Perioperative Anesthesia Care For Obese Patients

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The marked increase in the prevalence of obesity over the past 20 years has led to an increase in the number of bariatric and nonbariatric surgeries in this population. This in turn makes every anesthesiologist likely to deal with this challenging population. Perioperative targeted and organized assessment and preparation are important to reduce mortality and morbidity and improve recovery.

The World Health Organization defines obesity as body mass index (BMI) ≥30 kg/m^2, and further classifies it into 3 groups: class I (30-34.99 kg/m^2), class II (35-39.99 kg/m^2), and class III (≥40 kg/m^2), which is morbid obesity (MO).[1] Furthermore, there is a consensus in the literature that BMI 50 to 59.9 kg/m^2 is superobese, BMI 60 to 69.9 kg/m^2 is super-superobese, and BMI >70 kg/m^2 is hyperobese.[1] Obesity is a multisystem, chronic, proinflammatory metabolic disorder.[2] It has manifold negative effects on health. Table 1 summarizes the most relevant pathophysiologic changes associated with obesity. (See Key for definitions of all acronyms.)

Recently, Terkawi et al[3] presented their successful anesthesia experience with the heaviest man in the world (weighing 610 kg), which exemplifies the challenges associated with this patient population. In this review, we discuss the problems most relevant to the anesthesiologists.

Preoperative Assessment and Preparation

Preoperative assessment, preparation, and planning are important keys to successful anesthesia in obese patients. The anesthesiologist's vigilance should help to limit the morbidity and mortality that can be associated with surgery in these patients. The preoperative interview should take place sufficiently in advance of surgery to allow adequate patient preparation. Suggested preoperative assessment and preparations include the following:

- **Airway assessment:** The best way to predict difficult intubation in obese patients is still being debated, and the available studies based their findings on the use of regular laryngoscopes, which may make them irrelevant with the recent introduction of newer intubation tools (eg, the video laryngoscope). However, assessment tools are still important, if only to guide the selection of the most useful intubation tool for

Table 1. Pathophysiologic Changes and Disorders Possibly Associated With Obese and Morbidly Obese Patients[2,4-9]

Changes/Causes	Anesthetic Considerations
Respiratory system	
MO: results in a typical restrictive pattern; ↓ in FVC (25%-50% of predicted), FRC, and TLC, as well as ↓ in tidal volume and ERV (30%-60% of predicted). FRC ↓ exponentially as BMI ↑. Tidal volume may or may not be reduced.[6]	Rapid desaturation during apnea period of intubation; requires effective preoxygenation. Lower abdominal operations further ↓ FRC by 10%-15%; upper abdominal procedures ↓ FRC by 30%, and thoracotomy by 35%.[7] With anesthesia, pneumoperitoneum, and supine or Trendelenburg position, further reduction in FRC will occur. Once FRC falls below the closing capacity of the lung, premature airway closure and atelectasis can occur, which subsequently will lead to ventilation/perfusion mismatch and impaired oxygenation.
↓ Chest wall and lung compliance (especially with truncal obesity). Lung compliance can be reduced ≤40% in MO. Abdominal and peritoneal fat mass cause a cranial shift of the diaphragm (~4 cm in supine position), impairing lung expansion.	Results in rapid, shallow breathing and ↑ work of breathing, with subsequent ↑ in O_2 consumption and ↑ in CO_2 production. Trendelenburg position exaggerates these effects.
↑ Airway resistance due to small airway collapse, reduced volumes, and potential airway remodeling secondary to low adiponectin levels.	↑ Resistance is exaggerated in the supine and Trendelenburg positions.
CO_2 levels almost normal (unless OHS present) due to unchanged physiologic dead space and ratio of dead space to tidal volume. O_2 consumption ↑ due to metabolic activity of excess fat, and rises disproportionally with exercise.	The larger waist-to-hip ratio in android "abdominal" obesity has a more negative impact on gas exchange.
Mild ↑ of the alveolar-arterial O_2 gradient, hypoxemia on room air and ↑ O_2 consumption on exercise.	Ventilation/perfusion mismatch leads to hypoxemia.
↓ Tissue oxygenation.	↑ Risk for wound infection; can be prevented by optimization of perioperative ventilation and oxygenation, proper antibiotic selection with appropriate dosing to reach adequate tissue concentrations, tight glycemic control, proper fluid and pain management, avoidance of hypothermia.
Higher incidence of pre- and postoperative atelectasis that lasts longer than in nonobese patients.[10]	Predisposition to hypoxemia/hypoxia during postoperative course. Degree of atelectasis correlates positively with incidence of ARDS.
OSA	Leads to hypoxemia and hypercapnia, ↑ susceptibility to the respiratory depressant effects of sedatives, opioids, and anesthetics. ↑ Risk for difficult intubation, and postoperative complications; hypoxia, apnea, respiratory arrest, hypertension, arrhythmias, and cardiac arrest. ↑ Risk for liver disease, liver fibrosis, and nonalcoholic fatty liver disease.[11] ↑ Risk for right heart side HF. OSA in patients undergoing bariatric surgery was independently associated with significantly ↑ ORs of emergent endotracheal intubation, noninvasive ventilation, and AF.[12]
OHS	High risk for postoperative respiratory complications; more likely to develop opioid-related side effects.[2] Patients have compromised central respiratory drive. Main treatment is positive airway pressure therapy, and appropriate sleep referral may be mandated before major surgery.[13]
Bronchial asthma: obesity ↑ incidence and prevalence of asthma; exact mechanism not known, but possibly related to proinflammatory state in obesity.[14]	Obese patients with asthma experience more symptoms, are relatively resistant to steroids, and show ↑ morbidity.[14]

