Introduction

There has been a dramatic rise in both the incidence and prevalence of morbid obesity among adolescents, and projections are that obesity will continue to increase in the United States and worldwide (1). Over a similar period of time, improved survival of patients with cardiomyopathy (CM) and increased long-term survival after palliation or repair of congenital heart disease have resulted in an expanding population of adolescents living with heart failure (2). Because obesity usually disqualifies adolescents with heart failure from transplant listing (3), bariatric surgery may be the only available life-saving intervention.

Bariatric surgery has been shown to improve cardiac function in subjects with CM and may serve as an effective bridge to heart transplantation (4). Although there are no reliable data as to the exact number of bariatric surgeries performed specifically for heart transplant listing, anesthesiologists increasingly will be asked to manage obesity and heart failure simultaneously.

Case description

A 17-year-old girl presented for bariatric surgical consultation. Written informed consent for description of her case history was provided by the patient’s parent with the patient’s assent. She underwent surgical repair as a neonate of Shone’s complex with aortic coarctation and a subaortic membrane, followed by the resection of a recurrent subaortic membrane 4 years of age. She had no persistent clinically significant effects of her coarctation or subaortic membrane, but chronic left ventricular systolic dysfunction was present from infancy and worsened during adolescence. Her childhood repairs were complicated by complete heart block requiring a permanent pacemaker, which was subsequently converted to a biventricular pacemaker with internal cardiac defibrillator capability (BiV-ICD) after she developed ventricular tachycardia. She deteriorated to New York Heart Association class III functional status with 2–3 pillow orthopnea and limited exercise tolerance (2–5 min at 3–6 metabolic equivalents, e.g., moderate walking). The patient was
evaluated for cardiac transplantation. However, morbid obesity (height 168 cm, weight 127 kg, BMI 44 kg m$^{-2}$) precluded listing for heart transplant, and she was referred for laparoscopic sleeve gastrectomy.

Her preoperative medications included carvedilol, enalapril, furosemide, spironolactone, and digoxin. Preoperative evaluation was notable for the evidence of impaired glucose tolerance, hyperinsulinemia, and obstructive sleep apnea (OSA) on polysomnography (apnea-hypopnea index 8.5, nadir saturation 84%). Transthoracic echocardiography (TTE) showed no residual coarctation or subaortic obstruction, moderate tricuspid regurgitation with estimated right ventricular systolic pressure of 45–50 mmHg, and a dilated left ventricle with depressed systolic function (ejection fraction 33%).

Enalapril and furosemide were held for 24 h prior to surgery. The patient’s BiV-ICD was reprogrammed on the morning of surgery to asynchronous mode and the ICD function disabled. She placed herself on the well-padded operating table in the head-elevated laryngoscopy (ramped) position prior to any sedation. Per protocol, subcutaneous heparin was administered prior to the procedure start, and sequential compression devices (SCDs) were placed. Rapid sequence induction (RSI) with etomidate (16 mg), ketamine (60 mg), and succinylcholine (130 mg) was performed, and the trachea was intubated via direct laryngoscopy with a Grade I view. Transesophageal echocardiography (TEE) examination was performed, the findings of which were consistent with the preoperative TTE. Bicaval and right ventricular inflow-outflow views were then used to monitor central venous guidewire and pulmonary artery catheter placement through the right internal jugular vein. The TEE probe was removed prior to the surgery start to allow for endoscope placement. Anesthesia was maintained with desflurane (4.9–6.8 endtidal percent) and remifentanil [0.1–0.2 mcg kg$^{-1}$ min$^{-1}$] based on lean

