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Chapter 4

Obesity and Anesthesia Management

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Additional information is available at the end of the chapter

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Abstract

The prevalence of obesity is rapidly increasing throughout the world. Correspondingly, anesthetic procedures in obese patients are also increasing due to both treatment of obesity and other surgical problems of obese patients. Anesthesia-related complications are also seen in obese patients than in normal-weighted population. The importance of anesthetic applications in obese patients originates from physiological and pharmacokinetic alterations. Inhalation of these patients via mask or intubation during general anesthesia may be difficult or even impossible. Determination of extubation time after awakening from anesthesia is also a critical decision. Sleep apnea syndrome and postoperative atelectasis are more common in obese patients than in normal-weighted population. Another vital complication that should be emphasized is thromboembolism, whose incidence and severity may be decreased by pharmacological and functional preventive modalities. This patient population has elevated risk of perioperative mortality and morbidity. Prior to any elective surgical procedure, an obese patient should be thoroughly evaluated to check medical conditions that may increase perioperative mortality risk. Since anesthesiologists will gradually encounter more obese patients, they need a better comprehending of the difficulties of obesity during anesthetic procedures and taking more preventive measures for their patients to avoid complications, or rendering them less traumatic, if any.

Keywords: obesity, airway management, drug dosages, perioperative management, postoperative analgesia

1. Introduction

Though obesity is not a newly emerging problem with its epidemic character at both public and individual levels, there has been recent increase in the number of successful surgical interventions with low likelihood of serious morbidity. Body weight of more than 50% of adults in the United States (US) is 20% more than the body weight regarded optimum for the height. The percentage of such adults has increased from 30 to 50% just in 18 years [1].

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Overweight has been defined as an excess of total or expected "normal" body weight, including all tissue components (muscle, bone, water, and fat) of body composition. In practice, the terms obesity and overweight are often used interchangeably to refer to excess body fat, but ideally an index of obesity should reflect only excess adipose tissue and be independent of height, body fluids, and muscle, and skeletal mass.

Body mass index (BMI) is now the standard measure for describing different categories of obesity. It must always be remembered that BMI is an indirect measure of obesity since it only considers height and weight, irrespective of the source of any additional weight. BMI is calculated by dividing patient weight (kilograms, kg) by the square of their height (meters, m); BMI = kg/m^2. An increased BMI can be present from any cause of excess weight (body building, ascites, and very large tumor) even in the absence of additional fat. The United States and many countries classify obesity according to BMI, as shown in **Table 1** [2].

BMI	
<20 kg/m^2	Underweight
20–25 kg/m^2	Normal
26–29 kg/m^2	Overweight
30–39 kg/m^2	Obese
≥40 kg/m^2	Morbid obese
≥50 kg/m^2	Super-obese
≥60 kg/m^2	Super-super obese
World Health Organization (WHO) classification: BMI	
30–34.9 kg/m^2	Class I
35–39.9 kg/m^2	Class II
>40 kg/m^2	Class III

Body mass index (BMI) = weight (kilograms, kg) divided by the square of height (meters, m); BMI = Wt (kg)/Ht (m^2).

Table 1. Classification of obesity by body mass index (BMI).

While many obesity complications that pose threat to perioperative period (e.g., airway difficulties or joint problems) may be observed by physical inspection, other complications such as sleep apnea, systemic and pulmonary hypertension, and diabetes mellitus should be comprehensively assessed by careful anamnesis, physical examination, and laboratory tests. Obesity itself, its complications and treatment, is also important for the anesthesiologist. An individual who has 30% excessive weight has a 40% increased mortality risk due to heart disease and a 50% increased mortality risk due to stroke. Hospital costs are also higher in obesity, with increased risk of perioperative morbidity and mortality [3].

Preoperative assessments make perioperative period more efficient, decrease anxiety of both healthcare providers and cared patients, and make patients have realistic expectations which increase satisfaction from pain management and entire perioperative experience. Obesity is a health problem associated with many medical conditions (**Table 2**). Preoperative assessment allows for detection of possible interindividual differences in terms of physiology of airways, pulmonary system, cardiovascular system, metabolic system, and nervous system. Another benefit is the important contribution of anesthesiologists to surgeons in terms of patient's psychological attitude and preparation [4].

Organ system	
Respiratory	Restrictive lung disease, asthma, obstructive sleep apnea (OSA), obesity hyperventilation syndrome (OHS)
Cardiovascular	Hypertension, cardiomyopathy, congestive heart failure, coronary artery disease, peripheral vascular disease, thromboembolism, sudden death
Endocrine/metabolic	Type 2 diabetes mellitus, Cushing's syndrome, hypothyroidism, hyperlipidemia, vitamin deficiencies
Gastrointestinal	Hiatal hernia, inguinal and umbilical hernia, fatty liver, gallbladder stones
Musculoskeletal	Osteoarthritis on weight-bearing joints, low-back pain
Malignancy	Breast, prostate, cervix, uterus, colorectal
Psychiatric	Depression, low self-esteem

Table 2. Obesity-related medical conditions.

2. Preoperative assessment

It is essential to provide a clinical setting that makes obese patients feel comfortable with respect to physical conditions. Outpatient setting or room should be designed according to overweight/obese patients. Primary physicians or surgeons of the patients should not believe mistakenly that they have adequate knowledge about their patients' medical situation. Comorbidities or other accompanying diseases may not frequently be well-documented. Preoperative assessment by anesthesiologist should include the presence of hyperglycemia or type 2 diabetes mellitus, hyperlipidemia, hypertension, coronary artery disease, respiratory problems, liver disease, and obstructive sleep apnea (OSA). As per indicated surgical procedure, impacts of osteoarthritis should be considered regarding positioning of patient especially during elective surgery [5].

