REVIEW ARTICLE

Anesthetic Considerations for Bariatric Surgery

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According to the National Institutes of Health, obesity is a major health problem with clearly established health implications, including an increased risk for coronary artery disease, hypertension, dyslipidemia, diabetes mellitus, gallbladder disease, degenerative joint disease, obstructive sleep apnea, and socioeconomic and psychosocial impairment (1). The risk of developing one or more of these obesity-related conditions is based on body mass index (BMI), with 25–30 kg/m^2 being low risk and >40 kg/m^2 being very high risk (2). The prevalence of obesity in the 18- to 29-yr-old group increased from 12% in 1991 to 18.9% in 1999 (3).

Bariatric surgery encompasses a variety of surgical weight loss procedures used to treat morbid obesity. Obesity is clinically expressed in terms of BMI or Quetelet's index (4), which is derived by dividing weight by the square of height to estimate the degree of obesity. Thus, BMI = body weight (kg)/height^2 (m^2). Morbid obesity is a BMI more than 35 kg/m^2, and super morbid obesity is BMI more than 55 kg/m^2.

The indications for surgical treatment of severe obesity, as outlined in the 1991 National Institutes of Health Consensus Development Conference Panel, include an absolute BMI more than 40 kg/m^2 or BMI more than 35 kg/m^2 in combination with life-threatening cardiopulmonary problems or severe diabetes mellitus (1).

Patients seeking surgical weight loss must have proven attempts at medically supervised weight loss. Documentation of loss of <5% to 10% excess body weight or weight gain after at least 6 mo of diet modification, exercise, and medical therapy or nonimprovement in comorbid conditions during this period indicates failure. Studies have shown that weight loss of 5%–10% of initial body weight improves glucose intolerance and Type II diabetes, hypertension, and dyslipidemia (5–7).

The average expenditure is approximately $7000 per year per patient on weight loss programs and equipment. Unfortunately, long-term weight loss is the exception, and most patients regain weight, sometimes more than they initially lost.

Surgical Treatment of Obesity

Surgical approaches designed to treat obesity can be classified as malabsorptive or restrictive (8,9). Malabsorptive procedures, which include jejuno-ileal bypass and biliopancreatic bypass, are rarely used at present. Restrictive procedures include the vertical banded gastroplasty (VBG) and gastric banding, including adjustable gastric banding (AGB). RYGB, the "gold standard" of bariatric operations, combines gastric restriction with a minimal degree of malabsorption. VBG, AGB, and RYGB can all be performed laparoscopically (10,11).

At our institution, laparoscopic Roux-en-Y gastric bypass (RYGB) is routinely performed on patients weighing <160 kg without other contraindications to laparoscopy, including uncorrected coagulopathy and inability to tolerate laparotomy. Technical considerations and instrumentation technology currently make laparoscopic bariatric surgery difficult in patients weighing >180 kg (8,12).

Gastric restriction, or gastroplasty, separates the stomach into a small upper pouch (15–30 mL), which restricts food intake. This pouch communicates with the remainder of the stomach through a narrow channel, or stoma.

RYGB (Fig. 1), the most commonly performed bariatric procedure in the United States, involves anastomosing the proximal gastric pouch to a segment of the proximal jejunum, bypassing most of the stomach and the entire duodenum. It is the most effective bariatric procedure to produce safe short-term and long-term weight loss in severely obese patients (13). With RYGB, patients lose an average of 50%–60% of excess

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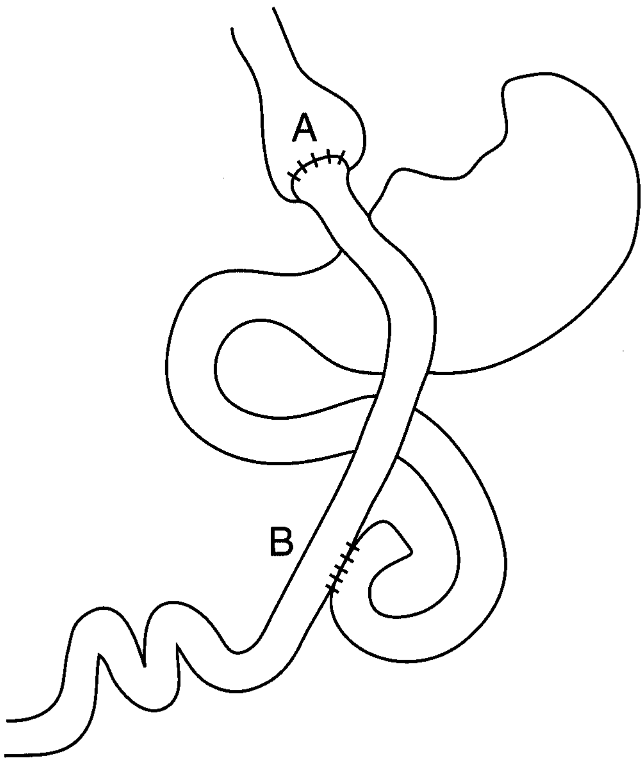

Figure 1. Roux-en-Y gastric bypass. A, A 15- to 30-mL gastric pouch with connected jejunal limb. B, Site of jejuno-jejunostomy.

body weight and show a decrease in BMI of approximately 10 kg/m^2 during the first 12 to 24 postoperative months. To the health care provider, the effect of weight loss on associated weight-related comorbidity is more important than absolute weight loss. Studies have shown that Type II diabetes resolves in up to 90% of patients (14).