Table 1  Summary of perioperative management considerations in adolescents with heart failure undergoing bariatric surgery

| Preoperative evaluation | • Cardiologic and transthoracic echocardiography (TTE) evaluation
| | • Medications: hold ACEi/ARB/diuretic
| | • Interrogate or reprogram pacemaker/AICD
| Venous thromboembolism prophylaxis | • Consider sequential compression devices, heparin/LMWH, or combination
| Positioning | • Head-elevated laryngoscopy position
| | • Have patients participate in positioning themselves
| Induction | • Choosing between ideal body weight (IBW), lean body weight (LBW), and total body weight (TBW) for dosing
| | • Most induction agents: use LBW
| | • Consider etomidate, ketamine as alternatives
| | • Succinylcholine: use TBW
| | • Nondepolarizing NMBDs: use IBW
| | • Cardiac output increases in obesity but decreases in heart failure
| Airway management | • Usually not difficult intubation
| | • Use head-elevated laryngoscopy position
| | • Consider rapid sequence induction to decrease apnea time
| Monitoring | • Preinduction arterial line
| | • Consider TTE during induction
| | • Consider transesophageal echocardiography as allowed by surgical procedure
| Anesthetic maintenance | • No clear benefit to any volatile anesthetic
| | • Consider adjunctive use of remifentanil
| Pneumoperitoneum | • Increase minute ventilation to counter systemic acidification
| | • Anticipate effects of increased intra-abdominal pressure
| Ventilator management | • Consider positive end-expiratory pressure, recruitment maneuvers, but be aware of potential adverse hemodynamic effects
| Rhabdomyolysis | • Proper positioning may help avoid compression injury
| | • Suggestion that aggressive fluid administration and forced diuresis may reduce incidence or severity
| | • No clear adverse of benefit
| | • Potential adverse hemodynamic effects in patients with heart failure
| Postoperative care | • Consider ICU for recovery
| | • Consider nonopioid and local anesthetic adjuncts for pain
| | • Consider empiric or early non-invasive positive pressure or ventilatory support

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body weight (LBW). Fluid and diuretic administration was guided by filling pressures and hemodynamics. A perioperative glucose level was within normal limits. The patient tolerated the procedure well. Total surgical time was 115 min. At case end, the trachea was extubated in the operating room and the patient was empirically placed on high-flow nasal cannula. She recovered in the intensive care unit (ICU) for hemodynamic and airway monitoring. Postoperative analgesia was achieved with intravenous acetaminophen and intravenous boluses of fentanyl given on an as needed basis. She was transferred from the ICU to the ward on postoperative day (POD) 2 and was discharged home on POD 5.

Discussion

The extensive physiologic and psychosocial morbidity that results from adolescent obesity has been well-described (5). To this can be added the vicious cycle that obesity and heart failure create. Heart failure decreases exercise tolerance, and it becomes difficult to achieve weight loss by traditional means. Weight gain, in turn, often worsens heart failure and its comorbid sequelae: hypertension, diabetes mellitus, dyslipidemia, OSA, pulmonary hypertension (PH), and worsening right heart dysfunction. At its extreme, this cycle threatens to be fatal—patients will be disqualified from heart transplant candidacy because of their obesity (generally required to have BMI < 30) (3).

Bariatric surgery has been demonstrated to be safe and effective as a treatment for morbid obesity in the adolescent population at large and has become increasingly common at a growing number of centers in the United States and worldwide (1). Guidelines for a multidisciplinary approach to bariatric surgery in adolescents were first published in 2004 and have since been updated (6).

Children with CM and poor ventricular function have increased risk of cardiac arrest under anesthesia (7). If weight-loss surgery can be safely performed in this high-risk subpopulation of adolescents with heart failure and cardiac comorbidities, it may offer a way out of the vicious cycle for these patients. Emerging evidence that bariatric surgery can improve heart failure (8) makes it plausible that some fraction of these patients may not progress to transplantation. For many, though, the concept of the ‘pretransplant’ bariatric procedure may become increasingly commonplace (4).

The overlap between adolescent obesity and heart failure is complex. Some patients may have had a diagnosis of heart failure (from structural heart disease or a CM) prior to the onset of obesity. Others may have been diagnosed with cardiac disease after obesity developed. Controversy exists regarding the conceptual validity of a direct causal link between obesity and impaired ventricular function (‘obesity cardiomyopathy’, mostly studied in adult populations) (9). There is a clear association between obesity and detrimental ventricular remodeling, characterized by myocardial hypertrophy and neurohormonal perturbations (10). The dominant pattern seems to be the development of ventricular concentric hypertrophy, which is associated with diastolic dysfunction independent of hypertension (11).