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Cardiovascular system	
Triad of ↑ CO, elevated circulating blood volume, and enhanced sympathetic activity are characteristic changes in obese patient. Blood volume ↑ proportional to body surface area, which contributes to ↑ preload and CO that may lead to LV hypertrophy and failure.	Anesthesia induction and intubation cause greater reduction in cardiac index in obese patient than in nonobese, which can ↓ 17%-33% in obese patients versus 4%-11% in nonobese. This ↓ can persist into the postoperative period in obese patients.[7]
Hypertension that may be complicated by concentric LV hypertrophy.	↑ Risk for intraoperative BP lability. Cerebral autoregulation may be altered.
Coronary artery disease.	Additional perioperative cardiac and hemodynamic monitoring as these patients have a higher risk for perioperative myocardial infarction.
Ventricular remodeling and diastolic dysfunction. Can occur independently of hypertension and become more relevant in those with significant respiratory dysfunction.	Diastolic dysfunction ↑ the risk for postoperative CHF, prolonged hospital stay, and complications in major surgery.
AF; as patient obesity ↑, risk for LAD ↑ (≤50% of severely obese patients may have LAD). The higher epicardial fat mass that may be associated with obesity can be associated with atrial arrhythmias.	Arrhythmias may be associated with hypoxia due to sleep apnea.
Pulmonary artery hypertension, as a consequence of prolonged hypoxia and hypercapnia of OSA and OHS. It can be complicated by RV enlargement and hypertrophy that can cause RV failure (cor pulmonale).	Avoid elevated PVR (by preventing hypoxemia, acidosis, hypercarbia, and pain) and avoid myocardial depressants. Maintain SVR, preload, and sinus rhythm.
Obesity-related cardiomyopathy.	↑ with the duration of obesity (>10 y) and the severity of obesity. Mostly manifests as diastolic CF.[15]
CF; the longer the duration of obesity the higher the risk. CF can be due to LV wall stress and elevated filling pressure secondary to the longstanding ↑ in stroke volume and ↓ in SVR to compensate for ↑ CO demands, or as a consequence of leptin-related hypertrophic changes, or hypertensive changes.	Hemodynamic goals: avoid tachycardia, hypertension, hypotension, hypoxia, and hypercarbia.

table continues on next page

Key

↑, increase(s), increased
↓, decrease(s), decreased, reduces
AE, adverse event
AF, atrial fibrillation
AHI, apnea-hypopnea index
AKI, acute kidney injury
ARDS, acute respiratory distress syndrome
AUC, area under the curve
BMI, body mass index
BP, blood pressure
CBW, corrected body weight
CF, cardiac failure
CHF, congestive heart failure
CO, cardiac output
CPAP, continuous positive airway pressure
DMV, difficult mask ventilation
DVT, deep vein thrombosis
EIT, electrical impedance tomography
ERV, expiratory reserve volume
FOI, fiber-optic intubation
FRC, functional residual capacity
FVC, forced vital capacity
GERD, gastroesophageal reflux disease
HF, heart failure
IBW, ideal body weight
ICU, intensive care unit
LAD, left atrial dilatation
LBW, lean body weight
LV, left ventricle
MetS, metabolic syndrome
MO, morbid obesity
NC, neck circumference
NMB, neuromuscular blockade
NMBA, neuromuscular blocking agent
NPO, nothing by mouth
NSAID, nonsteroidal anti-inflammatory drug
OHS, obesity hypoventilation syndrome
OR, odds ratio
OSA, obstructive sleep apnea
PACU, postanesthesia care unit
PEEP, positive end-expiratory pressure
PONV, postoperative nausea and vomiting
PPV, positive-pressure ventilation
PVR, pulmonary vascular resistance
RSI, rapid sequence induction
RV, right ventricle
SVR, systemic vascular resistance
TAP, transversus abdominal plane
TBW, total body weight
TLC, total lung capacity
TMD, thyromental distance
TSH, thyroid-stimulating hormone