An often overlooked, albeit important issue is the evaluation of medical reasons for obesity. Incidence of endocrine disease other than type 2 diabetes mellitus was reported as 47.4% among morbidly obese patients considered for bariatric surgery. Prevalence of hypothyroidism, pituitary diseases, and Cushing's syndrome is shown to be 18.1, 1.9, and 16.3%, respectively. Newly established endocrine diseases are present in 16.3% of all patients [6].

Psychological tests of morbidly obese patients frequently revealed depression, social impairment, and loss of interest in interindividual behaviors. Physicians should be aware of the likelihood of the presence of psychosocial problems in obese patients during the perioperative period [7].

Routine laboratory tests indicated for obese patients are summarized in **Table 3**. If the obese patient had history of bariatric surgery such as gastric bypass or other which represents a potential for malabsorption, a significant protein, vitamin, iron, or calcium deficiency may be present. Therefore, further additional tests are required in such patients to assess metabolic alterations (**Table 4**) [8].

Anesthesiologist should question all current medication of the patient, including over-the-counter and prescribed appetite-stimulating and weight-lowering drugs since most of these agents are associated with serious heart and lung problems and important morbidity and mortality (**Table 5**) [8].

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Fasting plasma glucose
Lipid profile
Electrolytes including sodium, potassium, calcium, and phosphorus
Liver function tests including AST, ALT, total, and direct bilirubin
Renal function tests including creatinine level
Complete blood cell count
Ferritin
Vitamin B12
Thyroid stimulating hormone (TSH)
25-Hydroxy vitamin D level
Testosterone level
Electrocardiogram (ECG)
Especially in >55-year-old women and >45-year-old men who has established or suspected heart disease or at higher risk for heart disease
P-A chest X-ray
Especially in >60-year-old patients with established or suspected lung or heart disease
Polysomnography
Other clinically indicated additional tests, such as echocardiography

Table 3. Routine preoperative tests for obese patients.

2.1. Assessment and optimization of airways and pulmonary system

Factors increasing perioperative risks in obese patients in terms of airways and pulmonary system include airway anatomy, rapid desaturation developed during anesthesia induction secondary

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to reduced functional residual capacity (FRC), tendency to desaturation in supine position, need for induction and recovery in vertical position, tendency to sleep apnea, chronic respiratory insufficiency, pulmonary hypertension, predisposition to deep venous thrombosis and its consequences, and need for active participation to encourage for postoperative mobilization [9].

Test	Month 6	Month 12	Month 18	Month 24	Afterwards
Complete blood count	√	√	√	√	√
Biochemistry profile	√	√	√	√	√
Iron	√	√	√	√	√
Magnesium	√	√	√	√	√
Albumin	√	√		√	√
Vitamin B12	√	√	√	√	√
Vitamin D		√	√	√	√
Other lipid soluble vitamins		√		√	√
Parathyroid hormone	√		√		√
Folate		√		√	√
Bone density		√		√	√
Lipid panel		√			
Uric acid		√			
Vitamin K		√			

Table 4. Preoperative laboratory tests recommended for patients with history of bariatric surgery.

Obesity is a common and important risk factor for obstructive sleep apnea (OSA). A near two-unit increment in BMI raises the probability of OSA by fourfold. While the prevalence of OSA in general population is 2 and 4% in women and men, respectively, it ranges from 3 to 25% and 40 to 78% in morbidly obese women and men, respectively. Sleep apnea in obese patients has usually obstructive character and originated from airway stenosis secondary to excessive amount of peripharyngeal adipose tissue and from reduction of upper airway muscle tonus during rapid eye movement (REM) sleep. BMI, neck diameter, lung function tests (LFT), arterial blood gas measurement during daytime room air, and sleep-related complaints could not adequately predict the presence and severity of OSA in obese patients [10].

Definitive diagnosis of OSA is established by polysomnography, where following criteria should be fulfilled: occurrence of ≥5 apneic events (≥10 s interruption of air flow despite attempting to breath) or ≥15 hypopneic events (>50% reduction of air flow for ≥10 s) per hour during 7-h sleep test. Apneic/hypopneic index (AHI) shows the total number of apneic and/or hypopneic events per slept hour. The severity of OSA is directly correlated with the increase in AHI [11].

The determination of OSA in obese patients has two important implications. First, patients with OSA are more prone to the suppressive effects of hypnotics and opioids on airway muscle tonus and respiration [12]. Postoperative parenteral or neuraxial opioid use may lead to respiratory complications that may result in death or potentially fatal events [13, 14]. Second, OSA complicates laryngoscopy and mask ventilation [15]. Moreover, oxygen stores are decreased due to reduced expiratory reserve volume (ERV) in obese patients [16]. Combination of these factors predispose to serious problems in airways.

Drug	Implications for anesthetic procedures (reported adverse effects)
Diethylpropion	Pulmonary hypertension and psychosis.
Dexfenfluramine	Associated with pulmonary hypertension and cardiac valve disease.
Fenfluramine	Associated with pulmonary hypertension and cardiac valve disease.
Fluoxetine	Selective serotonin reuptake inhibitor. Associated with diarrhea, nausea, headache, and dry mouth. Bradycardia, hemorrhage, convulsion, hyponatremia, hepatotoxicity, and extrapyramidal effects were reported.
Mazindol	Pulmonary hypertension, atrial fibrillation, and syncope episodes were reported.
Metformin	No adverse effect was reported.
Orlistat	Diarrhea and reduced levels of lipid-soluble vitamins were reported.
Phentermine	Association with cardiopulmonary problems could not be excluded.
Phenylpropanolamine	Increases risk of hemorrhagic stroke.
Sibutramine	May lead to mild increases in blood pressure and heart rate. Associated with arrhythmia and hypertension, which is likely to be related to cardiac arrest and stroke.
Diuretics	Hypovolemia, hypokalemia.
Herbal products	
Chitosan	No adverse effect was reported.
Chromium	No adverse effect was reported.
Ephedra	Hypertension, psychiatric symptoms, autonomic dysfunction, gastrointestinal symptoms.
Hydroxycitric acid	No adverse effect was reported.
Pyruvate	Death was reported in a patient with restrictive cardiomyopathy.

