common with the wider availability of sugammadex (below) for urgent reversal, if needed.

Vecuronium

The pharmacokinetic parameters uncorrected for weight are similar between obese and nonobese subjects. In obese subjects receiving 0.1 mg/kg vecuronium based on TBW, recovery times from neuromuscular blockade were approximately 60% longer than in normal-weight control subjects. The prolonged recovery from neuromuscular blockade in the obese patients can be explained by the larger dose of vecuronium. The similar pharmacokinetics will result in higher vecuronium plasma concentration in the patient with obesity. With higher doses and higher plasma concentrations, recovery from neuromuscular blockade will occur at a time when plasma concentration decreases more slowly, instead of the more rapid decline after a smaller dose when recovery occurs earlier during the distribution phase. To avoid overdose in the patient with obesity, administering vecuronium on the basis of IBW is recommended.

Cisatracurium

Cisatracurium is eliminated via Hoffman degradation, a pathway independent from kidney or liver function. As expected, TBW dosing results in a prolonged duration of action when compared with a control group of normal body weight patients. When administered to patients with severe

obesity based on IBW, the duration of action of cisatracurium was decreased when compared to normal size patients.

Reversal Agents of Neuromuscular Blockade

Rapid and complete recovery from neuromuscular blockade is particularly important in the morbidly obese patient. Residual neuromuscular blockade will further compromise respiratory function in the immediate postoperative phase. Obesity is a risk factor for residual blockade [25]. Acceleromyography should be used preferentially over traditional twitch monitoring when monitoring and reversing neuromuscular blockade [26] and has been shown to significantly reduce the incidence of residual block.

Neostigmine

The dose-response relationship of neostigmine for neuromuscular blockade reversal in morbidly obese patients has been poorly studied. When vecuronium is reversed with neostigmine at 25% recovery of twitch height, there is no difference between normal size and morbidly obese patients in time to a recovery of train-of-four (TOF) ratio to 0.7 (3.8–4.8 min). However, recovery time to adequate reversal (a train-of-four ratio of 0.9) is four times slower in morbidly obese patients (25.9 versus 6.9 min). The recommended dose of neostigmine is 0.04–0.08 mg/kg, not to exceed a total dose of 5 mg. A deep neuromuscular block (TOF ratio of 0) cannot be reversed with neostigmine.

Sugammadex

Sugammadex is the first selective relaxant-binding agent specifically designed to bind and encapsulate rocuronium and vecuronium. It can provide immediate reversal of an intubating dose of rocuronium at 16 mg/kg. The muscle relaxant is bound with high affinity within sugammadex's core and cannot bind to the acetylcholine receptor at the neuromuscular junction. The bound complex is excreted by the kidneys at a rate equal to the glomerular filtration rate. Unlike the acetylcholinesterase inhibitor neostigmine, sugammadex has no effect at the receptor level, and there is no need to coadminister antimuscarinic agents such as atropine or glycopyrrolate. Deep neuromuscular blockade (TOF =0, post-tetanic count of 1–2) can be reversed with 4 mg/kg sugammadex at IBW [27], and at a moderate level of blockade (TOF = 2), 2 mg/kg is recommended.

Sugammadex was approved for use in the European Union in 2008 and subsequently approved by the US Food and Drug Administration (FDA) in 2015.

Monitoring

In the relatively healthy patient undergoing bariatric surgery, noninvasive monitoring during anesthesia will suffice. There are no data showing that invasive monitoring improves outcome in patients with severe obesity without advanced cardiac or pulmonary disease [28].

During surgery, a combination of lead II and lead V5 electrocardiographic monitoring has a sensitivity of 80% to detect myocardial ischemia. Lead V4 and V5 monitoring has a sensitivity of 90%. The best combination is lead V4, V5, and II monitoring, resulting in a sensitivity of 98%. Cardiac abnormalities such as rhythm and conduction problems occur frequently in the patient with severe obesity. Atrial fibrillation is the most commonly occurring abnormal rhythm, especially in patients with OSA. If during surgery or in the postoperative phase atrial fibrillation develops, atrial distension due to fluid overload can be the causative factor. Prolonged QT interval syndrome is a precursor of torsades de pointes, which can result in sudden cardiac death. Many drugs used in the perioperative phase such as ondansetron, sevoflurane, and methadone prolong the QT interval and should not be used in patients with prolonged QT interval syndrome.