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Changes/Causes	Anesthetic Considerations
Miscellaneous	
MetS; a combination of central obesity, hypertension, dyslipidemia, and insulin resistance or impaired glucose tolerance. Incidence of MetS in patients presenting for bariatric surgery, 12.7%.[16]	Impaired glucose tolerance even without diabetes mellitus can lead to disturbances of the autonomic nervous system with abnormal adrenergic reflexes in ~25% of patients.[5] MetS is an independent predictor of postoperative complications, and ↑ risk for pulmonary (eg, atelectasis, pneumonia, ARDS, and respiratory failure) and cardiac AEs, AKI, as well as composite outcome.[16,17] Thus, medical optimization of these patients before surgery is warranted.
Type 2 diabetes, as a result of hepatic steatosis and dysregulation of glucose metabolism.	Optimize glycemic control, a very important factor to reduce infection. Glycosylation of collagen and its deposition in the joints result in stiff joint syndrome that may ↑ risk for difficult intubation. A good indicator of this syndrome is to ask the patient to put hands in a prayer position and look for stiff fingers or joint deformities.
GERD, chronic gastritis, and gastroparesis.	Sufficient NPO time (although there is a lack of specific recommendations for obese patients). Premedications and precautions; consider these patients to have a full stomach.
Hepatic steatosis; results from accumulation of fat in the liver. Hyperglycemia and hyperinsulinemia are associated with accumulation of fat around the islet cell of pancreas.	May affect drugs that are metabolized in the liver.
Renal: glomerular hyperfiltration and ↑ creatinine clearance. Obesity-related glomerulopathy can cause end-stage renal disease. Obesity has been considered a state of chronic low-grade systemic inflammation and chronic oxidative stress.[18]	May affect drugs that are cleared by the kidneys.
Hypothyroidism: Positive association between increases in BMI and TSH level. Apparent link between leptin and obesity and alterations of thyroid hormones.[19]	Subclinical hypothyroidism not uncommon in obese patients and is correlated with ↑ BMI. Drug metabolism may ↓. Patients may have ↑ sensitivity to respiratory depression from sedatives.
Thiamine deficiency	May present with neurologic symptoms that may be misinterpreted as regional or neuraxial anesthesia side effects.
Iron and vitamin B_{12} deficiency	Concomitant anemia of different underlying causes.

each individual patient. Importantly, BMI by itself is not a predictor of difficult intubation.[20] The following is a summary of the most useful tools:

- Mallampati score (≥3) and large neck circumference (NC; >40 cm) may increase the chances for difficult laryngoscopy (intubation with the traditional laryngoscope). NC should be measured at the level of the thyroid cartilage. A neck diameter of 50 cm carries a risk for difficult intubation of about 20%. This percentage doubles when neck diameter is 60 cm.[20]
- Thyromental distance (TMD; <6 cm) is another predictor.[20] TMD is the distance from the thyroid notch to the mentum in centimeters.
- A recent study found that the NC to TMD ratio, the Mallampati score, and the Wilson score were independent predictors of difficult intubation. Among them, an NC:TMD ratio >5 had the highest accuracy (AUC 0.865).[21]

Leoni et al[22] evaluated different preoperative, commonly used, difficult airway indices as predictors of DMV in obese patients (BMI >30 kg/m²). They found that limited mandible protrusion, Mallampati score (≥3), NC (>46 cm), and male gender were risk predictors, whereas history of OSA and TMD distance were not. They also found that the risk for DMV increases with the association of 2 (OR, 18.3), 3 (OR, 35.2), or 4 (OR, 64.9) of these independent predictors of DMV.

- **Respiratory and oxygenation status:** Pulmonary function tests and a sleep study can help in the management of intraoperative ventilation, planning extubation, and postoperative pulmonary care. Two important clinical entities should be screened for:

- OSA has been reported in ≤71% of patients with MO (≥35 kg/m^2) undergoing bariatric surgery.[23] OSA is typically diagnosed by a sleep assessment study (overnight polysomnography),[24] which might be done more selectively in patients who show higher probability of having the disease based on the results of the following screening questionnaires:
  - **STOP-BANG** questionnaire; **S**noring, **T**iredness, **O**bserved apnea, and high blood **P**ressure combined with **B**MI >35, **A**ge >50, **N**eck circumference >40 cm, and male **G**ender. Each item will receive 1 point with a maximum score of 8. Less than 3 points indicates a low risk for OSA; more than 3 points predicts high risk.[25] The questionnaire was validated in obese and MO surgical patients; for identifying severe OSA, a score of 4 has a sensitivity of 88%. For confirming severe OSA, a score of 6 is more specific.[26]
  - The American Society of Anesthesiologists' Task Force on Perioperative Management of Patients with Obstructive Sleep Apnea created a scoring system for perioperative risk from OSA.[27] They define no OSA as an AHI <5, mild OSA as an AHI of 6 to 20, moderate OSA as an AHI of 21 to 40, and severe OSA as an AHI >40.[27] AHI index is represented by the number of apnea and hypopnea events per hour of sleep.

    Patients with OSA and a hypopnea index >5 can benefit from overnight CPAP or bilevel positive pressure airway for 6 to 12 weeks before surgery,[28] although the exact period is not well defined.
- OHS (also known as Pickwickian syndrome) diagnostic criteria include BMI >30 kg/m^2 and awake $PaCO_2$ >45 mm Hg without other causes of hypoventilation.

- **Cardiovascular system assessments:** Common cardiac complications that might be present in obese patients are summarized in Table 1. Cardiac function evaluation in patients with MO can be very challenging, as these patients have limited ability to perform physical activity to determine their functional capacity (eg, metabolic equivalents) and usually have muffled heart sounds on auscultation due to chest wall fat.
- Patient transportation might be challenging and should be planned, particularly in superobese patients. We found that using a lifter helps ensure patient safety and reduces the possibility of injury to health workers (Figure). Respiratory and cardiovascular deterioration and the significant risk for nerve, joint, muscular and soft tissue injuries are important factors that should be kept in mind during patient positioning and transportation for surgery.