Table 5. Weight lowering drugs.

Anamnesis is the easiest way of evaluation of OSA in the preoperative period in patients who did not undergo polysomnography before. Such useful data could be obtained from patient's roommate or sleep partner. Anamnestic data about snoring, interruption of breathing during sleeping (a short-time attempt to inspire after apneic episodes and wheezy breathing or resuscitative nasal breathing), decreased daytime performance, morning headache, and irritability suggest sleep apnea. Systemic hypertension and increased neck diameter (>40–42 cm at cricoid cartilage level) is consistent with probable OSA diagnosis [11, 17]. Other abnormalities of OSA detected during physical examination include somnolence and mask airway and/or intubation difficulties (e.g., Mallampati class III or IV hypognathia, short thyromental distance) [12, 14, 15].

Some obese patients develop chronic daytime hypoventilation, called as obesity-hypoventilation syndrome (OHS) [18]. These patients also have chronic daytime hypoxemia (PO_2 < 65 mmHg), which could be easily detected by pulse oximetry at room air. Permanent hypercapnia ((PCO_2 > 45 mmHg) in the absence of serious obstructive pulmonary disease is pathognomonic for this syndrome in obese patients. These patients usually have advanced obesity (BMI > 40 kg/m^2) and risk of OHS is markedly increased with increasing BMI [19]. Majority of patients with OHS has also OSA; however OHS is not common in OSA patients. Those patients being at the "severe" end of OHS spectrum with cor pulmonale signs and symptoms are called "Pickwickian" [10, 18].

Careful determination of concomitance of obesity and OHS or COPD is important since this combination often leads to chronic daytime hypoxemia, which in turn causes pulmonary hypertension, right ventricular hypertrophy, and/or right ventricular failure. Perioperative morbidity and mortality rates are high in these disorders (Pickwickian), where patients need to undergo many tests to guide for perioperative medical optimization and postoperative care [10, 12, 20].

In perioperative setting, oxygenation is further diminished by reduction in muscular tonus of chest wall and diaphragm following general anesthesia induction and skeletal muscle relaxation. The net effect of this on obesity is the decrease of ERV and FRC by more than 50% and consequent decrease in the number of alveoli making efficient gas exchange, compared to the preinduction phase [21]. In addition, reduction in ERV and FRC increases predisposition to postoperative atelectasis and may inhibit effective clearance of secretions.

Main source of oxygen reserve during apnea is ERV. Therefore, preoxygenation is less effective in obese patients and the time required for hemoglobin desaturation to be reduced to below 90% after apnea is shortened [22]. Obese patients in relaxed condition under anesthesia have increased likelihood of hypoxemic complication due to "reduction in apneic oxygenation reserve" and difficulty of performing positive pressured mask ventilation [15]. In patients considered for bariatric surgery, elective awake tracheal intubation may be the safest approach if there are signs for difficult intubation (e.g., insufficient visualization of posterior pharyngeal wall). Before the induction, after placing a cylinder under the scapula and a support to the occipital region of the patient and asking for full extension at atlanto-occipital joint from the patient may ease awake or conventional laryngoscopy and intubation [23].

A study showed that laryngoscopy was more difficult to perform in obese patients (BMI > 30 kg/m^2) compared to patients with normal BMI [24]. However, authors in another study did not observe any correlation between difficult intubation and BMI, though they found an association between difficult intubation and increased neck diameter (>40–42 cm) or Mallampati score of III or IV [25]. This may be explained by higher probability of incidence of both increased neck diameter and increased Mallampati class in obese patients. Moreover, since obese patients have elevated gastric secretion volume and acidity in the preoperative period, premedication is applied by administration of cimetidine, ranitidine, citric acid, sodium citrate, or metoclopramide. Some investigators suggest this as an indication for awake intubation [26].

2.2. Cardiac assessment

2.2.1. Assessment and prevention of venostasis and thromboembolism

Evaluation of venous system should be prioritized in cardiovascular assessment as implied by mortality data. Venous emboli entered into pulmonary circulation are important causes of pulmonary dysfunction with a 30-day mortality of 1–2%. Majority of 30-day perioperative mortality after bariatric surgery originates from pulmonary embolism (the number of mortality for this reason is ≥ 3 times more than the number of mortality due to anastomosis leakage and consequent sepsis) [27]. Although several agents have been used to diminish the tendency to thrombosis, no consensus has been established. Since low-molecular-weight heparin may limit options for postoperative pain management, preoperative aspirin, and following warfarin (INR 2.0–3.0) may be considered as a reasonable choice. Use of warfarin, a vitamin K antagonist, may elicit some problems during the postoperative period as many patients develop malabsorption of lipids and lipid-soluble substances, including vitamin K after Roux-en-Y gastrojejunostomy (RNYG). Optimizing warfarin dosage may become difficult due to this malabsorption, where daily adjustments are required for at least a couple of weeks [28]. Preoperative exercise, prophylaxis through antithrombotic agents and variceal socks, hematocrit count below the level of polycythemia, increased cardiac output, and early ambulation decrease the risk in this patient group. Therefore, evaluation and prophylaxis including exercise status, pharmacological treatment, absence of symptoms and signs of venous disease and absence of evidence of venous disease, optimal hydration as well as early ambulation should be targeted [29].