A well-fitting blood pressure cuff encircling at least 75% of the arm should be used to obtain reliable blood pressure measurements. A blood pressure cuff that is too large will underestimate blood pressure. A cuff that is too small will overestimate blood pressure. Special conical-shaped cuffs for morbidly obese patients are available. If a blood pressure cuff cannot be fitted on the upper arm, a standard blood pressure cuff placed on the forearm is a useful alternative. Lower arm measurements overestimate blood pressure. The threshold to place an intra-arterial catheter should be low since invasive blood pressure measurement is accurate and complications of radial arterial line placement are rare.

The recommendation that a central venous line be inserted routinely in obese patients is not valid. Peripheral venous access can be more difficult, but this is not a definitive indication for a central line. If placement of a peripheral venous catheter is problematic, ultrasound can be used to locate a peripheral vein. Central venous access via the internal jugular vein is associated with a lower complication rate than subclavian vein puncture. Positioning the patient on a ramp similar to the positioning used for tracheal intubation with a roll under the shoulders will maximize neck exposure and facilitate placement. Thereafter, the patient can be placed in Trendelenburg position as tolerated. Insertion of a central venous catheter under ultrasound guidance facilitates correct placement and is currently the recommended approach [29].

The value of the central venous pressure (CVP) measurement does not necessarily reflect adequacy of circulating blood volume or response to fluid loading. A decreased CVP

can reflect venodilation or hypovolemia. An increased CVP can reflect decreased cardiac pump function, increase in thoracic pressure and/or pericardial pressure, or increased pulmonary artery resistance. In contrast to the CVP pressure readings, the shape of the CVP waveform can be highly diagnostic. For example, the presence of large v waves, which are diagnostic for tricuspid regurgitation, may indicate the presence of pulmonary hypertension and right heart failure.

Intravascular volume status is difficult to assess in obese patients. Pulse pressure variation, the decrease in arterial pulse pressure with positive pressure ventilation, is a more reliable indicator of hypovolemia than CVP. During inspiration of controlled ventilation, the great veins entering the heart are compressed, resulting in a reduction of right ventricle preload and an increase in afterload. The decreased preload and increased afterload decrease the stroke volume of the left ventricle at the end of the expiration cycle. When this is exaggerated, the blood volume of the patient is contracted, and a fluid bolus will improve CO. Commercial devices are being marketed that provide real-time changes in pulse pressure variation. However, these devices typically require positive pressure ventilation and higher tidal volumes, which may be contrary to the goals of lung protective ventilation strategies.

Pulmonary artery pressure monitoring has fallen into disfavor because it is a poor indicator of left ventricle preload or circulating blood volume, but it is still being used to assess pulmonary hypertension.

Transesophageal echocardiography (TEE) is an invaluable tool to assess the possible cause of sudden intraoperative cardiac or hemodynamic instability such as myocardial ischemia associated with wall motion abnormalities, emboli, and hypovolemia. TEE cannot be used routinely during bariatric surgery because the ultrasound probe is in the surgical field.

The degree of neuromuscular blockade should be monitored during surgery. During surgery, train-of-four monitoring (TOF) monitoring is used to guide the administration of neuromuscular blocking agents. Acceleromyography should be utilized over traditional qualitative twitch monitors, if available. At the end of surgery, the TOF ratio is used to guide administration of reversal agents. A deep neuromuscular block (TOF ratio of 0) cannot be reversed with neostigmine, and reversal should be delayed until a TOF count of 2 is observed. The administered dose of neostigmine should not exceed 5 mg, and the trachea should not be extubated with a TOF ratio of <0.9. As noted above, deep neuromuscular blockade can be reversed with sugammadex at 4 mg/kg IBW.

Electroencephalographic-based brain function monitors are being used to guide administration of anesthetic agents and to prevent awareness. The efficacy of these monitors is controversial, and routine use of brain function monitoring during surgery is not supported by data. However, its use is recommended in cases where a high risk for awareness may be suspected. Administration of nitrous oxide, ketamine, isoflurane, or halothane can be associated with a paradoxical increase in BIS.