Weight-loss surgery has been successfully performed in adults with severe heart failure (12,13). However, the etiology and prognosis of heart failure differs in adolescents, where it may occur as a late consequence of congenital structural heart disease or from a primary or acquired CM (14). The Pediatric Cardiomyopathy Registry, a large, multi-institutional prospective study of children with CM, has demonstrated that approximately 65% of pediatric CM remains idiopathic, with dilated (nonischemic) CM the most common phenotype (50%). Prognosis is worse for children diagnosed after age 5 and those with idiopathic CM. Risk of death or transplantation is 31% at 1 year and 46% at 5 years, with most deaths being from progressive heart failure. Sudden death is much less common in pediatric CM patients (12% of all deaths) than in adults with nonischemic dilated CM (15).

Anesthetic implications of pediatric CM and heart failure have been reviewed recently (2). Unfortunately, much of the evidence related to the field of bariatric surgery must be modified and extrapolated from an adult population. We review the available literature and offer recommendations on perioperative management (Table 1). When possible, we provide specific references to pediatric and adolescent patients.

Preoperative evaluation and optimization

Preoperative anesthesia and cardiology evaluation of patients with heart failure are essential in outpatient optimization and anesthetic planning. Medication regimens may need modification. For instance, angiotensin converting enzyme inhibitors (ACE-Is) and angiotensin receptor blockers have been associated with perioperative vasoplegia and hypotension; it is our practice to withhold these on the day of surgery. Patients may have implanted cardiac devices, which need interrogation or reprogramming prior to surgery. Anxiety about anesthesia may be pronounced in these patients and their families, which can be addressed during the preoperative visit through counseling, reassurance, and/or plans for premedication.
Venous thromboembolism prophylaxis

Venous thromboembolism (VTE) prophylaxis has been recommended for all bariatric surgical patients (6). In our practice, mechanical (sequential compression device) and/or pharmacologic (heparin or low molecular weight heparin) prophylaxis are typically initiated in the operating room prior to incision. Presence of PH appears to be a risk factor for postoperative VTE in adults (16). PH may be more common in obese adolescents with OSA (17), and the potential consequences of VTE are severe in the presence of RV dysfunction, PH, and diastolic dysfunction.

Positioning

It has been suggested that positioning can be optimized and the risk of pressure injuries reduced if patients position themselves on the bed prior to induction of anesthesia (18). It is our practice to delay IV premedication until after the patient participates in transferring themselves to the surgical table and verbally confirms a comfortable head-elevated position.

Induction

Hemodynamic instability on induction is common in children with CM. Although a recent retrospective review from Toronto of 236 anesthetics in children with CM found only four cardiac arrest events (1.7% incidence; three in a single patient) and no mortalities, 16% of patients experienced hypotension requiring inotropic support (19). This was noted in 61% of patients in a second, smaller retrospective series of pediatric CM patients (20).

Drug dosing presents a challenge. Comparisons of dosing induction agents based on ideal body weight (IBW), LBW, or total body weight (TBW) in adults have favored the use of LBW as the most appropriate scalar (21). LBW represents metabolically active tissue and increases with obesity. LBW can be estimated by the following formula (22):

\[ \text{LBW} = \text{IBW} + 0.3 \times (\text{TBW} - \text{IBW}) \]

Succinylcholine should be dosed by TBW (23), while nondepolarizing agents should be dosed by IBW (24). Cardiac output (CO) is increased in obesity and correlates with LBW (22). However, CO may be reduced and circulation time prolonged in heart failure. Thus, onset of anesthesia may be somewhat variable.

