ABSTRACT
Obesity in the pediatric population is considered a growing problem. It is likely that there will be a significant impact related to obesity on the health of future generations. Obesity has increased the incidence of a spectrum of diseases ranging from microvascular complications over the retina and peripheral nerves to an increased incidence of cancer. We have conducted an electronic search in MEDLINE, PubMed, ISI Web of Science, and Scopus scientific databases targeting studies published between 2000 till 2019. Several modalities have shown a wide spectrum of the effectiveness of weight control among adolescents. Despite achieving short-term success among obese adolescents, maintaining such change is challenging. The emergence of metabolic or bariatric surgeries has opened the door for long-term control over weight gain with considerable remission of unfavorable metabolic mediated or modulated effects associated with obesity such as diabetes mellitus and hypertension. The most commonly practiced metabolic surgery among adolescents is sleeve gastrectomy which is associated with comparable weight and metabolic control and a lesser risk of complication. Anesthesia is considered a major challenge among the pediatric population, especially those with significant obesity. Preoperative evaluation is always warranted to exclude and manage different associated comorbidities. The anesthetic challenges associated with pediatric obesity begin with intubation. Maintenance and emergence from anesthesia along with postoperative antiemetics and analgesia can pose additional challenges. Managing the postoperative period is considered a cornerstone in the early detection and management of any postoperative complication. Especially those complications related to the metabolic and nutritional aspects of the bariatric surgery. Finally, despite being a valuable option in managing obesity, bariatric surgery in adolescents comes with significant anesthetic challenges that need to be consistently evaluated and managed.

Key words: Pediatric anesthesia, pediatric diabetes, pediatric obesity

Introduction
Obesity is a multifactorial disease with multiple interconnections with many other prevalent conditions. Since 1980, the prevalence of obesity has doubled, with about one-third of the world population now classified as obese or overweight. Obesity has been connected to...
multiple health-related conditions, including cardiovascular incidents, diabetes mellitus, cancer, and many other pathophysiological processes. Additionally, obesity carries a significant economic burden on afflicted families. In the US, it has been estimated that health costs incurred by a single obese individual are US$1,901 per annum in 2014. Besides affecting adults, obesity is a growing problem in the pediatric population. A recent National Health and Nutrition Examination Survey revealed the prevalence of obesity among the pediatric population is about 18%. In this regard, Ahmad et al. have demonstrated that most adolescents aged (10 to 14 years) are at risk of remaining obese as adults.

The emergence of metabolic surgeries has led to both enhancing and accelerating weight and breaking the endocrinial vicious circle of obesity. Currently, bariatric or metabolic surgery (BS) is considered the most effective long-term therapy for severely obese patients (grade II) with associated metabolic diseases and for morbidly and super morbidly obese patients (grades III-IV). Despite being an effective approach to treating obesity and its metabolic complications, BS remains a significant challenge among pediatric populations. In the following review, therefore, we describe anesthetic considerations raised in the context of metabolic surgeries among the pediatric population.

**Material and Methods**

**Literature search**

Relevant literature reporting the interventions for controlling excess weight in children and adolescents was identified through an electronic search of papers published from 2000 to 2019 in MEDLINE, PubMed, ISI Web of Science, and Scopus. Keywords such as “childhood obesity”, “overweight,” “weight disorder,” “intervention,” “treatment,” “management,” “nutrition,” “behavior therapy,” and “diet therapy” were used.

**Study selection**

Having removed duplicates, the relevant papers were selected in three phases. In the first and second phases, titles and abstracts of papers were screened and irrelevant papers were excluded. In the last phase, the full text of recruited papers was explored deeply to select only relevant papers. Discrepancies were resolved by consultation and consensus.

**Bariatric Surgery Options in Pediatrics**

Bariatric procedures are divided into two broad categories, Restrictive (e.g., laparoscopic adjustable gastric band, LAGB, and Sleeve gastrectomy, SG) and Malabsorptive procedures, or a combination of both (e.g., Roux-en-Y gastric bypass, RYGB). SG, RYGB, and LAGB are the most common operations among adolescents seeking metabolic surgery options. However, the Food and Drug Administration has concluded that adjustable bands should not be used as a surgical option in obese patients below the age of 18 years.