The variables used to measure surgical outcome include operative time, length of skin incision, estimated blood loss, number of patients requiring intensive care unit stay, length of hospital stay, early and late (>30 days) complications, early (<30 days) reoperation, and weight loss. Using these variables, Nguyen et al. (15) found that, with the exception of length of operative time, laparoscopic RYGB was generally associated with better outcomes and cost-effectiveness than open RYGB. The rate of anastomotic leakage is also slightly more frequent with the laparoscopic approach (8), but it becomes comparable once the learning curve has been mastered (approximately 70 cases) (16). Other advantages of the laparoscopic procedure include reduced hospital stay, more rapid return to normal activity, improved cosmesis, and a marked reduction in the incidence of incisional hernia and wound infection (8,15). There are also smaller postoperative pain medication requirements, less pain intensity during mobilization, and improved pulmonary function.

Complications after RYGB include anastomotic leak, gastric pouch outlet obstruction, jejunostomy obstruction, deep vein thrombosis (DVT), pulmonary embolism (PE), respiratory failure, gastrointestinal (GI) bleeding, and wound infection. Late complications include prolonged nausea and vomiting, cholelithiasis, ventral hernia, anemia, and protein-calorie malnutrition. Nguyen et al. (15) discovered, in a prospective, randomized study, that these complications are more common after open RYGB than after laparoscopic RYGB, except for late anastomotic stricture, which was significantly more common after the laparoscopic approach. The more frequent leak rate with laparoscopic RYGB was thought to be related to the learning curve.

RYGB induces an undesirable "dumping syndrome" if the patient ingests a high-sugar liquid meal (17), with potential side effects of iron and vitamin B_{12} malabsorption. Dumping syndrome consists of early postprandial abdominal and vasomotor symptoms resulting from fluid shifts and release of vasoactive neurotransmitters (the pathophysiology of which is peripheral) and splanchnic vasodilation, coupled with a relative hypovolemia, leading to diarrhea and abdominal cramps. It occurs in approximately 10% of patients postgastric bypass surgery. Late dumping symptoms are due to reactive hypoglycemia, which results from an exaggerated insulin and glucagon-like peptide 1 release. Symptoms can be relieved with dietary modifications to minimize the ingestion of simple carbohydrates and to exclude fluid intake during ingestion of the solid portion of the meal. Severe cases may respond to agents such as pectin and guar (plant polysaccharide bulking agents that increase the viscosity of intraluminal contents) or to acarbose, an α-glucosidase inhibitor that blunts the rapid absorption of glucose (18,19). Octreotide, a somatostatin analog that alters gut transit and impairs the release of vasoactive mediators, may also be useful in patients refractory to all other therapy (18). It acts through its inhibitory effects on insulin and gut hormone release, a delay of intestinal transit time, and inhibition of food-induced circulatory changes (19).

The AGB (Fig. 2), recently approved by the Food and Drug Administration for use in the United States, is the newest gastric restrictive operation and is usually placed by a minimally invasive laparoscopic approach. It consists of an adjustable inflatable band placed around the proximal stomach to limit oral intake (8). It is a less dynamic operation than RYGB and has a learning curve of 30 operations. Up to 50% ± 28% average excess weight loss has been reported with AGB at 2-yr follow-up, with a complication rate of 19% and a mortality rate of 0.4% (20,21). Band erosion and erosive esophagitis were reported by Westling et al. (22) to be the most common complications requiring repeat surgery over 3

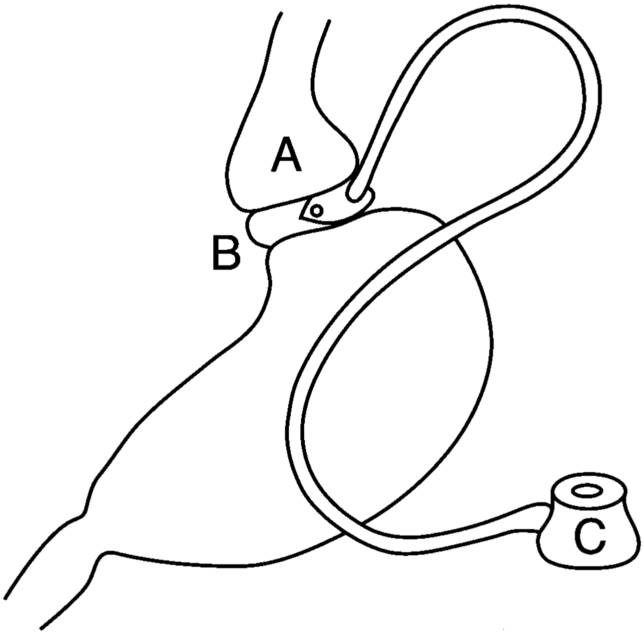

Figure 2. Adjustable gastric banding. A, Proximal pouch. B, Adjustable band. C, Needle access port through which saline is injected or removed to vary the size of the adjustable band.

yr. Other complications include herniation of the stomach upward inside of the band and band migration from overfilling (23). In a series of 250 laparoscopic AGB patients by Nehoda et al. (24), the most significant complications were early pouch dilations occurring in the first week; however, the most common complications were disconnections at the portal site between the tube and reservoir. Specific contraindications to AGB include inflammatory diseases of the GI tract (such as severe esophagitis, gastric or duodenal ulcers, or specific inflammation, such as Crohn's disease), upper GI bleeding (such as esophageal or gastric varices), portal hypertension, congenital or acquired anomalies of the GI tract (e.g., atresias or stenoses), intraoperative gastric injury (e.g., gastric perforation at or near the location of the intended band placement), liver cirrhosis, chronic pancreatitis, and allergy to the materials used to make the band.