A Foley urinary catheter may be placed before any major surgery, but not required if the surgery is anticipated to be of short duration and routine. A low urine output may be encountered during laparoscopic bariatric surgery. Pneumoperitoneum decreases urine output by increasing ADH, aldosterone, and plasma renin activity.

Preoperative Sedation

For most patients, premedication with sedatives should be used with caution. Respiratory depression caused by benzodiazepines and opioids is pronounced in patients with severe obesity, especially in those with OSA. The upper airway collapsibility of the patient with severe obesity combined with the decreased arousal response to airway occlusion makes these patients particularly sensitive to drug-induced respiratory depression. Benzodiazepines decrease upper airway muscle activity with consequent obstruction and cause central apnea during the initial post-administration minutes. If very anxious patients need premedication, small doses of midazolam can be administered upon transport to the operating room under continued visual monitoring and verbal communication during transport. Administration of oxygen during transport is recommended.

In the operating room, it is practical to have unpremedicated patients climb off the gurney and then position themselves on the operating room table.

Airway Management

According to recent data from the American Society of Anesthesiologists Closed Claim Database, almost 40% of adverse airway events during induction of anesthesia occurred in obese patients, with a significant proportion resulting in permanent brain damage or death [30]. This is not surprising since inability to mask ventilate and intubate the morbidly obese patient will result in rapid development of hypoxemia. An understanding of the different requirements for airway management and adequate preparation is vital to avoid untoward events.

The supine position, routinely used for induction of anesthesia in nonobese patients, is not appropriate for the patient with severe obesity. The supine position will decrease the FRC further and will increase the intra-abdominal pressure,

resulting in restriction of diaphragmatic movement with respiration. The torso of the morbidly obese should be elevated 25–30° prior to induction of anesthesia in reverse Trendelenburg position. Offsetting the mass loading of the abdomen and chest will increase the FRC, decrease the restrictive component of the lung function, and increase compliance. Therefore, reverse Trendelenburg positioning will not only improve the ability to ventilate the lungs by bag and mask but also will increase the time before desaturation starts to occur when there is an inability to manage the airway.

The standard "sniffing position" for tracheal intubation, which results in optimal alignment of axes of the head and neck in the nonobese, is inadequate for the patient with severe obesity. A "ramped" position, with the patient's upper body, head, and neck elevated until the external acoustic meatus and the sternal notch are in horizontal alignment, results in optimal position for tracheal intubation (Fig. 8.3). It also provides increased submandibular space facilitating manipulating the laryngoscope handle and laryngoscopy. Obesity itself is not an independent risk factor for difficult tracheal intubation, but patients with obesity plus a large neck circumference, excessive pretracheal adipose tissue, and high Mallampati classification do have a higher probability of difficult intubation. Obesity and OSA are independent risk factors for difficult mask ventilation. Since facial hair can make ventilation of the lungs by bag and mask ineffective, it is appropriate to ask patients to shave beards preoperatively.

When very difficult mask ventilation and/or tracheal intubation is suspected, awake fiber-optic intubation (FOI) is the technique of choice. Spontaneous ventilation and airway patency will be maintained in the awake patient, assuming sedatives are carefully titrated—keeping in mind that even small amounts may result in airway obstruction. Adequate topical anesthesia of the larynx and pharynx and gentle technique will result in intubation with minimal discomfort for the patient. Visualization of the larynx may be difficult due to airway narrowing by redundant folds of fat tissue. In a sitting patient, the pharyngeal space will be increased, and instructing the patient to protrude the tongue will further increase the diameter of the airway. Several reports have described the use of a laryngeal mask airway in an awake patient to open the surrounding tissues permitting easier visualization of the vocal cords and passage of the fiberscope. Video laryngoscopy, with multiple models available on the market, has become a ubiquitous and invaluable alternative to FOI and DL in the patient with severe obesity. The video laryngoscope allows for indirect visualization of the vocal cords and rapid intubation in the anesthetized patient. However, due to the indirect visualization, the tonsillar pillars and soft tissue in the pharynx and hypopharynx are not visualized well and are at risk for traumatic injury [31] during intubation; substantial training is required [32].

