



# Challenges of Robotic Gynecologic Surgery in Morbidly Obese Patients and How to Optimize Success

Gulden Menderes<sup>1</sup> · Stefan M. Gysler<sup>1</sup> · Nalini Vadivelu<sup>2</sup> · Dan-Arin Silasi<sup>1</sup>

Published online: 1 July 2019  
© Springer Science+Business Media, LLC, part of Springer Nature 2019

## Abstract

**Purpose of Review** Robotic surgery has been shown to have a significant benefit in obese gynecologic patients over open surgery. However, robotic surgery in these patients requires a thorough understanding of the physiologic adaptations caused by obesity, adequate preoperative optimization, specialized equipment and techniques, and careful attention to intra- and postoperative management in order to minimize complications. This article reviews the benefits of a minimally invasive approach in obese patients and provides a thorough guide to perioperative management of obese patients undergoing robotic gynecologic surgery. A useful set of tips and tricks to overcome many of the technical challenges in performing robotic surgery in the obese patients is included.

**Recent Findings** In the USA, obesity has risen to affect 39.8% of the population, which leads to increased incidence of mortality, hypertension, diabetes, heart disease, and stroke. Moreover, obese patients are at greater risk of perioperative complications during gynecologic surgery. With the use of laparoscopy, many of the perioperative risks of surgery in obese patients can be ameliorated. However, minimally invasive surgery in obese patients is technically challenging. Robotic-assisted laparoscopy addresses several of these challenges, allowing surgeons to offer minimally invasive approaches to patients with extreme BMIs while reducing perioperative risk.

**Summary** Obese patients undergoing gynecologic surgery receive a greater benefit than their non-obese counterparts from a laparoscopic approach, and current data support the safety and feasibility of robotic surgery in the obese population. Therefore, every effort to offer a minimally invasive surgery to obese patients should be made.

**Keywords** Robotic surgery · Gynecology · Obesity · Laparoscopic hysterectomy · Minimally invasive surgery · Anesthesia

## Introduction

In the USA and globally, obesity has become a problem of epidemic proportions. As of 2016, the prevalence of obesity, defined as body mass index (BMI) > 30 kg/m<sup>2</sup>, reached 39.8% in the USA [1]. In addition to increasing all-cause mortality, hypertension, diabetes, heart disease, and stroke, obese patients are at greater risk of perioperative complications [2,

3]. This is compounded by the fact that obesity increases the risk of developing conditions that require gynecologic surgery, including abnormal uterine bleeding, incontinence, pelvic organ prolapse, and endometrial hyperplasia and cancer. Thus, the proportion of obese women undergoing gynecologic surgery in the USA is on the rise.

With the advent of laparoscopic surgery, many of the perioperative risks of surgery in obese patients have been ameliorated. Patients experience shorter hospital stays, fewer wound infections, less risk of postoperative fever, and sepsis with laparoscopy versus laparotomy [4, 5•, 6]. Therefore, a minimally invasive approach to gynecology in morbidly obese women should be considered in appropriate cases. However, conventional laparoscopy becomes technically challenging with increasing BMI. Due to increased abdominal wall thickness and higher intra-abdominal fat content, entry, visualization, and manipulation can be severely limited in obese patients, resulting in longer operative times and surgeon fatigue [7]. Robotic surgical systems carry the advantage of improved

---

This article is part of the Topical Collection on *Other Pain*

---

✉ Gulden Menderes  
gulden.menderes@yale.edu

<sup>1</sup> Department of Obstetrics, Gynecology and Reproductive Sciences, Division of Gynecologic Oncology, Yale University School of Medicine, PO Box 208063, New Haven, CT 06520-806, USA

<sup>2</sup> Department of Anesthesiology, Yale University School of Medicine, PO Box 20805, New Haven, CT 06520-8051, USA

visualization and instruments with greater degrees of freedom to allow the surgeon to navigate the obese abdomen. The objective of this chapter is to discuss the benefits of robotic gynecologic surgery in the morbidly obese patients and strategies to overcome the challenges associated with performing these surgeries.

## Types of Obesity

Obesity is broadly defined by the World Health Organization as an abnormal or excessive fat accumulation that may impair health. The Quetelet Index, now referred to as body mass index (BMI), has fallen into favor as a simple way to categorize obesity by determining the ratio of patient weight to squared height. Thus, the categories of body have been defined as underweight ( $\text{BMI} < 18.5 \text{ kg/m}^2$ ), normal ( $20\text{--}24 \text{ kg/m}^2$ ), overweight ( $25\text{--}29 \text{ kg/m}^2$ ), obesity ( $30\text{--}34 \text{ kg/m}^2$ ), morbid obesity ( $35\text{--}40 \text{ kg/m}^2$ ), and supermorbid obesity ( $> 40 \text{ kg/m}^2$ ). While useful for broadly classifying a population, BMI does not account for body fat percentage or distribution, two factors that heavily affect the health impacts of obesity. As any surgeon can attest, not all patients of a given BMI share the same body habitus or physiology. Moreover, multiple studies have called into question the validity of BMI in estimating the risk of mortality, such that BMI may overestimate risk in some patients and underestimate it in others, depending on body composition. In that vein, some groups have found other measures, such as the ratio of waist to hip, are more suited to estimating individual risk of cardiovascular disease [8–11]. Taken together, these studies indicate that body composition, rather than weight-to-height ratio alone, is a better predictor of obesity-related cardio-metabolic risk factors.