2.2.2. Cardiovascular assessment

Cardiac output is expected to increase by 0.01/min for every kilogram of adipose tissue. Consequently, obese patients develop hypertension and associated cardiomegaly and left ventricular failure. To measure blood pressure accurately, an appropriate-sized cuff should be selected, which may not be as easy as it seems. Obesity not only leads to parenteral access difficulty, but also complicates noninvasive blood pressure monitoring. Direct arterial monitoring may be needed for accurate and continuous tracing of blood pressure and frequent arterial blood sampling, based on the extent of cardiopulmonary reserve [30].

Cardiac reserve may be limited in obese patients, where tolerance to hypotension, hypertension, tachycardia, or volume loading-induced stress in preoperative period may be diminished. Most of patients with Pickwickian syndrome also have right-sided heart failure. For this reason, routine preoperative assessment should also include electrocardiogram (ECG) in addition to anamnesis and physical examination featuring drug treatment and cardiopulmonary problems (especially in terms of left or right ventricular hypertrophy, ischemia, and conduction defects). In cases where biventricular failure is severe and not compensated with ≥2 month lasting exercises, measurement of central vascular volume when a large volume of blood loss is expected related to surgery or coagulation status. Physical examination of peripheral venous line may also allow for planning of the possible need for central venous catheter. Some physicians prefer transesophageal echocardiography to assess central volume instead of central venous pressure (CVP) measurement [31]. There are six risk factors to predict perioperative cardiovascular morbidity:

(i) High-risk surgery (e.g., emergent, major thoracic, abdominal, and vascular surgery)

(ii) History of coronary artery disease

(iii) History of congestive heart failure

(iv) History of cerebrovascular disease

(v) Preoperative insulin treatment

(vi) Preoperative plasma creatinine level >2 mg/dL

No additional cardiac tests are required for the elective surgery of patients where these risk factors are absent [32].

2.3. Metabolic assessment

2.3.1. Diabetes mellitus

Although 15% of patients with type I diabetes mellitus has also other comorbid autoimmune diseases such as Graves' disease, Hashimoto's thyroiditis, Addison's disease, and myasthenia gravis, no such an association has been reported in terms of obesity-related diabetes [33].

Current treatment of type II diabetics is initiated with exercise and dietary changes usually. A 5–10 kg weight loss, achieved by a 20% decrease in caloric intake and elevation of daily physical activity to 30 min for a total of 8 weeks often normalize fasting blood glucose levels. Nevertheless, this step is very difficult to achieve for most of patients, and patients will eventually switch to oral hypoglycemic agents, which stimulate secretion of insulin from pancreatic β-cells and improve insulin response of tissues by reversing postbinding defect [34]. Frequently used oral agents include tolazamide, tolbutamide, glyburide, and glipizide, the two latter being sulfonylurea class. Sulfonylureas have more long-lasting glucose-lowering effects (≥24 h) and lower drug-drug interaction potential [35].

By accelerating nonenzymatic glycosylation reactions, higher glucose concentrations lead to the formation of abnormal proteins which decrease flexibility and stretching resistance in wound healing, thereby causing toxic effects. Diminished flexibility may result in stiff joint syndrome and atlanto-occipital joint fixation which could hamper intubation [36].

Anastomosis-related infections are responsible for two-thirds of postoperative complications and about 20% of perioperative mortality in patients undergoing bariatric surgery and constitute number one risk in this patient group. Experimental data show that multiple factors may increase predisposition to infection in patients with glucose intolerance. Many alterations observed in leukocyte functions of hyperglycemic diabetic patients include decreased chemotaxis, impaired phagocytic activity of granulocytes as well as diminished intracellular destruction of pneumococci and staphylococci [37]. Phagocytic functions of granulocytes improve and intracellular killing capacity become near-normal if diabetic patients are aggressively treated, ensuring a blood glucose level <250 mg/dL [38].

2.3.2. Hypocalcemia

Inadequate calcium intake is both associated with obesity and hypertension; indeed, normalization of calcium intake could improve both hypertension and eating crises that lead to obesity [39].

2.3.3. Hyperlipidemia and hypolipidemia

Dietary control is an important treatment modality in all hyperlipidemia types [40]. Clofibrate and gemfibrozil, which are used for the management of hypertriglyceridemia, may cause myopathy especially in patients with hepatic or renal disease. Clofibrate may also increase the formation of gallbladder stones. Apart from bile acids, cholestyramine also binds to oral anticoagulants, digitalis class agents, and thyroid hormones. Nicotinic acid leads to peripheral vasodilatation, which should be likely to discontinue on the day of surgery. Probucol decreases synthesis of apoprotein A1. Rare malodorous perspiration and/or QT interval prolongation are seen during probucol usage, and sudden death in animals [41].

Hypolipidemia, albeit a rare condition, is associated with neuropathy, anemia, and renal failure. Although anesthesia experience is limited in patients with hypolipidemia, following may be recommended: maintenance of caloric intake and perioperative use of intravenous protein hydrolysates and glucose [42].

2.4. Psychological assessment and psychiatric considerations

Psychological assessment is very important for a successful outcome. Not just a week, but even a whole year following the surgery is not an easy period. Each patient needs to have increased awareness and strong-minded with a dedicated attitude of diarizing his/her diet [7]. Evaluations of anesthesiologist may provide important clues. Patient should be emotionally stable. Anesthesiologist may identify several factors about failure, which include drug abuse, untreated major psychiatric disorders, compulsive eating behavior, fibromyalgia, and chronic fatigue syndrome. Investigation, detection, and sharing of any of these may prevent potential frustration of surgical team and avoid patient getting stressed [43].