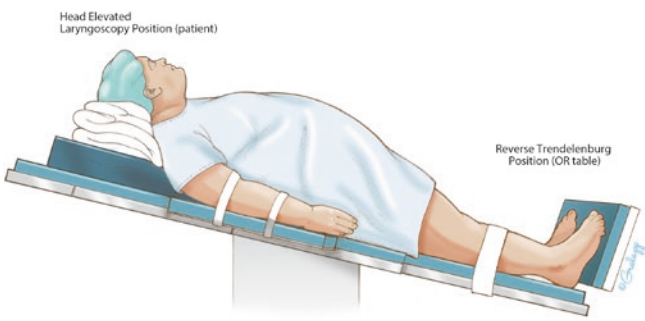

Fig. 8.3 Ramped position for tracheal intubation

Aspiration Risk

The traditional belief that patients with obesity are at higher risk for aspiration at induction of anesthesia is unfounded. The volume of gastric contents is not greater in fasted patient with obesity when compared to normal-weight subjects, and gastric emptying is not delayed, except in the setting of obesity-related disease as noted below. In fact, the proportion of high-volume low pH gastric content in obese unpremedicated subjects is lower (26.6%) when compared to normal-weight patients (42%).

Patients with comorbid conditions such as symptomatic gastroesophageal reflux disease, diabetes mellitus, and gastroparesis are at increased risk for gastric acid aspiration. A rapid sequence induction with cricoid pressure should be performed in these patients as well as in all patients with a prior gastric banding procedure. There are, however, emerging studies using biomarkers suggesting that cricoid pressure does not necessarily lead to decreased aspiration in these patients.

Pneumoperitoneum: Implications for Ventilation, Hemodynamics, and Urine Output

After insufflation of the abdomen, the increased intra-abdominal pressure and absorption of CO_2 account for the majority of physiologic alterations. The diaphragm moves in the cephalad direction, which may result in migration of the endotracheal tube into the right main stem bronchus. High peak inspiratory pressures followed by hypoxemia and hypotension will result if this phenomenon is not recognized and corrected in a timely fashion. Appropriate ventilatory adjust-

ments can eliminate most of the absorbed CO_2 and prevent acid-base disturbances. Reverse Trendelenburg position, >10 cm PEEP, and recruitment maneuvers can dramatically improve oxygenation in the morbidly obese in both open and laparoscopic cases [33].

Upon insufflation, heart rate and blood pressure typically increase; however, some patients may experience vagal-mediated bradycardia due to peritoneal stretching—a phenomenon typically short-lived and relieved with peritoneal desufflation and administration of IV atropine or glycopyrrolate. In patients with severe obesity, CO decreases with insufflation, while systemic vascular resistance, pulmonary vascular resistance, mean arterial pressure, right atrial pressure, and pulmonary capillary wedge pressure increase. In general, the impact of pneumoperitoneum on the cardiovascular system of the patient with severe obesity is well tolerated.

A decrease in renal perfusion occurs with pneumoperitoneum as well as increased release of antidiuretic hormone, plasma renin activity, and serum aldosterone, resulting in water retention and a rapidly decreasing urine output. The extent of intraoperative oliguria is directly related to the extent of increased intra-abdominal pressure. Despite the hormonal changes and transient oliguria, clinically significant renal impairment as measured by serum creatinine does not occur after laparoscopic gastric bypass with insufflation pressures not exceeding 15 mmHg. However, in patients with preexisting renal impairment, minimal insufflation pressure and adequate IV hydration should be instituted to avoid further exacerbation of renal insufficiency.

Effects of pneumoperitoneum on hepatic blood flow and function are similar to those of the kidneys, and transaminase levels may rise as much as sixfold 24 h after surgery. These effects may be enhanced in morbidly obese patients because many have underlying hepatic disease due to fatty infiltration.

Use of sequential compression devices (SCDs) in combination with pneumoperitoneum is associated with a significant improvement in CO, stroke volume, portal venous and hepatic arterial blood flow, and marked improvement in renal perfusion, urine output, and systemic vascular resistance.

Fluid Management

Goals for fluid management should center around maintenance of euvolemia, when possible. Extended fasting is avoided, and oral intake is resumed as soon as possible postoperatively [34]. The concept of the "third space" has been shown to be false; administered fluid either remains intravascular or distributes to the interstitial space. The increase in hydrostatic pressure damages the endothelial glycocalyx and alters vascular permeability, leading to gut wall edema and ileus.