In addition to risk stratification, body fat distribution can significantly impact operative management of the gynecologic patient. Indeed, patients with equivalent BMIs may present very different challenges in the operating room. If a patient has a predominance of peripheral fat, positioning and access to the perineum can be limited while the laparoscopic portion of the procedure can be accomplished with relative ease. Conversely, a patient with central adiposity will have a thicker abdominal wall, larger visceral volume, enlarged mesenteries, and abundant epiploica, causing the bowel to significantly impact visualization and make the intraperitoneal part of the operation more difficult. Thus, BMI alone is inadequate in the preoperative assessment of the patient, and careful note should be made of body fat distribution preoperatively. Accordingly, surgical planning, from a choice of procedure to operating room equipment and patient counseling, is inevitably impacted by body habitus.

## Benefits of Laparoscopy/Robotics in Morbidly Obese

As previously mentioned, there are myriad benefits to a minimally invasive approach in gynecologic surgery. In the general gynecologic population, it is well established that laparoscopic surgery results in less postoperative fever, urinary tract infection, pain, complications, length of stay, total cost of care, and an earlier return to normal function [12, 13]. In the past, laparoscopic surgery was reserved for non-obese women due to potential barriers of a thick abdominal wall limiting entry and maneuverability in the abdomen and excessive visceral fat obscuring the operative field [14]. With advances in minimally invasive technologies and increased operator experience, new data has shown that laparoscopic surgery in obese patients is safe and feasible. In fact, several studies comparing surgical outcomes of laparoscopic hysterectomy in obese women compared with those with normal BMI reveal a greater benefit in the former group [7, 13, 15–17]. The difference in outcomes has been due primarily to a significant reduction in postoperative wound complications, which occur at much higher rates in obese patients.

While it is clear that obese patients benefit greatly from a laparoscopic approach, they also represent the most challenging group of surgical patients. In recent years, development of the robotic surgical platform has provided surgeons with advanced laparoscopic instrumentation. The theoretical benefits of this system include increased degrees of freedom, motion scaling, tremor cancellation, and 3D visualization, which together facilitate the procedure while reducing surgeon fatigue. Moreover, the fulcrum of the robotic instrument is fixed at the fascial incision, which together with the wristed action reduces torque forces on the abdominal wall to reduce fasciotomy size and postoperative pain. Early studies evaluating robotic hysterectomy have shown reduced blood loss, shorter length of stay, and faster return to normal function, compared with conventional laparoscopy [18–20].

Lastly, one of the cited benefits of robotic surgery is a shorter learning curve to proficiency as compared with conventional laparoscopy. Thus, the robotic platform may allow a greater number of surgeons to efficiently perform laparoscopic procedures. Indeed, since the introduction of the robotic system, the proportion of robotic total hysterectomy (RTH) has increased to 9.5% and is continuing to rise, concomitant with a significant fall in abdominal hysterectomies [20]. Therefore, the robotic system may extend the benefits of laparoscopic surgery to more patients than was previously possible with conventional instruments. Taken together, these data suggest that robotic surgery may be the optimal technique for morbidly obese patients requiring gynecologic surgery.

## Physiologic Changes Encountered in Morbidly Obese

Understanding the significant differences in the anatomy and physiology of morbidly obese female patients is critical to the safe and successful performance of minimally invasive surgery in this population.