2.5. Musculoskeletal system assessment and other considerations for patient positioning

Several other considerations about obesity are also important for anesthesiologist in a prognostic and perioperative manner. Appropriate positioning of the patient, binding of monitoring devices, and performing intravenous access become complicated due to excessive and extensive subcutaneous fat tissue and enlarged extremities. Furthermore, assessment of blood pressure is also more difficult compared to normal-weighted patients (difficulty of selecting appropriate cuff) [44].

Assessment of positioning of obese patients prior to the surgery may abolish some postoperative problems. In a retrospective study, incidence of postoperative ulnar neuropathy was reported to be 29% in patients with BMI > 38 kg/m^2, compared to 1% of the control group [45]. Upper brachial plexus injury may also occur secondary to excessive rotation of the head and cervical vertebra to the contralateral side. Hyperabduction of the arm on the affected side may also lead to lower nerve root injury [46].

2.6. Risk classification

According to ASA Physical Status Classification System; patients with 30 < BMI < 40 are classified as ASA II, patients with a BMI ≥40 are classified as ASA III [47]. Also, for these patients, in 2007, DeMaria et al. suggested a risk stratification tool for bariatric patients. The Obesity Surgery-Mortality Risk Score (OS-MRS) assigns one point to each of five preoperative variables: BMI ≥ 50 kg m^2, male gender, hypertension, pulmonary embolic risk factors, and age ≥45 years. A score of 0–1 is classified as "A," 2–3 as "B," and 4–5 as "C" with associated mortality risks of 0.2, 1.1, and 2.4%, respectively [30]. This system was later validated by a multicenter study of more than 4000 patients [48].

3. Intraoperative management

3.1. Positioning in morbidly obese patients

Prevalence of obesity continues to increase rapidly throughout the world [49]. Therefore, all anesthesiologists should be familiar with this issue not only for obesity surgery, but also for other types of surgery [50]. Inappropriate surgical position may lead to serious physiological problems, and even physical injuries [51, 52]. On the other hand, appropriate position may ease procedures, including especially endotracheal intubation, reduce physiological problems, and minimize neural and soft tissue injury [53].

Operation tables having a carrying capacity of near 400 kg should be used for safe anesthetic and surgical procedures in obese patients. If no special operation table is present, two standard ones having a weight-bearing capacity of 200 kg may be adjoined. Patients should be tightly bound to the table, ensuring supporting of areas prone to pressure by gels and pads. These patients may develop renal failure and potentially fatal complications at even supine positions [54, 55]. In a study, Bostanjian et al. [54] described six patients undergoing bariatric surgery, rhabdomyolysis secondary to gluteal muscle necrosis developed after supine position, where the outcomes were fatal in three of cases.

Head-elevated laryngoscopy position, which is described as the position of head and shoulders above the level of the chest, i.e., above an imaginary horizontal line joining sternal notch and external auditory canal, makes laryngoscopy and intubation easy [56]. The position where the head is lifted 25° and reverse Trendelenburg in induction anesthesia were shown to prolong apnea in obese patients without desaturation [57]. Functional residual capacity (FRC) is severely diminished in the supine position after induction of anesthesia. If the reduction in FRC exceeds closure volume, small airways become also closed, ensuing a ventilation perfusion disturbance [58].

Supine position: Switching from the sitting position to the supine position causes an increase in venous load of the heart in some patients. Reduced diaphragmatic movement by abdominal organs leads to increased respiration work, relative hypoxemia, and marked reduction in lung volumes [59]. Lung volume is further decreased in general anesthesia procedures where muscles are completely paralyzed [60]. Compared to normal-weighed patients, FRC and pulmonary compliance are reduced in the supine position in obese patients, eventually increasing ventilation/perfusion mismatch [59]. All these alterations increase as the body mass index (BMI) is elevated. Induction of the anesthesia is recommended to be performed in the lateral decubitus position to overcome these difficulties [61]. Positive end-expiratory pressure (PEEP) may improve lung functions in mechanically ventilated patients [62]. Prolonged supine position should be avoided in patients with reduced cardiac reserve since venous return to the heart is diminished by increased compression onto the inferior vena cava secondary to abdominal pressure and weight. In such cases, operation table or the patient may be turned to the side so as to decrease aortocaval compression [53, 63].

Trendelenburg position: Patient's head is below the horizontal plane in Trendelenburg position, which may increase operative exposure and decrease bleeding in selected cases. It is less tolerated than that in the supine position. In obese patients who already have limited cardiac reserves, blood in lower extremities is added into central and pulmonary circulation by Trendelenburg position, making it hard to tolerate this position [64]. It should be especially avoided in morbidly obese patients. Further diminished residual capacity and pulmonary compliance in this position also lead to atelectasis and hypoxemia. In addition, endotracheal tube may be displaced depending on the position. In brief, this position is often not preferred in obese patients due to all these factors [53, 63].

Head-upward position: Upper torso of morbidly obese patients should be nearly 35–40° in the sitting position or reverse Trendelenburg position in a way where the operation table allows for adequate ventilation. Such position simplifies mask ventilation and conditions of tracheal intubation.

The combined effect of reverse Trendelenburg position and pneumoperitoneum during laparoscopic gastric bypass surgery decreases femoral blood flow and increases venous stasis, thereby increasing risk of pulmonary embolism. Therefore, prolonged applications of this position should be avoided with altering positions occasional breaks during surgery [65].