Maintenance with balanced salt solutions such as lactated Ringers is preferred, with boluses as needed when signs and symptoms of hypovolemia present. Under anesthesia, use of a vasopressor such as phenylephrine may be a better choice than repeated fluid boluses, as decreased blood pressure is more likely due to decreased vascular tone rather than hypovolemia. It is important to realize that heart rate, blood pressure, urine output, and central venous pressure are not particularly accurate measures of volume status, especially during laparoscopic procedures. Variations in stroke volume or pulse pressure can be utilized for goal-directed fluid therapy, but these measurements are less accurate in the presence of pneumoperitoneum and lower tidal volume ventilation. In addition, benefits of goal-directed fluid therapy have not been as evident when the patient is euvolemic, as is more commonly the case for enhanced recovery pathways [35].

Postoperative Considerations

In laparoscopic bariatric surgery, a deep neuromuscular block is needed to ensure an adequate surgical field. After completion of surgery, before tracheal extubation is attempted, it is imperative to completely reverse the neuromuscular block. Even minimal residual paralysis causes retroglossal and retropalatal narrowing during inspiration, which may result in upper airway collapse.

Use of continuous positive airway pressure (CPAP) reduces the risk for atelectasis, and noninvasive ventilation can be used as a prophylactic and/or therapeutic tool to improve gas exchange postoperatively. There is concern CPAP may increase the likelihood of an anastomotic leak by air forced into the gastric pouch. However, it has been demonstrated that changes in transmural gastric pouch pressure with the application of CPAP do not occur [36].

The American Society of Anesthesiologists (ASA) practice guidelines for the perioperative management of patients with OSA recommended that patients with OSA treated with CPAP should continue CPAP as soon as feasible after surgery [37]. The same guideline recommends that patients with OSA be monitored for 3 h longer than their non-OSA counterparts before discharge from the PACU. The recommendations for increased monitoring are based on expert opinion and not scientific evidence. The same guidelines caution performing upper abdominal laparoscopic surgery in an outpatient setting for patients with known or suspected OSA. In a series of 746 patients with obstructive sleep apnea after ambulatory laparoscopic gastric banding, 40% did have an incidence of hypoxia in either the OR or PACU [38]. However, there were no episodes of respiratory failure or tracheal reintubation.

Postoperative Nausea and Vomiting

Bariatric surgery is associated with a high incidence of postoperative nausea and vomiting (PONV). Besides the surgery itself, female sex, a history of PONV, and motion sickness are known risk factors. Opioids, volatile anesthetics, and nitrous oxide all have dose-related emetogenic effects. The most commonly used antiemetic agent for the prevention of PONV is the serotonin antagonist ondansetron, with a half-life of 4 h. This short half-life makes the efficacy of ondansetron for longer-lasting prophylaxis, such as in the ambulatory surgery setting, questionable. The incidence of post-discharge nausea and vomiting (PDNV) after ambulatory surgery is higher than PONV and has been reported to be as high as 50% in patients who did not experience PONV. Laparoscopic sleeve gastrectomy, currently the most commonly performed bariatric procedure, is particularly emetogenic. One Polish study demonstrated an 8.2% incidence for LSG, compared to 1.4% for laparoscopic Roux-en-Y gastric bypass, with the use of enhanced recovery pathways [39]. Aggressive antiemetic protocols using multiple agents, and sparing opioids as able, seem to be the key to reducing this rate.

Besides adequate hydration with intravenous fluids, antiemetic strategies covering a longer duration should be employed [40]. Multiple agents with different mechanisms of action (multimodal therapy) are more effective than a single agent. Dexamethasone, 8 mg, intravenously administered at the beginning of surgery combined with the transdermal cholinergic antagonist scopolamine is an effective longer-lasting strategy. For patients with several risk factors, additional medications such as haloperidol (0.5–1 mg) or promethazine (12.5 mg) can be added. Both can result in oversedation and should be administered with caution in patients with significant OSA. For patients with a history of intractable nausea and vomiting, the neurokinin-1 receptor antagonist aprepitant, 40 mg p.o., administered before surgery could be added and continued in the postoperative period. Opioid-sparing analgesia, beginning in the preoperative period and continued throughout the intraoperative period, and utilization of total intravenous anesthesia (TIVA) can help to decrease the rate of PONV in these patients [41, 42]. Non-pharmacological methods such as acupuncture and acupressure have limited efficacy, but may be worthwhile adjuncts.