Alternatives to thiopental and propofol as the induction agent may be desirable in heart failure, to avoid myocardial depression and hypotension. Etomidate has been advocated as the agent of choice for patients with impaired ventricular function. Within clinically relevant dose ranges, studies do not show evidence for myocardial depression with etomidate (25). However, use of etomidate remains controversial because of adrenal suppression (26). Ketamine may be an alternative to etomidate. While concern exists about ketamine’s sympathomimetic effects in patients with systolic dysfunction and PH, it does not increase pulmonary vascular resistance in anesthetized PH patients (27) and has demonstrated a good safety profile in this high-risk population (28).

Airway management

Reduced functional residual capacity may make obese adolescents less tolerant of apnea or suboptimal mask ventilation. In adolescents, obesity is an independent risk factor for difficult mask ventilation and desaturation, but in the absence of other risk factors (e.g., limited mouth opening, Mallampati class, and reduced neck mobility), obesity alone does not appear to significantly increase the risk of difficult tracheal intubation (29). RSI and tracheal intubation without elective mask ventilation minimize apnea time and reduce the risk of hypoxia and hypercarbia, which will be especially dangerous for patients with PH or impaired RV function. The potential benefits of this strategy must be weighed against potential risks of an RSI technique.

Intra-operative monitoring

In addition to standard monitors, additional invasive monitoring may be indicated. The risk of hemodynamic instability in this population may warrant preinduction placement of an arterial catheter. Monitoring with TTE during induction should be considered. After intubation, TEE can provide useful information on baseline function of left and right ventricles, diastolic function, volume status, valvular lesions, and any concomitant structural anomalies. However, its use may not be possible beyond the initial postinduction period, as bariatric procedures often require access to the stomach using an endoscope, and the presence of a TEE probe (even in the mid-esophageal position) may be undesirable during or after gastric resection, stapling, anastomosis, or banding. Pulmonary artery catheters may be used when the use of TEE is restricted to obtain information about CO, filling pressures, and right heart function.
Maintenance of anesthesia

A number of studies in adults have compared volatile anesthetics in the morbidly obese. Sevoflurane demonstrates marginally more rapid elimination compared with isoflurane in obese adults (30), and a similar marginal benefit is seen in desflurane compared with sevoflurane (31). Emergence was more rapid in one randomized trial of desflurane compared with sevoflurane in morbidly obese adults; desflurane was also associated with higher oxygen saturation and higher modified Aldrete score upon PACU admission, but no difference in PACU length of stay (32). These advantages were not replicated in two subsequent comparisons of desflurane and sevoflurane (33,34). There is also concern about the use of volatile anesthetics because of potential myocardial depression and vasodilation, but these effects have not been well-studied in adolescents with heart failure. Though there have been no studies specific to the pediatric obese population, the association between opiates and an increased risk of airway obstruction, hypoxemia, and other adverse respiratory events may favor the sparing use of long-acting opioids (35). The adjunctive use of remifentanil may be considered to decrease MAC requirements of volatile anesthetic and provide intra-operative analgesia without risk of postoperative respiratory depression. Remifentanil does not demonstrate significant myocardial depression (36). We routinely use a combination of a volatile anesthetic and remifentanil.

Ventilator management and the pneumoperitoneum

Carbon dioxide (CO₂) insufflation of the abdomen alters the integrity of peritoneal mesothelium, which facilitates absorption of CO₂. Incomplete compensation [it has been estimated that minute ventilation must increase by 21% to offset CO₂ absorption (37)] will result in hypercarbia and acidosis. Patients with heart failure have diminished reserve to tolerate these physiologic stressors. The direct increase in intra-abdominal pressure exerts important effects on the heart and lungs. There is TEE evidence in adult patients that pneumoperitoneum causes a reversible diastolic dysfunction in obese patients (38). It also causes fluid shifts and alters filling pressures. In one TEE study, pneumoperitoneum increased left ventricular and right ventricular systolic area by 78% and 61%, respectively. A similar increase in left ventricular and right ventricular end-diastolic area (EDA) was also seen (LVEDA increased by 48%, RVEDA increased by 45%). Reverse Trendelenburg position, however, reverses this effect, decreasing LVEDA and RVEDA 18% and 27%, respectively (39).