Prone position: Prone position was shown to increase oxygenation in normal-weighed patients under anesthesia than that in supine position [66]. As long as the chest and pelvis are supported such adequately that allows for abdominal movements, prone position is usually well-tolerated by obese patients. Cardiovascular functions are preserved when appropriate position and supports are provided. Otherwise, cardiac venous return is diminished by compression onto the inferior vena cava and femoral veins, which in turn leads to decreased volume in the left ventricle, causing hypotension. Prone position in obese patients under anesthesia improves pulmonary functions and increase FRC, pulmonary compliance, and oxygenation [53, 67].

Lateral decubitus position: This position is often tolerated well by obese patients. A decrease in the abdominal fat mass' compression on the abdomen diminishes intraabdominal pressure, which eases diaphragmatic movements during mechanical ventilation. However, maintenance of the same position for a long while may lead to vascular congestion and resulting in hypoventilation in underlying lung [68].

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Lithotomy position: This position causes increased venous return and cardiac output, and high risk of thromboembolism secondary to venous stasis after prolonged surgery. Another complication of this position may be the development of compartment syndrome when the lower extremities are inappropriately positioned [53, 69].

3.2. Airway management

Obesity leads to many anatomic alterations in airways. Upper thoracic and lower cervical fat pillows result in a limited range of motion in atlantoaxial joints and cervical vertebra. Excessive tissue folds in the pharynx, short and thickened neck, suprasternal, presternal, and posterior cervical fat tissue, and thick submental fat tissue are formed. All these alterations contribute to potentially difficult airway management, which has been reported as 10.3–20.2% in obese patients compared to 1.5–3.2% of general population [70]. Despite all these anatomical and pathological changes, extent of BMI did not appear to influence difficulty of laryngoscopy. This type of difficulty is rather associated with advanced age, male sex, temporomandibular joint pathology, Mallampati class III and IV, history of obstructive sleep apnea, and abnormal upper teeth [71]. Neck diameter has been defined as the best determinant for intubation difficulty in morbidly obese patients. While the probability of problematic intubation was 5% in patients with a neck diameter of 40 cm, this was found to be 35% in patients with a neck diameter of 60 cm [72]. Increased adipose tissue on pharyngeal walls in obese patients complicates mask ventilation and intubation by leading to alterations in upper airway anatomy. The presence of obstructive sleep apnea is an additional pathology that increases the risk for difficult intubation, hence warranting careful consideration in this patient population [73].

The prevalence of aspiration is low in obese patients, though risk of aspiration-related pulmonary complication is known to be increased in this group [74]. Gastroesophageal reflux that may cause aspiration is common in obese patients. Attention should be paid in patients with history of gastric band application especially in terms of aspiration [64].

Intraoperative ideal ventilation strategies are still contradictory in morbidly obese patients, where diminished lung and thorax compliance is particularly important. The increased amount of thoracic fat tissue is associated with decreased FRC that may be increased by elevation of upper torso though this may not provide an increment as effective as in normal-weighed people [75]. While lung volume is not altered, respiratory load, oxygen consumption, and carbon dioxide synthesis are increased following diminution of lung and thorax compliance, which in turn leads to decreased tolerance to respiratory stress. By causing cyclic alveolar collapse, low FRC and unchanged closure volume induce alveolar injury associated with mechanical ventilation [29]. These patients have predisposition for postoperative atelectasis. An association between the extent of atelectasis and the incidence of postoperative ARDS was also demonstrated [76]. An adequate PEEP administration is important to decrease probability of atelectasis during mechanical ventilation. In obese patients, PEEP provides beneficial effects both on PaO_2 and alveolar-arterial oxygen difference, even these benefits were shown to be more prominent as compared to normal-weighed people [15].

Studies showed that applications of PEEP of 10–15 cm H_2O, lung-protective low tidal volume of 6–8 ml/kg, and pressure limit below 30 cm H_2O proved to be beneficial to obese patients [77]. Combined use of recruitment maneuvers and PEEP revealed better effects on intraoperative oxygenation and compliance compared with PEEP use alone during obesity surgery or in surgical obese patients. A meta-analysis reported that pressure-controlled ventilation and volume-controlled ventilation did not differ in terms of outcomes [78].

3.3. Induction and maintenance

All agents used in anesthesia may also be used in obese patients. However, obesity alters pharmacokinetic parameters depending on the lipid solubility and tissue distribution of the administered anesthetic agent. Nonadipose mass is also increased in obese patients. Drug dosages should be adjusted by considering volume of distribution for loading dose and by considering clearance for maintenance dose. Obese people may highly metabolize lipophilic agents compared to underweight people. Pharmacokinetic studies show that weakly or intermediately lipophilic drugs (e.g., vecuronium) are mainly distributed into nonadipose tissues and the dose needs to be calculated according to the ideal body weight. If the clearance is equal to or less than nonobese patients, the ideal body weight should be taken into account for maintenance dose. If the clearance is increased with obesity, then the total body weight should be considered for maintenance dose.

The ideal body weight is calculated as the sum of 49.9 and 0.89 kg for each cm above the height of 152.4 cm in men, and as the sum of 45.4 and 0.89 kg for each cm above the height of 152.4 cm in women. Agents partially distributed into the adipose tissue have variable pharmacokinetic characteristics; they usually have prolonged and unpredictable effects due to altered volume of distribution and clearance rates, respectively [79].