Medical Therapy for Obesity

Approved indications for drug treatment include a BMI of ≥30 kg/m^2 or a BMI from 27 and 29.9 kg/m^2 in conjunction with an obesity-related medical complication. The combination of phentermine and fenfluramine (Phen-Fen) was the most popular treatment for obesity until it became associated with valvular heart disease and pulmonary hypertension. As a result of this, Phen-Fen is no longer approved by the Food and Drug Administration and should never be used for this purpose.

Sibutramine and orlistat are newer antiobesity medications approved for long-term use. Sibutramine inhibits the reuptake of norepinephrine, serotonin, and dopamine, thereby causing anorexia. These mechanisms act synergistically to increase satiety after the onset of eating rather than reduce appetite (25). It does not promote the release of serotonin, unlike fenfluramine and dexfenfluramine, which primarily increase the release of serotonin in brain synapses and also inhibit the reuptake, thereby causing anorexia (26). These differences in mechanisms of action may explain why there have been no reports thus far of sibutramine causing cardiac valvular lesions. Because sibutramine does not deplete the neural synapses of catecholamines, dangerous hypotension unresponsive to indirectly acting vasopressors (seen with fenfluramine and dexfenfluramine) does not generally occur (27).

The most frequent adverse effects of sibutramine treatment include dry mouth, insomnia, anorexia, and constipation (28). Sibutramine also causes transient dose-related increases in both systolic and diastolic blood pressure by a mean of 2–4 mm Hg and induces a small increase in heart rate of 3–5 bpm (29). Although blood pressure decreases with weight loss, this stimulatory effect on blood pressure remains detectable as long as sibutramine is taken. A randomized, controlled trial (30) showed that 13% of those treated with sibutramine, compared with 4% of those treated with placebo, lost ≥10% of their initial weight. Sibutramine results in peak weight loss after approximately 6 mo that is maintained for at least 1 yr (30,31).

Orlistat is a synthetic derivative of a product from *Streptomyces toxytricini* that inhibits mammalian lipase (32). It blocks digestion and absorption of dietary fat by binding lipases in the GI tract. Serum low-density lipoprotein cholesterol concentrations decrease in addition to the weight loss (33). GI complaints induced by fat malabsorption are the most common. A decrease in serum concentration of fat-soluble vitamins (A, D, E, and K) has been observed in approximately 5%–15% of patients (33–35). Some trials with orlistat achieved an average weight loss of 9% compared with 5% in the placebo group at the end of 1 yr (33–35). In isolated cases, orlistat has been blamed as a causative factor of aggravated hypertension in previously treated hypertensive and normotensive patients, but a cause-effect relationship has not been definitely proven (36–38). Warfarin's anticoagulant effect may increase because orlistat decreases the absorption of vitamin K (39). Both orlistat and sibutramine induce ≥5% to 10% weight reduction, with maintenance for up to 2 yr (40).

There is a paucity of studies and literature on direct interactions between sibutramine or orlistat and anesthesia medications. However, anesthesiologists should be aware of the side effects of these drugs and their effects on body systems and tailor their anesthesia accordingly.

Metabolism/Elimination

Histological and liver function test abnormalities are relatively common in the obese, but clearance is usually not reduced. Up to 90% of morbidly obese patients show histological abnormalities of the liver, with one-third of them having fatty change involving more than 50% of hepatocytes (41).

In a prospective study of 127 consecutive morbidly obese patients presenting for bariatric surgery, 75% had histological evidence of hepatic steatosis, which was severe and diffuse in 20% (42). Twenty to thirty percent of obese patients without evidence of concomitant liver disease have increased liver function tests. Increased alanine aminotransferase (ALT) is the most frequent hepatic abnormality in the obese population. For every 1% reduction in body weight, ALT activity improves by 8.1% (43). In a study of 198 patients awaiting gastric banding (44), 18.7% had increased liver enzymes. ALT increased by 14.1%, aspartate aminotransferase by 9.6%, and γ-glutamyl transpeptidase by 6.6% before surgery. ALT and aspartate aminotransferase returned to normal after surgery in all the patients in direct proportion to the extent of weight reduction after gastric banding. Palmer and Schaffner (43) showed that in overweight adults without primary liver disease, a weight reduction of $\geq$10% corrected abnormal hepatic test results, decreased hepatomegaly, and resolved some stigmata of liver disease. More recently (45), 75 morbidly obese patients who had intraoperative liver biopsies at the time of RYGB had an 84% rate of hepatic steatosis, with only approximately 20% having moderate to severe inflammation and fibrosis. Despite these histologic and enzymatic changes, no clear correlation has been found between routine liver function tests and the capacity of the liver to metabolize drugs (46).

Renal clearance of drugs is increased in obesity because of increased renal blood flow and glomerular filtration rate (GFR) (47). Ribstein et al. (48) assessed the influence of obesity on renal function and urinary albumin excretion in normotensive and hypertensive subjects and found that the GFR and effective renal plasma flow were increased in overweight compared with lean subjects irrespective of the presence of hypertension. Brochner-Mortensen et al. (49) documented up to a 40% increase in GFR in obese patients; this may be an important contributing factor to proteinuria, the most cited renal abnormality in these patients (50). Other studies (51–53) have also independently shown increases in measured GFR in obese compared with normal-weight subjects.

Preoperative Considerations

Preoperative Evaluation

Attention should focus on issues unique to the obese patient, particularly cardiorespiratory status and the airway. Patients presenting for bariatric surgery should be evaluated for systemic hypertension, pulmonary hypertension, signs of right and/or left ventricular failure, and ischemic heart disease. Signs of cardiac failure—such as increased jugular venous pressure, added heart sounds, pulmonary crackles, hepatomegaly, and peripheral edema—may be difficult to detect.