Pneumoperitoneum is associated with rapid worsening of atelectasis and a decrease in pulmonary compliance (40). Reverse Trendelenburg position does not appear to significantly improve pulmonary compliance (41), but it may mitigate the increase in atelectasis by reducing the upward-directed transmission of intra-abdominal pressure. However, it may reduce venous return to the heart and may worsen venous stasis in the pelvis and lower extremities, especially if SCDs are not used (39).

Ventilator maneuvers may be effective in mitigating the adverse physiologic consequences of pneumoperitoneum in obese patients. Positive end-expiratory pressure has been shown to be effective in improving oxygenation in obese patients undergoing laparoscopic surgery (42). Alveolar recruitment maneuvers also demonstrate efficacy in reducing atelectasis (43). However, these strategies should be used with caution in obese patients with heart failure, as they may produce significant decreases in venous return and CO.

Rhabdomyolysis

Rhabdomyolysis (RML) has been reported as a common complication of bariatric surgery in the adult population as a result of tissue compression during perioperative immobility (44). Although there is no evidence describing the incidence of RML in the pediatric population, tissue compression because of excess weight in dependent regions is also a concern in this population, and avoidance of RML must be a concern for the pediatric anesthesiologist. Aggressive fluid administration (> 13 ml·kg⁻¹·h⁻¹) and forced diuresis (urine output > 2.3 ml·kg⁻¹·h⁻¹) have been proposed as strategies to reduce the incidence or severity of RML in adults (45). Diuretic administration may be necessary to maintain high urine output because elevated intra-abdominal pressure in obese patients with pneumoperitoneum has been associated with decreased renal function and decreased urine output (46).

Wool et al. (47) randomized 100 adult bariatric patients to conservative (15 ml·kg⁻¹) vs liberal (40 ml·kg⁻¹) intra-operative IV crystalloid administration and found no differences in the proportion of patients with a serum creatine phosphokinase level > 1000 IU·L⁻¹. While some centers still empirically use liberal fluid administration and/or forced diuresis, the potential adverse effects of such strategies may be more significant in the subpopulation of bariatric surgical patients with severe heart failure. Pulmonary capillary wedge pressure or TEE may be helpful in guiding fluid management.

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Postoperative management

The need for postoperative ICU care will depend on the patient’s intra-operative course and the severity of their comorbid diseases. A strategy employing routine use of postoperative noninvasive positive pressure ventilation has demonstrated benefits in improving lung function and avoiding pulmonary complications (48). Maintaining the patient in a head-up position and providing adequate analgesia may also help avoid postoperative pulmonary complications. Nonopioid adjunctive medications and local anesthetic strategies should be considered. There are no clear studies comparing local port site infiltration, epidural analgesia, and regional anesthetic techniques such as transversus abdominus plane (TAP) block in this setting. A recent Cochrane review concluded that evidence for the use of TAP blocks in abdominal surgery overall remains limited (49). This technique has not been well-evaluated specifically in obese adolescents having laparoscopic bariatric procedures, but could be considered as a rescue technique for patients who experience poor postoperative pain control.

Conclusions

As the prevalence of obesity continues to increase, especially in the adolescent population, anesthesiologists must deal with the various pathophysiologic changes associated with obesity. Anesthesiologists must be prepared for altered pharmacological management, and physiologic perturbations that may place the obese adolescent at an increased risk of postoperative pulmonary complications, VTE, and development of RML. In addition, the growing population of obese adolescents with heart failure undergoing bariatric surgery is increasing. Perioperative management in this subpopulation warrants attention to the ways in which obesity, preexisting cardiac dysfunction, and the physiological stressors associated with laparoscopic bariatric surgery interact. Routine measures such as drug dosing, positioning, and monitoring are not so ‘routine’; they require careful thought and planning. Further studies are needed to more clearly delineate outcomes for obese adolescents with heart failure undergoing bariatric procedures so that a stronger evidence base can be obtained for best practices in their perioperative care.

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Conflict of interest

No conflicts of interest declared.

References

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