3.4. Induction agents

3.4.1. Thiopental sodium

Thiopental sodium, a frequently used agent for the induction of general anesthesia, is rapidly distributed to highly perfused organs such as brain, liver, lung, intestines, kidneys, heart, and pancreas after bolus administration into the plasma. Reduced plasma concentration and consequent loss of its effect after a short while depends on its rapid distribution to peripheral tissues. High lipophilicity of thiopental increases its volume of distribution and elimination half-life in obese patients. Due to uptake by fatty tissues, its plasma levels decrease within 10 min after induction and the agent is eliminated via liver. A clearance rate of the drug increases twofold in obese patients compared to patients with normal weight. It is reported that administration of the drug according to nonfat body weight is more reasonable for the purposes of induction anesthesia. Nevertheless, increased cardiac output leads to more rapid distribution of thiopental from its effective compartment into the plasma, hence causing an accelerated awaking in procedures where it is administered as single-dose bolus [5, 11].

3.4.2. Propofol

Although propofol has a high lipophilicity, dose adjustment should be performed according to the total body weight due to its high clearance [80]. Its high lipophilicity and rapid distribution from plasma into peripheral tissue render it as the currently most commonly used induction agent in morbidly obese patients. It could be used safely as total intravenous anesthetic drug. Its short-acting nature after single-dose bolus administration is explained by its redistribution from the compartment it acts on, into the plasma and peripheral tissues. As in thiopental sodium, cardiac output is also an important marker in achieving peak plasma concentrations of this agent. When administered as continuous infusion in obese patients, both its volume of distribution and clearance increases along with increased total body weight [53, 59].

3.4.3. Etomidate

Use of etomidate should be considered in patients with hemodynamic instability. Its use is contradictory due to increased incidence of end-organ dysfunction and in-hospital mortality secondary to adrenal suppressive effects in patients administered etomidate for anesthesia induction. Its induction dose should be adjusted by nonfat body weight due to similar pharmacokinetic and pharmacodynamic properties to propofol and thiopental [53, 59].

3.4.4. Opioids

Opioids were quite commonly used to control sympathetic response to tracheal intubation and surgical stress during induction and maintenance of the anesthesia. These agents effectively block the response to nociceptive stimulation in the perioperative period. Increased cardiac output and alteration in body composition (increased fatty tissue and nonfat body weight) in obese patients may change pharmacokinetic properties of the opioids. Administration of opioids leads to upper airway obstruction, central sleep apnea, obstructive sleep apnea, ataxic respiration, and hypoxemia [53, 59].

Fentanyl, one of the most frequently used opioids in anesthesia, has a significantly higher clearance in obese patients, which exhibits a nonlinear increase with the total body weight [53, 59]. As fentanyl, the onset of action of sufentanyl is 3–5 min. Although it has similar plasma clearance, its volume of distribution and elimination half-life is increased in obese patients compared to normal-weighed patients [53, 59, 81].

Alfentanyl, a derivative of fentanyl, has one-tenth of the potency than that of fentanyl. It is more lipophilic and has lower volume of distribution than that in fentanyl. Increased cardiac output decreases concentration of plasma alfentanyl during early distribution phase [53, 59, 81].

Remifentanyl is an ester opioid, which is rapidly metabolized by tissue and plasma esterases. Its administration by continuous infusion is widely adopted. Effects will terminate within 5–10 min after cessation of the infusion, which should be given adjusted to the ideal body weight. Administration of remifentanyl based on the total body weight in obese patients may cause some adverse effects such as bradycardia, hypotension, and muscle rigidity due to supratherapeutic plasma concentrations [53, 59, 81].

3.5. Inhalation agents

Release of inhalation agents is increased due to high solubility in lipids and excessive fat tissue. Furthermore, obese patients were reported to have slow recovery from anesthesia because of extended release of the inhalation agent from adipose tissue [81, 82]. In fact, this slow recovery not only originates from accumulation in adipose tissue but also from increased sensitivity in central nervous system secondary to decreased blood flow in adipose tissue. On the other hand, duration of recovery after procedures of 2–4 h was reported to be similar between obese and nonobese patients [83]. Recovery time after desflurane and sevoflurane, which have low lipid solubility, is also rapid in obese patients [84]. Torri et al. [85] compared obese and nonobese patients and reported that alveolar and inspiratory sevoflurane concentrations were not much changed, yet exhaling of sevoflurane from alveoli was slower in obese patients.

3.5.1. Isoflurane

Isoflurane is more lipophilic than sevoflurane and desflurane, therefore not commonly used in obese patients. Blood flow is decreased as long as the body weight increases. In clinical practice, impact of body mass index on uptake of isoflurane is not clinically relevant [59, 81].

3.5.2. Sevoflurane

Having low lipophilicity and solubility, sevoflurane is rapidly absorbed and eliminated compared to isoflurane [59, 81].

3.5.3. Desflurane

Desflurane, due to its limited distribution in adipose tissue and least lipophilicity and solubility among available inhalation agents, is recommended in obese patients. Nevertheless, the effect of BMI on the absorption of desflurane is not significant. Recovery and wakening from desflurane than that from isoflurane occur more rapidly in both obese and nonobese patients [59, 81].

3.6. Neuromuscular blockers

Neuromuscular blockers are polar and hydrophilic agents, so they have limited distribution in adipose tissue [86]. Except succinylcholine, administrating doses of neuromuscular blockers are usually calculated according to ideal body weight.

3.6.1. Succinylcholine

This neuromuscular blocker is a short-acting agent with a rapid onset of action. It may be preferred in obese patients in order to provide quick tracheal intubation. Pseudocholinesterase levels and extracellular fluid are elevated in obese patients, which determine the duration of action of succinylcholine and thereby warrant the need for dose adjustment with respect to the total body weight [87].

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3.6.2. Vecuronium

Vecuronium has a nondepolarizing aminosteroid structure and is mainly eliminated via the liver and gallbladder. Since its duration of action may be prolonged when its dose is calculated according to the total body weight, the dose should be adjusted according to the ideal body weight [88].