### Cardiovascular System

Increased body mass in obese patients leads to a variety of cardiovascular alterations which result in physiological abnormalities. At a metabolic level, more energy is required to physically move the bigger body mass and to meet perfusion requirements of the excess tissue [21]. Cardiovascular changes occur in the form of larger stroke volume, increased cardiac output, decreased vascular resistance, and overall increased cardiac work. These changes, aimed at adapting to increased metabolic demand, ultimately result in heart disease. Elevated cardiac stroke volume and cardiac output cause hypertension and cardiomegaly. The increased cardiac size elevates systemic arterial pressure, ultimately leading to congestive heart failure [21, 22]. Ventricular dysfunction causes an increase in pulmonary artery pressure which contributes to cardiac failure, manifesting as peripheral edema. In addition to the above-mentioned changes, unexplained cardiac arrhythmias are also more common in obese patients. Obesity-related cardiopathology includes eccentric and concentric ventricular hypertrophy, which leads to tachyarrhythmia or to a prolonged Q-T interval on electrocardiogram (ECG) [21]. Both of these cardiopathologies are risk factors for sudden death. Along these lines, obese patients have been shown to have 20 to 55% larger cardiac diameters, hypertrophied ventricles, and increased cardiac weight compared with normal weight individuals in many autopsy studies [23–25]. Further, obesity is an independent risk factor for a venous thromboembolic event (VTE), which is even more pronounced in the perioperative period [26, 27]. Surgeons operating on obese patients should consider these cardio-metabolic alterations and make VTE prophylaxis a priority in order to prevent potentially catastrophic surgical outcomes.

### Pulmonary System

Pulmonary gas exchange is affected by obesity. Morbidly obese individuals have poorer exercise capacity and also poorer pulmonary gas exchange compared with healthy, non-obese counterparts [28]. The increase in mechanical ventilatory constraints and lower lung volumes from large amounts of abdominal fat causes poor lung function [28]. The decrease in lung volumes, specifically expiratory reserve volume (as an index of decreased functional residual capacity), is a cause for poor gas exchange in the lung [29]. Reduced

chest wall expansion and increased oxygen demand result in decreased lung compliance. In addition, total lung volume, total lung capacity, functional vital capacity, and functional residual capacity (FRC) are all decreased. These changes are characteristic of a restrictive pattern. Specifically, vital capacity is reduced by 20 to 50%, and maximum voluntary ventilation is reduced by approximately 30%. This results in a substantial alteration in the FRC and total lung capacity. The expiratory reserve volume is also compromised by 35 to 60%, secondary to cephalad displacement of the diaphragm by the obese abdomen [29]. These values are even worse in patients who have the added compromise of obstructive sleep apnea (OSA) or obesity hypoventilation syndrome (OHS) [22]. In addition, general anesthesia further reduces FRC by an additional 20%, and this, coupled with the steep Trendelenburg position often required to safely perform gynecologic laparoscopy, further compromises FRC.

There are additional risk factors that impair respiratory function in obese patients. An increase in the amount of upper airway soft tissue and tongue size leads to an increase in upper airway resistance. Mask ventilation and oxygenation can be challenging secondary to a sharp decrease in lung volume with the induction of anesthesia [22]. Direct laryngoscopy can be made particularly difficult by adipose breast tissue compromises the already small space between the chest and the mouth, into which the handle of a conventional laryngoscope fits. Taken together, reduced lung compliance, increased airway resistance, and the possible presence of a large volume of gastric contents, even after an overnight fast, may put obese patients at risk for pulmonary aspiration.

Waist–hip ratio seems to influence gas exchange in the obese patients [30]. Vaughan et al. demonstrated that as waist circumference decreases in morbidly obese patients, the  $P(A-a)O_2$  decreases, illustrating that pulmonary gas exchange is related to abdominal obesity [31]. Moreover, they showed a significant relationship between changes in expiratory reserve volume and  $PaO_2$  and  $P(A-a)O_2$ , demonstrating an improvement in gas exchange as expiratory reserve volume increased from surgical weight loss due to the reduction in waist circumference [31]. One can speculate that a large fat mass surrounding the hips offers protective effects against the abdominal fat mass such that the gas exchange impairment is reduced [30]. In fact, a large fat mass surrounding the hips may help to keep the abdominal fat mass from sagging caudad. A sagging abdominal fat mass may result in more ventilation–perfusion mismatching compared with a nonsagging abdominal fat mass. Therefore, fat distribution of obese patients has a significant influence in ventilation–perfusion status.

Morbidly obese individuals have impaired gas exchange lying down compared with sitting upright. Functional residual capacity is further reduced when moving from the sitting to the supine position. This may well lead to airway closure during tidal breathing in obese patients, which results in

additional hypoxemia and an increase in  $P(A-a)O_2$  [30]. Airway closure leads to reduced alveolar ventilation, causing ventilation–perfusion mismatch. In case of a severe mismatch, these changes may even result in alveolar collapse beyond the closed airways, causing a shunt to develop [30]. For these above-mentioned reasons, it is of paramount importance to maintain efficient communication between surgical and anesthesia teams throughout the procedure to be able to overcome these pulmonary challenges.

### Gastrointestinal System

Morbid obesity is associated with increased prevalence of disordered esophageal motility, dysphagia, gastroesophageal reflux disease (GERD), and esophageal erosions [32, 33]. Jaffin et al. previously reported that 61% of the obese population had an esophageal motility disorder, the majority of whom had an incompetent lower esophageal sphincter [34]. The presence of esophageal motility disorders before surgery can be associated with postoperative dysphagia. Some motility disorders can also precede surgery and, thus, be exacerbated postoperatively [35].