The most common symptoms of pulmonary hypertension include exertional dyspnea, fatigue, and syncope, which reflect an inability to increase cardiac output during activity (54). Identification of tricuspid regurgitation with echocardiography is the most useful confirmation of pulmonary hypertension (55). An electrocardiogram may demonstrate signs of right ventricular hypertrophy, such as tall precordial R waves, right axis deviation, and right ventricular strain. The higher the pulmonary artery (PA) pressure, the more sensitive the electrocardiogram (56). Chest radiograph may show evidence of underlying lung disease and evidence of prominent pulmonary arteries (56). Mild to moderate pulmonary hypertension warrants avoidance of hypoxemia, nitrous oxide, and other drugs that may further worsen pulmonary vasoconstriction. Inhaled anesthetics may be beneficial because they cause bronchodilation and decrease hypoxic pulmonary vasoconstriction (57). With severe pulmonary hypertension, PA catheterization and monitoring may be necessary.

Peripheral and central venous access and arterial cannulation sites should be evaluated during the preoperative examination, and the possibility of invasive monitoring should be discussed with the patient. Baseline arterial blood gas measurements will help evaluate carbon dioxide retention and provide guidelines for perioperative oxygen administration and possible institution of and weaning from postoperative ventilation.

Patients scheduled for repeat bariatric surgery may confront the anesthesiologist days, months, or years after the initial surgery, so the anesthesiologist should be familiar with possible metabolic changes in these patients. Common long-term nutritional abnormalities include vitamin B_{12}, iron, calcium, and folate deficiencies. Vitamin deficiency is uncommon in patients compliant with daily vitamin supplements, especially in patients followed up with regular postoperative visits. With rapid weight loss, patients may also be protein depleted. Electrolyte and coagulation indices should be checked before surgery, particularly if patient compliance has been poor or if the patient is acutely ill.

Chronic vitamin K deficiency can lead to an abnormal prothrombin time with a normal partial thromboplastin time because of deficiency of clotting factors II, VII, IX, and X (58). For elective surgery, the administration of a vitamin K analog, such as phytonadione, can be used to correct the coagulopathy within 6–24 h. Fresh frozen plasma will be required for emergency surgery or active bleeding (59).

Concurrent and Preoperative Medications

It is recommended that the patient's usual medications, except insulin and oral hypoglycemics, be continued until the time of surgery. Antibiotic prophylaxis is important because of increased risk of postoperative wound infection. Published rates of wound infection after gastric operations for obesity are approximately 5% (60), and rates after clean contaminated GI surgery are 2%–3% (61). A metaanalysis of open bariatric surgery quoted the infection rate of restrictive procedures (VBG, silastic ring vertical gastroplasty, and AGB) as 3%–11%, whereas that of combination procedures (RYGB and extended RYGB) was 5.27% (62). Other authors have quoted wound infection rates of 11.7%–15.8% after open gastric bypass (63,64). In a prospective, randomized study, Nguyen et al. (15) found that open RYGB had an approximately 10 times more frequent incidence of wound infection (10.5% versus 1.3%) when compared with the laparoscopic approach. The increased incidence of wound infection is due to longer incisions, generally longer operative times because of obesity, tissue trauma from excessive traction, difficulty in dead-space obliteration, and inability of adipose tissue to resist infection (65). Antibiotic prophylaxis is, however, also recommended by many practitioners for the laparoscopic approach.

Anxiolysis, analgesia, and prophylaxis against both aspiration pneumonitis and DVT should be addressed during premedication. Oral benzodiazepines are reliable for anxiolysis and sedation because they cause little or no respiratory depression. IV midazolam can also be titrated in small doses for anxiolysis during the immediate preoperative period. Pharmacologic intervention with H_2-receptor antagonists (e.g., cimetidine, ranitidine, famotidine) and nonparticulate antacids (e.g., sodium bicitrate) and proton pump inhibitors (e.g., omeprazole, lansoprazole, rabeprazole) will reduce gastric volume, acidity, or both, thereby reducing the risk and complications of aspiration.

Morbid obesity is a major independent risk factor for sudden death from acute postoperative PE (66,67). Heparin, 5000 IU subcutaneously, administered before surgery and repeated every 12 h until the patient was fully mobile, reduced the risk of DVT (68). Recently, low molecular weight heparins (LMWH) have gained popularity in thromboembolism prophylaxis because of their bioavailability when injected subcutaneously (69). Two recent studies examined two different doses of two different types of LMWH for use in the prophylaxis of DVT in patients undergoing bariatric surgery. Scholten et al. (70) found that 40 mg every 12 h rather than 30 mg every 12 h of enoxaparin resulted in a decreased incidence of postoperative DVT complications without an increase in bleeding complications. In the second study, Kalfarentzos et al. (71) evaluated two different doses of nadroparin (5700 IU versus 9500 IU) for DVT prophylaxis in patients undergoing RYGB and found that the smaller dose (5700 IU) given once daily is safe and well tolerated and has equal thromboembolism prophylaxis as the larger dose (9500 IU) in high-risk patients. Nadroparin is currently not commercially available in the United States. Studies have shown that unfractionated heparin 5000 IU given subcutaneously three times daily is equivalent to the LMWH enoxaparin given once daily for thromboprophylaxis (72). In a survey of members of the American Society for Bariatric Surgery regarding their current practices for thromboprophylaxis (73), small-dose heparin, 5000 U every 8–12 h, was the most preferred method (50% of members), followed by pneumatic compression stockings (33%), LMWH (13%), and other methods (4%). In combination with subcutaneous heparin, we favor placement of pneumatic compression devices on the feet because knee- or thigh-length devices tend to slip and fall off.