3.6.3. Rocuronium

Being a weakly lipophilic and quaternary ammonium neuromuscular blocker, it is highly ionized with a limited extracellular distribution. Induction dose of 1.2 mg/kg calculated according to the ideal body weight provides excellent intubation settings within 60 s. Administration dose should be adjusted according to the ideal body weight in order to avoid prolonged drug metabolism [59, 87].

3.7. Reversal of neuromuscular blocking agents

Obese patients have increased risk due to upper airway collapse and use of neuromuscular blockers. Therefore, neuromuscular block should be completely reversed before tracheal intubation. Doses of agents reversing neuromuscular blockers should be calculated according to the total body weight. Rapid and thorough reversal of neuromuscular block is particularly important for early restoration of lung functions during early postoperative period [89].

3.7.1. Neostigmine

A delayed time to antagonize neuromuscular block by neostigmine has been reported in obese patients. In the study of Suzuki et al. [90], the time elapsed to make train-of-four ratio as 0.9 increased fourfold than normal to antagonize vecuronium. Block should not be reversed by neostigmine under deep neuromuscular block. Recommended dose for neostigmine is 0.04–0.08 mg/kg, whose total dose should not exceed 5 mg [89, 90].

3.7.2. Sugammadex

A modified and most potent derivative of cyclodextrin, sugammadex binds to steroidal muscle relaxants with high affinity. Muscle relaxants are encapsulated within lipophilic cavity. Resultant inclusion complex is excreted through kidneys. Affinity of sugammadex to rocuronium is higher than to either pancuronium or vecuronium. It has no effect on acetylcholine, endogenous steroids, or other muscle relaxing agents. It is not recommended for use in severe renal impairment. In intermediate and deep block, dose calculation is inadequate if done according to the ideal body weight; therefore, the dose needs to be adjusted by the total body weight or ideal body weight plus 40% [89, 91].

3.8. Regional anesthesia

Regional anesthesia may be preferred to avoid potentially difficult airway control or postoperative respiratory complications. Detection of landmarks for central blocks or peripheral nerve blocks is especially very compelling in morbidly obese patients. Seventh cervical vertebra or gluteal fissure may be used to identify midline for central blocks. Distribution of the local anesthetics is hard to estimate due to lipid infiltration into epidural space and increased intraabdominal pressure, in which case 75–80% of normal local anesthetic dose may suffice. Regional block practices are regarded as more difficult in obese patients. In a study of 2020 supraclavicular block applications, success rate in obese patients was 94.3% compared with 97.3% in nonobese patients, which was significantly different [92]. The prospective study by Nielsen et al. [93] with over 9000 regional block procedures showed that the failure rate was 1.62 times higher in obese patients than in nonobese patients. Block procedures may be safely performed under the guidance of ultrasonography in obese patients [93, 94].

4. Postoperative care

Obesity is associated with some problems also during postoperative period. The steps of postoperative care of an obese patient should be carefully assessed before the surgery. Postoperative care should aim to prevent from respiratory dysfunction, hypothermia, hemodynamic instability, thromboembolism, nausea, vomiting, and pain [95, 96].

Monitoring should be continued in the recovery unit, while the patient is in sitting position or the head is upward at 45°. Oxygen support should be maintained until arterial oxygen saturation values return to preoperative levels or the patient becomes completely mobilized. In order to be discharged into the ward, the patient should meet routine criteria for leaving wakening room, no hypopnea or apnea period should occur, and preoperative arterial oxygen saturation values should be reached [96].

The prevalence of myocardial infarction is higher in this group compared to nonobese population. In addition, a new onset of atrial fibrillation may be seen during postoperative period. Close monitoring of these patients should be continued also after the surgery [97, 98].

Although being rare, rhabdomyolysis is a fatal complication in this patient population. Predisposing factors include hypotension, dehydration, immobility, and prolonged surgical interventions. In particular, pain in deep tissues of gluteal region should signal rhabdomyolysis. Creatine kinase levels are elevated in such patients [99].

Obesity is a risk factor for thromboembolism, where prophylaxis is recommended in all surgical interventions, except minor surgery. While oral agents such as rivaroxaban and dabigatran are not recommended for obese patients, low-molecular-weight heparin is recommended for prophylactic purposes [96, 100].

The incidence of postoperative nausea-vomiting is not increased in obese patients, albeit a contradictory issue [101].

An effective postoperative pain management is important to prevent pulmonary complications and provides sufficient respiratory depth. Pain management through intramuscular route is not recommended in obese patients. Opioid-induced upper airway obstruction and respiratory depression are more likely to be seen in obese patients with obstructive sleep apnea. When deciding postoperative analgesia in obese patients, selecting a multimodal analgesia method rather than a unimodal method will provide more effective pain control and avoidance of potential complications [95, 96, 102].

4.1. Intensive care

Obesity was found to be associated with increased need for mechanical ventilation and longer duration of stay with tracheostomy and at intensive care unit. No increase in mortality was shown.

For mechanical ventilation, 5–7 ml/kg of tidal volume calculated according to the ideal body weight is recommended as well as maintaining a peak inspiratory pressure below 35 cm/H_2O [76, 103].

If the obese patient is hemodynamically stable and gastrointestinal system is functional, enteral route is preferred over parenteral route for nutrition. Guideline of Society of Critical Care Medicine and American Society for Parental and Enteral Nutrition reports that hypocaloric nutrition support preserves nitrogen balance and decreases morbidity in obese patients [104].

"Obesity paradox" is defined as the better prognosis of obese patients after acute cardiovascular decompensation despite the established role of the obesity for developing of cardiovascular diseases. Nevertheless, the effects of obesity on critical illness, death, or long-term outcomes are conflicting [105].

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