SG is considered one of the commonest, if not the commonest, bariatric surgery for adults or adolescents nowadays. It entails the removal of most (80–90%) of the greater curvature of the stomach, which leaves a tubular remnant stomach about 10 to 15% of its original size. The SG has gained popularity as one of the safest options among different bariatric procedures related to its technical simplicity and a lesser spectrum of complications compared to RYGB. Additionally, it has near-equivalent weight loss and efficiency regarding comorbidities to RYGB, with fewer revision surgeries and better nutrient absorption. Alqahtani et al. have demonstrated no major complications and a low rate of minor complications (4.3%) in both short- and middle-term outcomes.

In comparison to SG, RYGB is considered a valid alternative to SG in adolescent and pediatric populations. Inge et al. have demonstrated that adolescents have remission of diabetes and hypertension more often than adults on a five-year follow-up period. In a Swedish national analysis, Olbers et al. have demonstrated a significant decrease in cardiovascular complications of adolescent participants; however, increasing costs on the rate of additional surgical interventions and nutritional deficiencies.

**Comorbidities of Pediatric Obesity**

Obesity has always been marked by a higher incidence of multiple underline organ dysfunction. Similarly, pediatric obesity brings significant consequences. Childhood obesity is potentially associated with devastating comorbidities, including diabetes mellitus type 2 (DM 2), coronary artery diseases (CADs), hypertension, obstructive sleep apnea (OSA), nonalcoholic fatty liver disease (NAFLD), and metabolic syndrome that may progress later in life. Certain correlated diseases such as OSA, respiratory, and cardiovascular disorders in obese pediatric patients represent the most difficulties associated with anesthetic and surgical procedures.

**Obstructive sleep apnea (OSA)**

OSA is a sleep disorder characterized by a degree of respiratory cessation, which is usually accompanied by sleep disruption, hypoxemia, arrhythmias, and arterial oxygen desaturation. OA prevalence ranges from around 35-75% in obese children. Although the exact cause is unknown, studies have shown that obesity contributes to OSA by
anatomical narrowing by redundant soft tissues, including the tongue, soft palate, and pharyngeal wall. OSA may also be caused by abnormal neuromuscular tone. These anatomical changes represent a substantial difficulty for any anesthesiologist during endotracheal intubation.

**Respiratory intricacies of pediatric obesity**

Pediatric obesity has long been recognized as having substantial consequences on the respiratory system secondary to an alteration in the metabolic rate proportional to body mass index. Adiposity also precipitates changes in both lungs and chest wall secondary to the fat deposition that will eventually lead to a picture similar to restrictive lung diseases. Thus, altering the effectiveness of apneic oxygenation (AO) and increasing respiratory impedance during tracheal intubation.

**Cardiovascular complications**

The global prevalence of cardiovascular system complications among the pediatric age group has been potentially linked to obesity. Increased cardiac output and blood volume secondary to increased bodily demand causes a persistent increase in heart workload, eventually leading to left ventricular hypertrophy (LVH). The long-living LVH, together with chronically high vascular resistance, maybe later be complicated by cor-pulmonale, magnifying the cardiovascular-associated adverse events within any anesthetic protocol. Moreover, metabolic syndrome has been thoroughly linked to cardiovascular events in the obese pediatric population. The metabolic syndrome includes insulin resistance, dyslipidemia, hypertension, nonalcoholic fatty liver disease, and proinflammatory syndrome.

**Preoperative Assessment of the Pediatric Population**

It is important to consider the ethics related to bariatric surgery in the pediatric population. The managing team must ensure that no other acceptable medical intervention can treat or reverse the patient’s obesity-related medical condition, except for the surgical interference. The medical team should treat patients based on beneficence, no maleficence, autonomy, and justice.