Intraoperative Considerations

Positioning

Specially designed tables or two regular tables joined together may be required for safe anesthesia for bariatric surgery. Regular operating room tables have a maximum weight limit of approximately 205 kg, but operating tables capable of holding up to 455 kg, with a little extra width to accommodate the extra girth, are available. Electrically operated or motorized tables facilitate maneuvering into various surgically favorable positions. Bariatric surgical patients are prone to slipping off the operating table during table position changes; therefore, they should be well strapped to the operating table. The use of a bean bag is also recommended. Bean bags (Vac-Pac®; Olympic Medical, Seattle, WA) are soft pads available in various sizes and shapes that are filled with thousands of tiny plastic beads (74). The patient is positioned on the bean bag, which is then molded around the patient, and a suction line is attached to it, creating a vacuum inside the bean bag which allows outside atmospheric pressure to force the beads together so they cannot move. It is worthwhile to note that all materials used to manufacture Vac-Pac® are latex free.

Particular care should be paid to protecting pressure areas, because pressure sores and neural injuries are more common in this group, especially in the super obese and the diabetic. Brachial plexus and sciatic nerve palsies have been reported (75). Stretch injuries may be caused by extreme abduction of the arms, thereby stretching the lower roots of the brachial plexus. The upper roots are most likely stretched by excessive rotation of the head to the opposite side (76). Sciatic nerve palsy may be caused by prolonged ischemic pressure from tilting the table sideways. Lateral femoral cutaneous nerve injury may occur if the lower limb falls and hangs freely. Ulnar neuropathy has been associated with increased BMI. A retrospective study by Warner et al. (77) documented such an association because 29% of patients with ulnar neuropathy in their series had a BMI $\geq$38 kg/m^2, compared with only 1% of the control subjects. The extent and degree to which a nerve is injured should be well documented so that recovery and prognosis can be discussed with the patient. Electromyography and nerve conduction studies provide valuable clinical information in this respect. A mild degree of reversible neural insult that results in impulse conduction failure across the affected segment is termed *neuropraxia* (76). It is a focal conduction block from local myelin injury of primarily larger fibers, with recovery expected within weeks to months. Axonotmesis describes physical disruption of only the axon, with preservation of endoneurial and other connective tissue structures. There is loss of nerve conduction at the injury site and distally, with disruption of axonal continuity and Wallerian degeneration. Recovery of function depends on the time for the process of Wallerian degeneration and neural regeneration to occur. Prognosis is good because the original end organs are reached (76). Neurotmesis implies complete severance of the nerve, with complete disruption of all supporting connective tissue structures. It carries a poor prognosis for complete functional recovery (76). Gradings of this type help with the discussion of prognosis with patient and family. Despite careful positioning and appropriate padding, nerve injury may still occur in this at-risk population. Fortunately, most resolve with time.

Laparoscopy and Anesthesia

Pneumoperitoneum causes systemic changes during laparoscopy. The gas most often used for this purpose is carbon dioxide. Positioning, such as Trendelenburg, can worsen the systemic changes of pneumoperitoneum (78).

Systemic vascular resistance is increased with increased intraabdominal pressure (IAP). The degree of IAP determines its effects on venous return and myocardial performance (79). There is a biphasic cardiovascular response to increases in IAP. At an IAP $<$10 mm Hg, there is an increase in venous return, probably from a reduction in splanchnic sequestration of blood, with a subsequent increase in cardiac output and arterial pressure. Hypovolemia, however, blunts this response (80). Compression of the inferior vena cava occurs at an IAP $>$20 mm Hg, with decreased venous return from the lower body and consequent decreased cardiac output (79). Increased renal vascular resistance at an IAP $>$20 mm Hg decreases renal blood flow and GFR (81). Femoral venous blood flow can be reduced by both pneumoperitoneum and Trendelenburg positioning, with an increased risk of lower-extremity thrombosis (82). Abdominal viscera further exert weight on the diaphragm during Trendelenburg positioning, causing a reduction in vital capacity, and placement of surgical packs and retractors in the upper abdomen may worsen the situation (83). Sprung et al. (84) studied the effect of morbid obesity, 20 mm Hg pneumoperitoneum, and body posture (30° head down and 30° head up) on respiratory mechanics, oxygenation, and ventilation during laparoscopy. In contrast however, they did not find body position to have any significant effect on respiratory mechanics during laparoscopy. They reported that, whereas arterial oxygen tension was adversely affected only by increased body weight, respiratory mechanics were affected by both obesity and pneumoperitoneum but varied little with body position. We have witnessed situations in which cephalad displacement of the diaphragm and carina from pneumoperitoneum caused a firmly secured endotracheal tube to be displaced into a bronchial mainstem. Hypercarbia and hypoxemia may be caused by ventilation-perfusion mismatch because of restriction of diaphragmatic mobility from pneumoperitoneum that leads to uneven distribution of ventilation to the nondependent part of the lung. Absorption of carbon dioxide can worsen hypercarbia and acidosis, which can be offset by hyperventilation. Catastrophic complications that should be kept in mind include massive gas embolism, pneumothorax, and mediastinal emphysema.