Postoperative Analgesia

Adequate postoperative pain relief is critical for patient comfort, pulmonary toilet, and early ambulation. Postoperative analgesia must be balanced to avoid opioid-related complications like PONV, sedation, ileus, and respiratory depression. The laparoscopic approach provides substantial benefit with less postoperative pain and medication use.

Postoperative oral administration of analgesics can be utilized in the ambulatory surgery setting, and oral absorption of drugs is essentially unchanged in obese patients, with liquid preparation being best tolerated. The most common analgesic drugs given orally are nonsteroidal anti-inflammatory drugs (NSAIDs), acetaminophen, and opioids. NSAIDs are not generally given due to potential risk of bleeding, particularly for surgical staple lines.

Patient-controlled analgesia (PCA) was developed to allow intravenous administration of analgesics in an incremental fashion, so that respiratory depression and heavy sedation could be avoided. PCA use is highly recommended for the severely obese patient, compared to intermittent bolus dosing [43]. Bupivacaine infusion devices for continuous postoperative infiltration of the surgical wound have been developed to avoid the risk of respiratory depression associated with opioids. Mixed results have been seen for potential benefits of heating and humidifying carbon dioxide (CO_2) insufflation for postoperative pain relief in laparoscopic surgery. The European Association for Endoscopic Surgery practice guidelines state that "the clinical benefits of warmed, humidified insufflation gas are minor and contradictory" [44]. Theoretically, intraperitoneal (IP) administration of local anesthetics can provide analgesia without opioid-related complications. A single randomized clinical trial examined the use of continuous IP infusion in laparoscopic adjustable gastric banding [45]. A statistically significant decrease in VAS was noted in the IP infusion group with no differences in shoulder pain and additional medication use.

Obese patients with obstructive sleep apnea syndrome (OSAS) appear to be more sensitized to sedation than normal individuals. Mortality may occur in OSAS patients after minimal doses of anesthetics or sedatives due to a change in airway tone resulting in obstruction [46].

The ASA Guideline for Patients with Obstructive Sleep Apnea Syndrome (OSAS) is intended to improve perioperative care and reduce the risk of adverse outcomes in patients with OSAS who receive sedation, analgesia, or anesthesia. During preoperative evaluation, the severity of the patient's OSAS, the type of surgery and anesthesia, and the requirement for postoperative opioid analgesics should be considered [37]. There is tremendous interest in establishing enhanced recovery after surgery (ERAS) guidelines that utilize opioid-sparing strategies for analgesia [42, 47], including the use of preoperative acetaminophen and gabapentinoids, and intraoperative dexmedetomidine, transversus abdominis plane or rectus sheath blocks [48], ketamine, esmolol infusion and lidocaine infusion with the goals of decreased opioid-related adverse events, rates of PONV [49], and shortened time to discharge or even same-

day laparoscopic sleeve gastrectomy [50]. However, there is significant heterogeneity among published reports of ERAS [51], and further work is needed in this area.

Question Section

1. The obese patient is at increased risk for respiratory complications due to:
   A. Hypoxemia
   B. Higher respiratory rates
   C. Lower tidal volumes
   D. Decreased functional residual capacity
   E. Obstructive sleep apnea
   F. All of the above
2. The "sniffing" position of an obese patient during anesthesia induction is preferred to the supine position.
   A. True
   B. False
3. At the end of a laparoscopic sleeve gastrectomy, a 64-inch-tall, 120-kg anesthetized patient is noted to have zero train-of-four twitch and 1 post-tetanic count. The rocuronium-induced neuromuscular blockade should be reversed with:
   A. Neostigmine 0.08 mg/kg with glycopyrrolate
   B. Sugammadex 2 mg/kg at ideal body weight
   C. Sugammadex 4 mg/kg at total body weight
   D. Sugammadex 4 mg/kg at ideal body weight
4. A 60-inch-tall, 100-kg woman presents for bariatric surgery. Any of the following dosing would be appropriate *except*:
   A. Succinylcholine 50 mg for intubation
   B. Rocuronium 54 mg for intubation
   C. Propofol 140 mg for induction
   D. Succinylcholine 100 kg for intubation

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