Besides ethical concerns, many associated medical considerations may change or halt any bariatric procedure. Meticulous preoperative assessment of the adolescent is essential to ensure effective and safe bariatric intervention. Pratt et al. have addressed multiple parameters to be examined before arranging a bariatric intervention, including laboratory studies, cardiac, pulmonary, and gastrointestinal function, and the ability of postoperative compliance and psychological status. Moreover, the nutritional assessment is important to detect the baseline micronutrient deficiency, which is common in the pediatric population and may have an adverse consequence on the composite outcome. An extension of the nutritional panel has been recommended to include thiamin (B1), vitamin B12, and B6, calcium, parathyroid hormone (PTH), alkaline phosphatase, vitamins A, D, E, and K, phosphorus, magnesium, copper, and zinc.

Besides the basic metabolic pattern, cardiac function should be thoroughly examined before the bariatric procedure. Many obese children suffer from a wide spectrum of cardiovascular comorbidities ranging from hypertension (HTN) to arrhythmia. Schlottmann et al. have demonstrated that properly controlling the associated cardiac comorbidities is essential for proper postoperative outcomes. The proper cardiac evaluation may include medical history, physical examination, and a 12-lead electrocardiogram. Together with preoperative cardiac concerns, OSA is associated with increased mortality and postoperative adverse outcomes following bariatric procedures. Preoperative detection of OSA is crucial before any surgical procedures requiring general anesthesia or even sedation. OSA can increase the risk of intraoperative hypoxemia, hypercapnia, atelectasis, laryngospasm, and the need for reintubation.

Interestingly, one of the essential preoperative steps is the assessment of the feasibility of the patient and family compliance with the postoperative follow-up. The postoperative follow-up aims to monitor weight loss and any remission of the associated metabolic comorbidities. Additionally, the preoperative dedication to compliance with the follow-up is essential for the early detection and management of any micro- or micronutrient deficiency.

**Anesthetic Challenges**

Despite recent advances in anesthesiology, pediatric obesity is still a significant challenge facing anesthesiologists. Pediatric anesthesia is associated with a significant risk of morbidity and mortality because obese children are more difficult to ventilate, to intubate, and to cannulate. Further, pediatric obesity also complicates anesthesia drug dosage calculations. Anatomical and pharmacological issues are caused by a short neck, increased subcutaneous fat, and unpredictable pharmacokinetics of drugs. Moreover, the pediatric populations are at high risk of developing laryngospasm on extubation and morbidly obese patients are liable to obstruction.

**Obtaining vascular access and fluid management**

Recent research has shown that obese children often require multiple attempts to obtain successful venous access.
A high-frequency linear ultrasound probe has also been tried for obtaining venous and arterial access and showed a significant increase in the success rates of the first cannulation attempt to 85.78%.[48] Invasive arterial blood pressure monitoring is only needed in pediatric bariatric surgery in case of significant hemodynamic instability or inaccurate measurement of non-invasive blood pressure monitor due to patient position.[49] Alimian et al.[50] have compared liberal vs. restrictive fluid management in bariatric surgeries and showed no difference in the effect of both kinds of fluid management. Still, only one study proved that liberal fluids administration is associated with a lower risk of acute kidney injury.

Airway Management

Proper airway assessment to predict difficulty in intubation and/or ventilation is an essential step in preparation for such a challenging case in anesthesia. Mallampati score has always been the cornerstone in predicting difficult ventilation or intubation. It has a sensitivity of 53% to predict difficult intubation and 17% to detect difficult ventilation.[51] However, it is difficult to properly assess the pediatric population due to a lack of cooperation.