Airway Management

Preoxygenation is very important in these patients to compensate for their high lability with rapid desaturation during intubation and to ensure enough oxygen reserve during the intubation process, which might be prolonged when intubation is difficult. As these patients are also likely to be difficult to ventilate by mask, proper face mask selection is critical. Preoxygenation for 3 minutes in the 25-degree head-up ("ramped") position achieves a 23% increase in oxygen tension and a clinically significant increase in the desaturation safety period, in comparison to preoxygenation in the supine position.[29] This preoxygenation technique can be further enhanced by augmenting the FRC using 5 to 10 cm H_2O CPAP.[30]

Figure. Using a lifter to transport a patient facilitates patient safety and safeguards medical team members.

It also has been found that noninvasive PPV improves oxygenation and end-expiratory lung volume in MO patients compared with conventional preoxygenation when performed for a 5-minute interval.[31] A 30-degree reverse Trendelenburg position during anesthesia induction provided the longest safe apnea period compared with the 30-degree back-up Fowler position (ie, only the cephalad half of the operating room table is tilted upward at a 30-degree angle with a break in the table at the level of the patient's hips) and horizontal-supine positions.[32]

The incidence of difficult intubation in obese patients has been reported between 13% and 24%; difficult face mask ventilation was as high as 79%.[5] To overcome DMV, NMBAs have been suggested, given early in the induction sequence, although this approach is always controversial.[1] To overcome challenging intubation in these patients, multiple maneuvers were tested. The most successful are proper patient positioning in ramped position, and the use of video laryngoscopes, intubating laryngeal mask airways or awake FOI equipment.[33]

A ramped position has been proposed to facilitate ventilation and visualization of the glottis for intubation. The external auditory meatus and sternal notch should align horizontally at the same level.[34] Dhonneur et al, in a study with 318 MO patients, found that video-assisted tracheal intubation had a 100% success rate, shorter duration to tracheal intubation, and better arterial oxygenation quality compared with the Macintosh laryngoscope.[35]

If awake FOI is mandatory, adequate airway topicalization (anesthetizing) and/or remifentanil (0.05–0.1 mg/kg/min IBW) can be successfully used.[34] One of the major airway issues that occurs after anesthesia induction is collapse of the soft tissue of the pharynx as a consequence of loss of muscle tone, which is more pronounced in MO patients,[36] especially when they lie supine and when they have associated OSA. This is why OSA is a good predictor for difficult intubation. This fact has caused some experts to believe that intubation should be done awake. We recommend that when awake FOI is required, the patient should be in the semi-sitting position and it might be better if the anesthesiologist approaches the patient from the front.

An endoscopic mask is available (eg, VBM, Medizintechnik GmbH) that allows continuous oxygen flow and PPV during the intubation procedure. Recently, a case of successful use of an endoscopic mask to facilitate awake FOI was reported in a MO patient, and it is felt that PPV during the procedure helped to open up the collapsed posterior soft tissue.[37] This approach might be prudent in patients dependent on assisted ventilation due to severe OSA. Interestingly, awake video laryngoscopy–assisted intubation under airway topicalization and sedation was found feasible in MO patients.[38]

The bottom line is that the anesthesiologist's experience with these different tools, the degree of difficult intubation anticipated, and the patient's clinical condition should be considered when selecting the appropriate tool to use. The role of airway adjuncts, such as the video laryngoscope, is still under evaluation. At present, their use depends on the skills of the individual clinician.

RSI is a common practice in obese patients, and is used to avoid the risk for aspiration. Rather than giving a hypnotic (such as propofol) followed by a muscle relaxant (such as rocuronium) after loss of consciousness and the ability to mask-ventilate has been confirmed, both drugs are administered almost simultaneously, to shorten the time span between spontaneous breathing and intubation.

Additionally, cricoid pressure is maintained to prevent regurgitation of stomach contents. A comprehensive review by Fried concluded that the risks and benefits of RSI and cricoid pressure should be weighed in fasted obese patients undergoing elective surgery who have no other risk factors for pulmonary aspiration.[39] Interestingly, extensive meta-analysis did not find evidence to support or discourage the use of RSI to lower aspiration risk.[40] Furthermore, the application of cricoid pressure seems to make intubation more problematic. Thus, a reasonable approach is to use RSI when indicated (eg, a patient with GERD), but not as routine practice in fasted obese patients who come for elective surgery but are at low risk for aspiration.[34]

Anesthesia Induction and Maintenance

The physiologic and anthropometric changes (eg, increased CO, changes in regional blood flow, and increases in both fat and lean body mass) that are associated with obesity have a great influence on drug pharmacokinetics. Moreover, the pharmacodynamics of some anesthetics also may be altered as a result of respiratory pathophysiology (eg, OSA), which may exaggerate side effects of anesthetics and narrow their therapeutic window.[41] In obese patients, fat mass and lean body mass are not proportional. As a general rule in obese patients, lipophilic drugs have an increased volume of distribution whereas hydrophilic drugs show only minor changes.[5]

Anesthesiologists should be knowledgeable about the appropriate dosing and selection of anesthetic and analgesic drugs in obese patients (Table 2). Obesity tends to be an exclusion criterion in many clinical drug trials. There is a lack of pharmacokinetic and pharmacodynamic studies of many drugs in MO patients, and a need for such studies, especially given the increase in the number of these patients who come for surgery. As a rule of thumb, LBW is the most appropriate dosing scalar for the majority of anesthetic medications and opioids, except for the nondepolarizing NMBAs, where IBW is more appropriate.[41] However, succinylcholine remains the only drug that should be dosed based on TBW.