Monitoring

Invasive arterial monitoring should be used for the super morbidly obese with severe cardiopulmonary disease and for those with poor fit of the noninvasive blood pressure cuff because of severe conical shape of the upper arms or unavailability of appropriately sized cuffs. Blood pressure measurements can be falsely increased if a cuff too small for the arm is used (85). Cuffs with bladders that encircle a minimum of 75% of the upper arm circumference or, preferably, the entire arm, should be used (86). Comparable and accurate blood pressure readings can be obtained from the wrist (87) or ankle (88) with appropriately sized blood pressure cuffs in situations in which difficulty occurs with upper-arm noninvasive blood pressure measurement. We use central venous catheters in cases in which peripheral IV access cannot be obtained, whereas PA catheters are reserved for serious cardiopulmonary disease. Another strong indication for central venous catheterization is postoperative IV access, which can be problematic in this patient population and is probably more easily performed in the anesthetized patient.

Induction, Intubation, and Maintenance of Anesthesia

Preparation should be made for the possibility of a difficult intubation, and a surgeon familiar with surgical airways should be readily available. A towel or folded blankets under the shoulders and head can compensate for an exaggerated flexed position from posterior cervical fat (89). The object of this maneuver, known as "stacking," is to position the patient so that the tip of the chin is at a higher level than the chest, to facilitate laryngoscopy and intubation. Brodsky et al. (90) used a logistic regression model to quantify the relationship between the ease of intubation and patient characteristics. They predicted that odds of a problematic intubation in a particular patient with a neck circumference 1 cm larger than that of another patient are 1.13 times the odds of the patient with a 1-cm-smaller neck circumference. Therefore, the probability of a problematic intubation was approximately 5% with a 40-cm neck circumference, compared with a 35% probability at 60-cm neck circumference. This model identified neck circumference as the single best predictor of problematic intubation.

Pharmacology/Weight-Based Dosing

Highly lipophilic substances (Table 1) (91–102), such as barbiturates and benzodiazepines, show significant increases in volume of distribution (VD) for obese individuals relative to normal-weight individuals (91,103,104). Less-lipophilic compounds have little or no change in VD with obesity. Certain exceptions to this rule include digoxin (105), procainamide (106), and remifentanil (101), which are highly lipophilic drugs but which have no systematic relationship between their degree of lipophilicity and their distribution in obese individuals. Consequently, their absolute VD remains relatively consistent between obese and normal-weight individuals, and their doses should be calculated on the basis of ideal body weight (101,105,106).

Drugs with weak or moderate lipophilicity can be dosed on the basis of ideal body weight (IBW) or, more accurately, lean body mass (LBM). These values are not identical, because 20%–40% of an obese patient's increase in total body weight can be attributed to an increase in LBM. Adding 20% to the estimated IBW dose of hydrophilic medications is sufficient to include the extra lean mass. Nondepolarizing muscle relaxants can be dosed in this manner. The majority of anesthetic drugs are strongly lipophilic. Increased VD is expected for lipophilic substances, but this is not consistently demonstrated in pharmacological studies because of factors such as end-organ clearance or protein binding.

Desflurane has been suggested as the inhaled anesthetic of choice in this patient population because of its more rapid and consistent recovery profile (108). Two different studies (109,110) compared sevoflurane with isoflurane for use during bariatric surgery and favored sevoflurane because of its more rapid recovery, good hemodynamic control, infrequent incidence of nausea and vomiting, prompt regaining of psychological and physical functioning, early discharge from the hospital, and small cost. Rapid elimination and analgesic properties make nitrous oxide a good inhaled choice during bariatric surgery, but high oxygen demand in the obese limits its use. Obesity increases oxygen consumption and carbon dioxide production (111). This is due to excess metabolically active tissue and an increased workload on muscles and other supportive tissue. DeDivitiis et al. (112) performed left and right heart catheterization in 10 morbidly obese but otherwise healthy individuals and noted that the mean oxygen consumption was increased by up to 25% and increased linearly with increasing body weight. The arteriovenous oxygen difference was normal, however, suggesting that cardiac output increases primarily to serve the metabolic requirements of excess fat (113).

Complete muscular relaxation is crucial during laparoscopic bariatric procedures to facilitate ventilation and to maintain an adequate working space for visualization and safe manipulation of laparoscopic instruments. Complete relaxation also facilitates the introduction of surgical equipment and extraction of excised tissues. Collapse of pneumoperitoneum may be an early indication that muscle relaxation is inadequate, because muscle tone competes with the pressure limit set for the pneumoperitoneum. Tightening of the musculature around the surgeon's finger palpating the port site may also be a sign of inadequate paralysis.

Combined epidural and general balanced anesthesia has been advocated to allow better titration of anesthetic drugs, use of a larger oxygen concentration, and optimal muscle relaxation for upper abdominal surgery in the obese (114). This does not reflect current practice, because most bariatric procedures are performed under a minimally invasive laparoscopic approach, with less depression of postoperative pulmonary function, decreased pain, improved oxygenation, and less atelectasis when compared with laparotomy

Table 1. Weight-Based Dosing of Common IV Anesthetics (91–102)