The role of ultrasound

Studies conducting the role of ultrasound to predict difficult ventilation or difficult intubation have shown some contradicting results. One study showed that measuring the distance between the skin and the vocal cords or the suprasternal notch is highly predictive of difficult intubation.[52] Another study showed that the distance between the skin and the thyrohyoid membrane is also predictive of difficult intubation.[53] On the other side of the coin, Alessandri et al.[54] could not find a statistically significant difference between measuring the distance between skin and hyoid or skin and epiglottis in predicting difficult intubation. Furthermore, ultrasound can be used to confirm the size of ETT required for intubation by the accuracy of 88 to 100% compared to 35% for age-based formula (i.e., age/4 + 4) in non-cuffed ETT, or 60% in case of cuffed ETT.[55] Other studies found that the overall accuracy of the age-based formula is as low as 27%.[56] Moreover, distance from the skin to the epiglottis can successfully predict difficult bag-mask ventilation.[54]

Confirmation of intubation

Anesthesiologists use several methods to confirm endotracheal intubation.[57] Auscultation of bilateral air entry in lungs,[58,59] tube misting,[60] or self-inflating tube bulbs[61] proved to be unreliable.[62] Therefore, more objective methods like capnography[63] and ultrasound to confirm intubation should decrease the adverse events.

The anesthesiologist can use the ultrasound either with a static method by injecting the tube cuff with saline for visualization or by the dynamic method using an ultrasound scan during the intubation procedure with a sensitivity reaching 100%.[64-67] Depth of intubation is essential as misplacement can lead to either barotrauma or dislodgement of the tube. Traditionally, Borselow tape equation was used in pediatric patients to verify the depth of intubation followed by lung auscultation.[68] The pitfall in Borselow is that the anatomy is not typical in all individuals, and x-ray can be time-consuming.[69] Recent studies showed that ultrasound is a more sensitive and specific way to evaluate intubation depth.[70]

Difficult intubation

The difficult airway society produced a stepwise algorithm for managing difficult pediatric airways.[71] In contrast to difficult adult intubation, where awake intubation is the gold standard, the pediatric population does not show cooperation for such a technique. However, modified awake intubation with topicalization of the airway and insertion of the supraglottic device may help in cases like the Pierre Robin sequence.[72] Video laryngoscopy or flexible bronchoscopy shall be ready for use in anticipated difficult cases.[73]

Ventilation

When it comes to ventilation, Sevdi et al.[74] showed no statistical difference in efficacy between pressure-controlled ventilation and volume-controlled ventilation in pediatric bariatric surgery regarding acid-base status, respiratory function tests, post-op, fluid intake, urine output, pain score, and rate of complications.

Anesthesia regimen

Calculating the doses of anesthetic drugs in obese children is still a dilemma.

Lean body mass is commonly used for dose calculation, as in propofol.[75] The intubation dose of succinylcholine is calculated based on the total body weight.[76] However, normal fat mass (based on allometric theory and partition of body mass into fat and fat-free components) may provide a better relationship between the size and body composition effects on the pharmacokinetics of all drugs.[77] Many smartphone applications are implemented in pediatric anesthesia to help in dose calculation and distraction of the patients on induction.[78]

Regarding anesthesia maintenance, sevoflurane and desflurane have comparable efficacy, but both have higher efficacy and faster emergence than isoflurane. Moreover, desflurane has more rapid emergence and return to normal recognition reducing the risk of undesirable postoperative
Hashim, et al.: Pediatric obesity anesthetic challenges

Due to the unpredictable pharmacokinetics of drugs in pediatric obese patients, total intravenous anesthesia TIVA was not the method of choice. However, with EEG-based monitoring, the proper understanding of pharmacology, and the availability of advances in equipment, TIVA has become an attractive option.

Anesthetic adjuvant as alpha 2 agonist dexmedetomidine reduces the risk for postoperative delirium. The The ED95 values of dexmedetomidine for pediatric sedation infused over 10 min are 0.75 and 0.74 µg kg⁻¹ with and without obesity, respectively, based on total body weight.