It is traditionally felt that succinylcholine is the drug of choice for RSI due to its rapid onset of action and short duration.[41] Recent evidence suggests sugammadex is a better agent than neostigmine in reversing NMB in obese patients. Carron et al found that sugammadex allowed a safer and faster recovery from profound rocuronium-induced NMB than did neostigmine

Table 2. Summary of Drug Doses Commonly Used During Anesthesia[2,41]

Drug	Dose	Comments
Acetaminophen IV	15 mg/kg (LBW)	Clearance is ↑, so dosing may need to be more frequent, max dose 4-6 g/day.[1] Check liver function.
Alfentanil	130-245 mcg/kg, and infusion 0.5-1.5 mcg/kg/min (LBW)	
Antibiotics	TBW	Subcutaneous soft tissue penetration looks impaired in obese patients. Cefuroxime 1.5 g IV is sufficient against gram-positive but not gram-negative organisms.[42]
Cisatracurium	0.15-0.2 mg/kg (IBW)	Duration of action prolonged when given based on TBW.
Dexmedetomidine	0.2 mcg/kg/h (TBW)[43]	When used as infusion it ↓ opioid use, nausea, and the PACU length of stay. But it does not affect late recovery (eg, bowel function) or improve overall quality of recovery.[43,44]
Enoxaparin	0.5 mg/kg (TBW)	DVT prophylactic dose, divided into bid doses.
Etomidate	0.2 mg/kg (LBW)	Despite more hemodynamically stable characteristics, etomidate induction is associated with a substantially ↑ risk for 30-day mortality, cardiovascular morbidity, and prolonged hospital stay, in a general population.[45] A recent study suggested that etomidate can be dosed according to IBW in MO patients.[46]
Fentanyl	2-3 mcg/kg (LBW)	Clearance significantly higher, and increases linearly with "pharmacokinetic mass," which is highly correlated to LBW.
Ketamine	1-2 mg/kg (LBW)	Might be used in hypotensive patient. Adding 1 mcg/kg/min to propofol and remifentanil TIVA mixture was found to provide more hemodynamic stability, satisfactory recovery profile, and adequate postoperative pain relief.[47]
Lidocaine	1.5 mg/kg bolus, and 2 mg/kg/h infusion both as CBW[48]	Bolus followed by infusion until end of surgical procedure with indicated doses shows lower opioid consumption and better quality of recovery.[48,49]
Midazolam	Premedication 0.15-0.35 mg/kg (TBW), max 5 mg. If used as continuous infusion, use IBW	Concomitant use with opioids can potentiate its respiratory AEs.
Morphine	0.05-0.10 mg/kg (LBW)	Better to avoid due to longer duration of action, particularly in patient with OSA or OHS.
Neostigmine	0.05 mg/kg (CBW)[50]	Or 70 mcg/kg LBW; total dose ≤5 mg.[51]
Propofol	1.5-2.5 mg/kg for induction (LBW), maintenance infusion (TBW)	The most common induction agent used; its high lipophilicity and rapid distribution profile account for its short duration of action. Volume of distribution and clearance at steady state increases with ↑ TBW.
Remifentanil	1 mcg/kg for endotracheal intubation, and 0.2-2 mcg/kg/min for infusion (LBW)	Its rapid onset of action (1 min) and ultra-short half-life (5-10 min) make it a good option for intraoperative pain management. Aids in maintaining adequate relaxation and reducing volatile anesthetic or propofol requirements.
Rocuronium	0.6-1.2 mg/kg (IBW)	1.2 mg/kg has rapid onset. The use of rocuronium (1 mg/kg) reversed with sugammadex (16 mg/kg) was found superior to succinylcholine as it allows earlier re-establishment of spontaneous ventilation.[52]

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Drug	Dose	Comments
Succinylcholine	1-1.5 mg/kg (TBW), ≤150 mg total dose	As in MO patients, the amount of pseudocholinesterase and the extracellular fluid ↑; doses should be administered based on TBW. Postoperative myalgia seems to be more severe and problematic in obese patients[53]; pretreatment with low-dose nondepolarizing NMBAs or sodium channel blockers such as lidocaine is highly recommended in this population.[54] It is a very useful and effective medication in the treatment of laryngospasm in obese patients.
Sufentanil	1-2 mcg/kg (LBW)	
Sugammadex[a]		A final consensus on optimal sugammadex dosing in obese patients has not been reached. Different dosing scalar have been suggested: 2 mg/kg (IBW + 40%)[55] and 2 mg/kg (CBW)[50]; however, TBW seems to be the most safe and effective dosage regimen for complete reversal from NMB with sugammadex in MO patients.[56] Caution: A case report has shown that the use of sugammadex does not guarantee absence of the risk for recurarization.[57] Train-of-four still must be checked before extubation.
Thiopental sodium	3-5 mg/kg (LBW)	Very similar to propofol pharmacokinetics.
Vecuronium	0.1-0.12 mg/kg (IBW)	No rapid onset dose, has longer duration of action when given based on TBW.