Drug	Dosing	Comments
Propofol	IBW Maintenance: TBW	Systemic clearance and V_D at steady-state correlates well with TBW (92). High affinity for excess fat and other well perfused organs. High hepatic extraction and conjugation relates to TBW.
Thiopental	TBW	Increased V_D. Increased blood volume, cardiac output, and muscle mass (91). Increased absolute dose. Prolonged duration of action (93).
Midazolam	TBW	Central V_D increases in line with body weight. Increased absolute dose. Prolonged sedation because larger initial doses are needed to achieve adequate serum concentrations (93, 94).
Succinylcholine	TBW	Plasma cholinesterase activity increases in proportion to body weight. Increased absolute dose (93).
Vecuronium	IBW	Recovery may be delayed if given according to TBW because of increased V_D and impaired hepatic clearance (93, 95).
Rocuronium	IBW	Faster onset and longer duration of action. Pharmacokinetics and pharmacodynamics are not altered in obese subjects (96, 97).
Atracurium Cisatracurium	TBW	Absolute clearance, V_D, and elimination half-life do not change. Unchanged dose per unit body weight without prolongation of recovery because of organ- independent elimination (98, 99).
Fentanyl Sufentanil	TBW TBW Maintenance: IBW	Increased V_D and elimination half-time, which correlates positively with the degree of obesity (100). Distributes as extensively in excess body mass as in lean tissues. Dose should account for total body mass.
Remifentanil	IBW	Systemic clearance and V_D corrected per kilogram of TBW—significantly smaller in the obese. Pharmacokinetics are similar in obese and nonobese patients (101). Age and lean body mass should be considered for dosing (102).

IBW = Ideal body weight; TBW = Total body weight; V_D = volume of distribution.

(115). With the introduction of easily titratable drugs such as remifentanil, propofol, and desflurane, decreased intraoperative dosing is not generally required for prompt emergence. Michaloudis et al. (116) described a technique of continuous spinal anesthesia combined with general anesthesia for intraoperative anesthetic management and postoperative analgesia in 27 obese patients undergoing laparotomy for gastroplasty. They found this technique to be safe during surgery and effective for postoperative analgesia.

Tidal volumes of up to 15–20 mL/kg have been recommended as one method to improve functional residual capacity (FRC) in the anesthetized obese patient (117). This has not been shown to improve oxygenation significantly, even though FRC may be increased above closing volume. Bardoczky et al. (118) evaluated the effects of large tidal volume ventilation on oxygenation and ventilation in morbidly obese patients during anesthesia and found that increasing tidal volumes up to 22 mL/kg increased the peak inspiratory airway pressure, end-expiratory (plateau) airway pressure, and compliance of the lungs without significantly improving arterial oxygen tension, but it resulted in severe hypocapnia. They concluded that tidal volumes >13 mL/kg IBW offer no added advantage during ventilation of morbidly obese patients during anesthesia. Also, in light of evidence that the lung can be injured by excessive expansion (volutrauma) from large tidal volumes leading to pulmonary edema and that positive end-expiratory pressure (PEEP) actually reduced lung water content in this type of edema (119), it seems prudent to use moderate levels of PEEP (enough to preserve hemodynamic stability) rather than large tidal volumes in an attempt to improve oxygenation. We routinely use tidal volumes of 10–12 mL/kg to avoid barotrauma and respiratory rates of up to 12–14 breaths/minute to maintain normocapnia during laparoscopic bariatric surgery with carbon dioxide abdominal inflation. We have also successfully used pressure control ventilation with vigilant monitoring of exhaled tidal volumes to achieve adequate oxygenation and normocapnia.

We have found that intraoperative fluid requirements are usually larger if postoperative acute tubular necrosis is to be prevented. Patients usually require up to 4–5 L of crystalloid for an average 2-h operation. This adds up to twice the calculated maintenance fluid requirement plus the calculated deficit based on a 12-h fasting period for an average 70-kg patient for the first hour by using the 4-2-1 formula (4 $mL \cdot kg^{-1} \cdot h^{-1}$ for the first 10 kg; 2 $mL \cdot kg^{-1} \cdot h^{-1}$ for the next 10 kg; then 1 $mL \cdot kg^{-1} \cdot h^{-1}$ for every kilogram thereafter). The next hour usually requires the same amount of crystalloid, after which the amounts are reduced to approximately twice the calculated maintenance requirement, based on LBM, for the next 12 h (200 mL/h overnight).

Other Technical Issues

Anesthesiologists help facilitate proper placement of an intragastric balloon and nasogastric (NG) tube during surgery to help the surgeon size the gastric pouch.

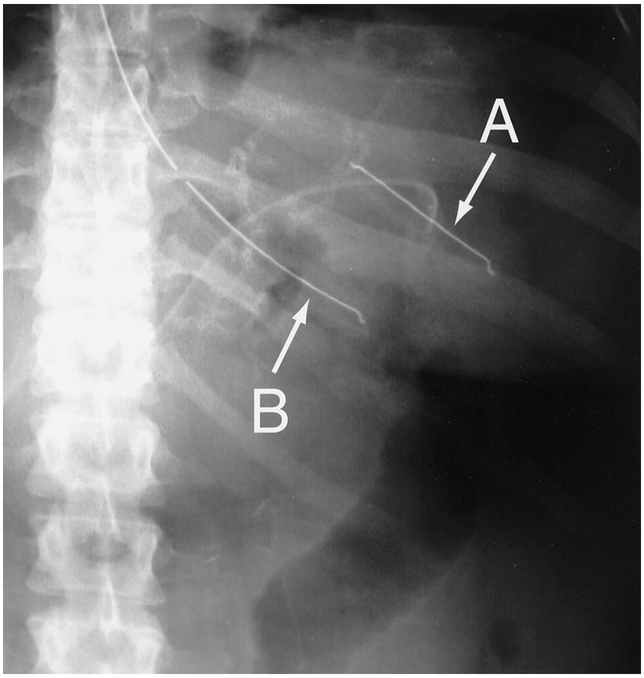

Figure 3. Radiograph of postoperative Day 1 Gastrografin swallow. A, Transected end of the nasogastric (NG) tube left in the gastric remnant. B, New properly placed NG tube replacing the transected one.