Analgesia
Opioid-sparing analgesia is the most appropriate approach for performing bariatric surgery on obese children as they have increased opioid sensitivity, increased risk of obstructive sleep apnea syndrome, and decreased bowel function in the immediate postoperative period. Epidural catheters devoid of opioids can relieve pain postoperatively. Although transverses abdominal plane block is commonly used post-laparoscopic surgeries, Albrecht et al. showed that it does not improve pain scores or reduce opioid consumption. Non-steroidal anti-inflammatory drugs (NSAID) are another opioid-sparing plan used to relieve visceral and inflammatory effects. Further research needs to be done on the pharmacokinetics of NSAIDs in obese pediatric patients due to the lack of information. The most commonly prescribed analgesia in the pediatric population is acetaminophen. Research on pediatric obese patients with NAFLD showed upregulation of cp450 – 2E1 with an increased risk of increased production of hepatotoxic metabolites. Pediatric bariatric surgery patients are at increased risk of postoperative nausea and vomiting, which may require multimodal antiemesis.

Postoperative Considerations in Pediatric Bariatric Surgery

Bariatric surgery, considered among the most life-modifying surgeries, requires adequate postoperative care for long-lasting and enduring outcomes. Postoperative care involves active monitoring and bodily inspection to prevent post-surgical stress response of organs and ensure a thorough amelioration of health. Like any other medical intervention, pain management in pediatric bariatric surgery needs the earliest supervision. The medical team needs to perform adequate measures to scale pain intensity and restrain it by properly administering analgesics. Besides this, the medical team should be attentive to the early postoperative period’s comprehensive metabolic panel (CMP). The multidisciplinary team may order CMP under preoperative comorbidities to diagnose any irregularities in basic blood tests following the bariatric surgery.

Respiratory problems are early postoperative complications following bariatric surgery. Gupta et al. evaluated the prevalence of postoperative pneumonia (PP) and respiratory failure (PRF) following bariatric surgery. They found that they account for one-fifth of complications accompanied by the delay in the discharge of patients and eventually death. Pulmonary complications resulting from pneumoperitoneum and inappropriate patient positioning require proper consideration by a multidisciplinary team. Using non-invasive positive-pressure ventilation (NIPPV) preoperatively can subsequently reduce the risk of postoperative hypoxemia by preoxygenation delaying the desaturation. Apart from this, research has shown that prompt ambulation in a postoperative intensive care unit can cause a significant reduction in complications and reduce the length of hospitalization.

Besides the pulmonary complications, dumping syndrome is a frequent complication of bariatric surgery. Dumping syndrome typically occurs after one hour of the meal and involves gastrointestinal disturbances that include nausea, vomiting, abdominal pain, and bloating associated with tachycardia, hypoglycemia, and diaphoresis. Dumping syndrome in adolescents following bariatric surgery can make them more susceptible to frustration and post-surgery depression, impacting their quality of life. However, the symptoms can be effectively managed by pharmaceutical formulations and proper guidance on meal proportions.

It has been reported in various research studies that bariatric surgery in adolescents makes them highly vulnerable to nutritional deficiencies in the future as compared to adults. Bariatric surgeries accelerate gastric pouch emptying and reduce gastric secretions and intestinal absorption, thus interrupting the nutritional status. Olber et al. assessed the long-term nutritional complication in adolescents and found that 32-46% of patients predominantly suffered from iron deficiency anemia within five years. Other nutritional deficiencies include 16-22% for vitamin B12 and around 3-78% for vitamin D. Thus, it is crucially important for the multidisciplinary team to monitor nutritional profiles annually and prescribe suitable supplements to cater to any nutritional deficiencies in the future.

Conclusion

Childhood obesity is a prevailing condition associated with multiple comorbidities. Bariatric surgery is one of
the therapeutic protocols for childhood obesity. One of the most challenging aspects of pediatric bariatric surgery is the anesthesia. Ultrasound can be of great value in predicting difficult intubation, confirming endotracheal tube placement, and obtaining vascular access. There is no significant difference in efficacy between volume-controlled ventilation and pressure-controlled ventilation. Liberal fluid therapy may be preferred over restrictive fluid therapy to prevent acute kidney injury. Opioid-sparing analgesia shall be used, including epidural catheters devoid of opioids. NSAID therapy may be preferred over restrictive fluid therapy to predict acute kidney injury. Opioid-sparing analgesia shall be used, including epidural catheters devoid of opioids. NSAID

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Conflicts of interest
There are no conflicts of interest.

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