CBW = IBW + 0.4 × (TBW – IBW)

IBW in male = 50 kg + 2.3 kg for each inch over 5 ft; in female = 45.5 kg + 2.3 kg for each inch over 5 ft.

LBW in male = (1.10 x weight [kg]) – 128 × (weight^2/[100 × height {m}]^2); in female = (1.07 x weight [kg]) – 148 × (Weight^2/(weight^2/[100 × height {m}]^2)

MO: either BMI >40 kg/m^2, or BMI >35 kg/m^2 with associated comorbidities such as diabetes mellitus, hypertension, OHS, OSA, pulmonary arterial hypertension, and RV and LV failure.

[a] At press time, not approved by FDA for use in the United States.

in patients with MO.[49] The same conclusion was found by Gaszynski et al.[48] Also, sugammadex has better ability to prevent postoperative residual curarization in comparison with neostigmine. (Note that sugammadex is not approved by the FDA at press time.) Continuous quantitative monitoring of neuromuscular function (instead of an empirical approach) should be used to guide the intraoperative administration of NMBAs, and residual NMB should be excluded before extubation as it is an independent risk factor for postoperative respiratory complications.[58] It is crucial to correctly use and interpret the neuromuscular monitoring equipment in these patients. For example, in patients with very high levels of adipose tissue at the wrist, the face is the recommended monitoring location. When wrist circumference is >18 cm, ulnar nerve supramaximal stimulation currents of >70 mA can be required, which monitoring devices may be unable to achieve.[2] Patients should be extubated fully awake after confirming recovery from NMB by assuring that train-of-four ratio exceeds 90%. Extubation should be in the semi-sitting or ramped position to minimize the risk for aspiration and help ventilation.

Among the volatile anesthetics, desflurane appears to be the best option, as it is the least lipophilic and least soluble available agent, and theoretically has limited distribution in the adipose tissue, suggesting faster emergence and recovery characteristics. However, clinical studies comparing it with sevoflurane yielded conflicting results in terms of emergence time.[41] Although De Baerdemaeker et al did not find any difference between desflurane and sevoflurane use and time to recovery,[59] McKay et al found desflurane to be faster.[60] The duration of anesthesia exposure (ie, 2-4 hours) and the severity of BMI are factors that were found to determine the clinical significance of this difference. On the other hand, sevoflurane has a potential clinical effect on renal function,[61] as it results in inorganic fluoride (compound A) that is nephrotoxic at concentrations >50 mmol/L.[41] Kaur et al found similar hemodynamic effects from desflurane and sevoflurane, whereas the immediate and intermediate recovery was significantly faster with desflurane, allowing fast-tracking and early discharge of patients.[62] Finally, because isoflurane is more lipophilic than sevoflurane and desflurane, it has fallen out of favor for use in obese patients.[41] However, for procedures that last 2 to 4 hours, it shows similar recovery times in obese and nonobese patients when used at 0.6 minimal alveolar concentration.[63] Overall, the choice of inhaled anesthetic is likely of limited relevance.

Ventilation and Oxygenation

Optimal ventilation and oxygenation helps prevent postoperative respiratory complications. The pulmonary changes associated with obese patients (Table 1) can put the patient at increased risk for ventilator-induced lung injury during general anesthesia. During general anesthesia, the FRC can fall below closing capacity of the lung, inducing a cyclic opening and closing of small airways during mechanical ventilation.[5] FRC can fall after induction of anesthesia to ~50% of preanesthesia values.[6] PEEP can be optimized based on the assessment of pressure-volume loops and titrated based on PaO_2. Ultrasound has been successfully used to optimize PEEP in critical care, but has not yet been used in the intraoperative setting.[64] EIT may be a promising clinical approach to lung function monitoring in patients with mechanical ventilation. EIT has been successfully used to assess lung recruitability and to titrate PEEP. Erlandsson et al found that EIT enables rapid assessment of lung volume changes in MO patients and optimization of PEEP.[65] High PEEP (15 cm H_2O) levels need to be used to maintain a normal FRC and to minimize shunt. Volume loading prevents circulatory depression despite a high PEEP level. Using EIT-based center-of-ventilation index in nonobese patients undergoing laparoscopic cholecystectomy, Karsten et al found that the use of initial recruitment maneuvers and a PEEP of 10 cm H_2O preserved homogeneous regional ventilation during laparoscopic surgery in most, but not all, patients and improved oxygenation and respiratory compliance.[66] As the lung does not increase with increasing BMI, the tidal volume should always be adjusted to IBW.[8]

It has been shown that obese patients are at greater risk for postoperative atelectasis than nonobese patients. Intraoperative alveolar recruitment with a vital capacity maneuver maintained for 7 to 8 seconds followed by PEEP 10 cm H_2O was effective in preventing lung atelectasis and was associated with better oxygenation, shorter PACU stay, and fewer pulmonary complications in the postoperative period in obese patients undergoing laparoscopic bariatric surgery.[67] A lung-protective strategy using low tidal volume (6-10 mL/kg IBW) and a pressure limit <30 cm H_2O was suggested, with PEEP ranging between 10 and 15 cm H_2O.[5] Altering tidal volume and respiratory rate does not improve arterial oxygenation, whereas PEEP did.[7]

The best ventilation strategy is to optimize gas exchange and pulmonary mechanics and to reduce the risk for respiratory complications. A recent quantitative systematic review and meta-analysis found some evidence that recruitment maneuvers added to PEEP compared with PEEP alone improves intraoperative oxygenation and compliance without AEs. There is no evidence of any difference between pressure- or volume-controlled ventilation in respiratory outcomes.[68]

The main focus on mechanical ventilation in obese patients is to "keep the lung open" during the entire respiratory cycle.[6] Table 3 summarizes recommended strategies.