They also help perform leak tests with saline and methylene blue to ensure anastomotic integrity. Care should be taken during injection of saline or methylene blue through the NG tube to ensure that the endotracheal tube cuff maintains a tight seal; otherwise, aspiration of methylene blue can occur, leading to chemical pneumonitis. It is also important to completely remove all endogastric tubes (not just merely pull them back into the esophagus) before gastric division, to avoid unplanned stapling and transection of these devices (Fig. 3). After an RYGB pouch is created, the anesthesiologist should not blindly insert the NG tube; in this situation, the monitor should be watched carefully while the NG tube is advanced, to avoid disruption of the anastomosis.

Postoperative Considerations

A 45% incidence of atelectasis has been reported in obese patients after upper abdominal surgery (120), and initiation of continuous positive airway pressure (CPAP) treatment has been advocated, starting in the recovery room and continuing overnight, to prevent postoperative acute airway obstruction (121,122). Bilevel positive airway pressure (BiPAP) has also been used to combat nocturnal airway obstruction (123). Joris et al. (124) investigated the effect of BiPAP—a combination of pressure support ventilation and PEEP— on postoperative pulmonary function in obese patients during the first 24 h after gastroplasty. They found that prophylactic BiPAP system therapy with a 12 cm H_2O inspiratory positive airway pressure and 4 cm H_2O expiratory airway pressure significantly reduced pulmonary dysfunction and accelerated the reestablishment of preoperative pulmonary function. The possibility of stomach inflation, which is probably best avoided early after gastric surgery, was not addressed by this study. However, Huerta et al. (125) recently assessed the efficacy of postoperative CPAP for patients undergoing gastrojejunostomy as part of the RYGB procedure. They did not find any correlation between CPAP use and the incidence of major anastomotic leakage, despite the theoretical risk of anastomotic injury from pressurized air delivered by CPAP.

After a laparotomy for bariatric surgery, patients may avoid taking deep breaths because of pain. Adequate analgesia and a properly fitted elastic binder for abdominal support may encourage patients to cooperate with early ambulation and incentive spirometry. Although incentive spirometry has been recommended by some authors to prevent postoperative atelectasis (126,127), adequate evidence is lacking in this respect. A systematic retrospective review on the use of incentive spirometry in preventing postoperative pulmonary complications did not reveal evidence to support its use during cardiac or upper abdominal surgery (128). Of the 46 articles reviewed, only 1 reported that incentive spirometry, deep breathing, and intermittent positive pressure breathing were equally more effective than no treatment in preventing postoperative pulmonary complications after upper abdominal surgery (129). Current widespread use of laparoscopic techniques for bariatric procedures results in less postoperative pulmonary dysfunction (115), possibly reducing the need for incentive spirometry. Patients with a history of severe sleep apnea may require overnight observation in the intensive care unit because prolonged obstructive apnea is a real possibility, especially when parenteral narcotics are used.

Postoperative Analgesia

The pain from an open bariatric surgical procedure can be quite significant. Epidural local anesthetics and/or narcotics via the thoracic route are a safe and effective form of postoperative analgesia in these patients. Intrathecal narcotics are also a viable option. Potential advantages of thoracic epidural analgesia in the setting of bariatric surgery include prevention of DVT, improved analgesia, and earlier recovery of intestinal motility. Investigators have been unable to document a difference in the incidence of thrombophlebitis and PE with continuous epidural analgesia (130,131). Less oxygen consumption and decreased left ventricular stroke work have, however, been documented as benefits of local anesthetic epidural analgesia (132).

A recent abstract (133) looked at patient-controlled thoracic epidural analgesia after gastric bypass surgery and found that it provided adequate postoperative pain control with few side effects and no serious complications. Most of the patients were able to start oral intake on the second postoperative day and were discharged home by the fourth postoperative day. Another study on thoracic epidural analgesia (134) found distinct advantages over morphine patient-controlled analgesia (PCA) in providing a superior quality of analgesia and shortening the duration of postoperative ileus. Continuous spinal analgesia has been used for postoperative analgesia after open VBG with demonstrated safety, efficacy, and a small incidence of morbidity (116).

Laparoscopic bariatric surgery induces less postoperative pain and is less likely to interfere with pulmonary mechanics (115). Most laparoscopic bariatric patients do well with local anesthetic wound infiltration and basic parenteral narcotics, such as PCA. In a study of 200 patients who underwent VBG (135), effective postoperative analgesia sufficient to allow mobilization was achieved by IV infusion of opioids or PCA. Choi et al. (136) also prospectively investigated the efficacy of IV morphine PCA in morbidly obese patients undergoing RYGB surgery and found that it provided satisfactory analgesia without deleterious effects on oxygen saturation, blood pressure, heart rate, or respiratory function. Patients can be switched to liquid oral narcotics on the first postoperative day after contrast (Gastrografin) swallow has eliminated anastomotic leaks, or as soon as they can tolerate them. Supplementation with oral or rectal nonnarcotic analgesics may be considered, but chronic nonsteroidal antiinflammatory drugs should be discouraged because of concern about gastric ulcers after bariatric procedures.

Conclusion

Bariatric surgery is a safe and viable option in the management of obese patients when nonsurgical treatment options have been unsuccessful. Anesthetic management of these patients should take into consideration the specific problems associated with obesity and optimize them before surgery. Success of medical therapy is marginal at best, with a loss of only 5%–10% body weight at 6 mo to 1 yr with up to 2 yr of maintenance. Combined gastric restriction and bypass or simple gastric restriction have 30-day morbidity and mortality rates of 1% and 0.3%, respectively (137), with the most common 30-day complications (major and minor) being respiratory in nature, from atelectasis to PE. Laparoscopic morbidity and mortality rates have been quoted as much less frequent (8).

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