Vascular Access and Fluid Management

Placement of central venous catheters should be avoided as much as possible, as these patients may have concomitant CF and may decompensate if placed in the supine or head-down position to facilitate line insertion. Even in the absence of major cardiac issues, prolonged periods in those positions can cause respiratory decompensation, mainly in the awake patient. Central line placement in the sitting position carries a high risk for air embolism.[2] Therefore, anesthesiologists should resist the temptation to embark on central line placement in these high-risk patients, when good peripheral lines can achieve the same result. Ultrasound-guided vascular access can be of great benefit for inserting central lines, if absolutely indicated, peripherally inserted central catheters and peripheral lines. It can help to identify the vessels, measure the depth, assess for anatomical variations, assess for the presence of thrombosis, and rule out complications.[64]

To avoid overload consequences and maintain good hydration and oxygenation, careful perioperative fluid management is crucial in MO patients. A conservative fluid approach seems best. Traditional parameters (ie,

Table 3. Recommended Ventilation Strategies Based on Available Evidence[2,5,6,8,9]

• Tidal volume of 6-10 mL/kg (IBW) with respiratory rate that maintains normocapnia (aim: pH 7.3-7.45).
• Use of recruitment maneuvers (plateau pressure ~40-55 cm H_2O) for 7-8 sec, as long as the patient is hemodynamically stable, after induction and before extubation, and whenever indicated.
• Application of PEEP 10 cm H_2O until extubation, always after recruitment maneuvers, and whenever possible considering cardiovascular status. Severely obese patients may require ≤15 cm H_2O.
• Use of reverse Trendelenburg position whenever possible, from the time of preoxygenation to extubation.
• FiO_2 between 0.4 and 0.8, even during the preextubation period, as higher levels may lead to formation of resorption atelectasis.
• Avoid losing PEEP effect by suctioning the tube or by accidental disconnection of the circuit.
• Use a ratio of the duration of inspiration to expiration of 1:1-1:3.
• Monitor peak airway pressure and airway plateau pressure (≤30 cm H_2O).
• Extubation should be after ensuring adequate reversal of NMB, with the patient positioned almost upright or in reverse Trendelenburg, and fully awake.

Table 4. Possible Complications In Obese Patients After Bariatric Surgery (in order of frequency)[76-79]

Complication	Prevalence, %
Total wound infections	2.57-6[a]
AKI[77]	5.8
Urinary tract infection	3.9[a]
Peripheral nerve injury	0.4-4.6
Venous thromboembolism[79]	0.9[a]-2.2
Systemic infections	1-1.6[a]
Ventilator dependence >48 h	0.32-1.8[a]
Pneumonia	0.5-1.5[a]
Wound disruption	0.15-1.4[a]
DVT[79]	1.3
Pulmonary embolism[79]	0.9
Cardiac arrest	0.08-0.5[a]
Myocardial infarction	0.02-0.5[a]
Stroke	0.02-0.2[a]
Acute renal failure	0.12
Rhabdomyolysis	Rare/unknown

[a] Data from Bamgbade et al[76] extracted from different types of operations that were not specified. Numbers from Turner et al[78] were recalculated to represent the incidence among the whole study population (32,426 patients).

Table 5. Possible Peripheral Nerve Injuries in Obese Patients

• Stretch injury to the brachial plexus and ulnar neuropathy among the most commonly reported.[80]
• Compression damage to the lateral femoral cutaneous nerve (meralgia paresthetica); patients usually develop pain, paresthesia, or hypersensitivity in the anterolateral aspect of the thigh.[81] Lithotomy position and increased intraabdominal pressure from laparoscopic insufflation ↑ risk.
• Bilateral sciatic nerve palsy after bariatric surgery was reported in a patient with BMI 78 kg/m^2 after prolonged laparoscopic surgery, despite adequate precautions.[82]
• Vagal nerve injury, especially in gastric banding surgery. Usually presents with nausea and vomiting secondary to decreased gastric motility.[80] On the other hand, excessive vagal nerve stimulation that may be associated with an intragastric balloon overstretching the gastric wall may lead to bradyarrhythmia and cardiac arrest.[83]

BP, central venous pressure, and urine output) are not accurate in predicting volume status in these patients. Indeed, in patients undergoing laparoscopic bariatric surgery, intraoperative urine output was found to be low regardless of the use of relatively high-volume fluid therapy, which suggests it is not a good measure to guide fluid therapy.[28] Other functional parameters have been suggested (eg, stroke volume variation and PPV).[69] Fluid therapy should always be administered based on patient IBW.[70]

Perioperative Pain Management

Perioperative pain management in obese patients is a very important element in reducing the overall morbidity that may complicate surgery. As many obese patients have baseline pulmonary and airway issues (eg, OSA and OHS), an ideal analgesic regimen should not cause further respiratory depression and sedation, and should be robust in improving postoperative recovery (eg, respiratory function). Therefore, multimodal analgesia is a sound approach.

According to the ASA Closed Claims database, 48% of respiratory AEs secondary to opioids occurred in obese or MO patients.[71] This should make us cautious using opioids in obese patients and suggests considering further adjuvant pain management approaches like dexamethasone, lidocaine, and NSAIDs (Table 2). NSAIDs are not contraindicated in asthmatic patients, and use of drugs like diclofenac and ketorolac seem appropriate.[1] Continuous peripheral nerve blocks, local anesthetic wound infiltration, or TAP block also are useful. If opioids are required, they should be used in a minimally effective dose. Ultrasound-guided TAP block after laparoscopic bariatric surgery has been found to be feasible and reduces opioid requirements, improves pain score, decreases sedation, promotes early ambulation, and results in greater patient satisfaction.[72,73] If patient-controlled analgesia with opioids is still to be used, fentanyl might be better than morphine, background infusions should be avoided, and the lockout period should be adjusted to minimize sedation and respiratory depression.[2]

Recently, Ziemann-Gimmel et al[74] found that the use of opioid-free total IV anesthesia (with propofol, ketamine, and dexmedetomidine) was associated with a large reduction in relative risk for PONV compared with balanced anesthesia (volatile anesthetics and opioids).

Postoperative Recovery and Care

There are no clear guidelines as to where the immediate postoperative care of the obese patient should take place, whether in the PACU or the ICU. The decision rests largely on the judgment of the anesthesiologist and surgeon.

To reduce postoperative pulmonary complications, different techniques have been used. The most useful are summarized here:

- Frequent chest physiotherapy and use of incentive spirometry.

- Avoid placing the patient in the supine position; head-up position (30-45 degrees) improves respiratory mechanics (increases FRC).
- Use of noninvasive CPAP as early as possible when the PaO_2 to FiO_2 ratio falls to <300.[6] It has been found that Boussignac CPAP improved blood oxygenation compared with passive oxygenation with a nasal catheter but had no influence on CO_2 elimination in non–CO_2-retaining MO patients.[75] There is insufficient literature to evaluate the effect of CPAP or noninvasive PPV on the postoperative respiratory status of patients with OSA.
- Administer robust PONV and pain control with minimal sedation.

Possible postoperative complications in obese patients are summarized in Table 4. Obese patients had a higher mortality rate than nonobese patients.[76] AKI after bariatric surgery was reported as high as 5.8% (defined as a postoperative increase in serum creatinine by 0.3 mg/dL within 72 hours).[77]

Neurologic complications after bariatric surgery can be classified into immediate (mostly mechanical injury) or late (mostly secondary to malnutrition). They include the peripheral, central, and enteric nervous system.[80] Possible peripheral nerves injuries in obese patients are summarized in Table 5.

Rhabdomyolysis is a rare complication of bariatric surgery. Chakravartty et al performed a systematic review including 145 patients who developed rhabdomyolysis after bariatric surgery.[84] Risk factors were male gender, elevated BMI (>50 kg/m^2), prolonged operating time, and patient positioning (lithotomy or lateral decubitus). Rhabdomyolysis increases the risk for developing acute renal failure and mortality. Patients usually presented with severe postoperative pain involving areas of contact with the operating table, such as the gluteal, lumbar, and shoulder muscles, thus careful padding of these pressure points is important. If patients who received epidural or regional analgesia report breakthrough pain, this should raise suspicion for the possibility of underlying rhabdomyolysis, and serum creatine kinase should be checked (>10,000 U/L if rhabdomyolysis is present). Furthermore, when postoperative epidural analgesia is used, it has been suggested that regular postoperative creatine kinase levels be checked to identify rhabdomyolysis early.[84] Copious hydration and mannitol have been used successfully.[85] However, liberal intraoperative fluids did not prevent rhabdomyolysis.[86]

Anesthesiology Training in the Morbidly Obese Patient: Present and Future

There is no current fellowship in the United States in bariatric anesthesia, nor is a mandatory rotation for residents in dealing with MO patients required by the Accreditation Council for Graduate Medical Education.[87] Leykin and Brodsky recently published a comprehensive and unique book about perioperative anesthesia management in obese surgical patients, and they highly support specific training.[87] There is also a need for more guidelines and research in this area. A "road map" model toward establishing clinical practice guidelines for anesthesia in MO patients has been suggested.[88]

In conclusion, the marked increase in the obese population makes it almost certain anesthesiologists will be taking care of this population. Although historically, physicians have been afraid of doing surgery in superobese patients, advances in anesthetic medications, ventilator techniques, and other devices now permit safe anesthesia with better postoperative recovery in heavier patients. Anesthesiologists should be fully knowledgeable of the challenges these patients present and have the skills to attend to them, and they must be continually aware of ongoing research in bariatric surgery. Similarly, primary care providers, internists, and surgeons who operate on these patients should be aware of the considerable perioperative challenges.

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