The esophageal pathology of obesity is clearly related to increased intra-abdominal pressure, which is two to three times greater in morbidly obese patients compared with non-obese counterparts [36]. Furthermore, gastric function may also be abnormal in obese patients. Several studies have suggested that obese patients are more likely to have large gastric volumes, lower gastric pH, and delayed emptying, which places them at increased risk of gastric acid aspiration during and after surgery [22, 36].

### Preoperative Considerations

As previously discussed, obesity carries a high risk of medical comorbidities and, in general, an overall increase in perioperative risk [37]. While obesity per se does not impart increased surgical risks [38, 39], OSA, OHS, hypertension, diabetes, metabolic syndrome, and renal disease are common among obese patients and can modulate perioperative morbidity. Thus, preparation for robotic surgery should begin with a thorough medical history and physical examination, with particular attention to screening for OSA [40], hypertension, and diabetes. Cardiology consultation should be considered if abnormal EKG, OSA, or other significant cardiac history is present [41]. Tight blood glucose control should be emphasized, with a goal of Hgb A<sub>1C</sub> of < 7.0% [42•].

The physical exam should focus on documentation of body habitus for surgical planning and thus appropriate preoperative counseling. While morbid obesity severely limits the pelvic examination, the uterine size and mobility and the vaginal caliber should be assessed. Any cephalad mobility of the

uterus portends adequate access to the pelvic sidewalls to permit robotic surgery. If the vaginal caliber is excessively small in relation to the corpus, a mini-laparotomy may be required to deliver the specimen and the patient should be counseled to expect this possibility. The authors do not routinely obtain imaging studies preoperatively; however, the presence of a fixed mass, history of extensive abdominopelvic surgery, or markedly abnormal anatomy should prompt imaging studies and evaluation for cancer where indicated. If malignancy is identified or expected, careful attention must be paid to the ability to remove the uterus without intra-abdominal spillage. If the specimen is not expected to fit within a laparoscopic specimen retrieval bag (< 20 cm at our institution), laparotomy may be indicated. However, in our practice, uteri greater than 1000 g can be safely removed vaginally [6, 43]. Lastly, careful examination of the abdomen often reveals intertriginous candidiasis and erysipelas which are common in patients with dependent panniculi. Identified infections should be treated preoperatively.

While the overall risk of venous thromboembolism (VTE) is low in gynecologic surgery, obesity is a significant independent risk factor for VTE [44, 45]. Morbidity can be severe from perioperative VTE; thus, every effort should be made to mitigate this risk. Preoperatively, medications, vitamins, and herbal supplements should be discontinued if associated with bleeding or hypercoagulability [42•]. Hormonal therapy should be discontinued 4–6 weeks prior to surgery and a barrier method of contraception employed if applicable. The use of prophylactic inferior vena cava (IVC) filter placement is controversial due to an associated risk of complications. However, for patients with recent or current VTE, BMI > 55 kg/m<sup>2</sup>, pulmonary hypertension, or absolute contraindication to chemical prophylaxis, a prophylactic IVC filter is appropriate. Morbidly obese patients should be counseled on the increased risk of perioperative DVT and the importance of early ambulation and prophylactic anticoagulation.

In summary, obesity is associated with a number of medical conditions that pose increased risks during gynecologic surgery. However, a thorough approach to preoperative assessment and management can significantly reduce untoward complications through preoperative medical management.

### Perioperative Considerations

Laparoscopy in the morbidly obese is challenging by definition, and thus, the preparation of patient, surgeon, operating room, and staff is paramount in order to safely and efficiently complete an operation. Beginning with the patient, preparation for the operation may include dietary restriction, antiseptic procedures, and mechanical bowel preparation (MBP). The theoretical advantage of MBP is to reduce intestinal volume and mass to improve intraoperative manipulation and

visualization. However, the authors and others prefer to forgo routine MBP, finding that the benefits are minimal and in certain cases the added weight of intraluminal contents helps maintain the bowel out of the pelvis with the Trendelenburg position. A meta-analysis of elective colorectal surgery has revealed no statistical advantage of MBP [46]. However, the studies reviewed were primarily open procedures and further evidence is needed for laparoscopic procedures.

Operating room preparation is critical, as specialized equipment and instruments tailored to the obese patients are frequently required and therefore must be available to prevent unnecessary delay and increased risk of conversion to an open approach. These include, but are not limited to, bariatric operating table and stirrups, positioning equipment, bariatric trocars and instruments, angled laparoscope, bowel fans, and other specialized instruments to improve intra-abdominal visualization. The absence of adequate instrumentation may needlessly result in conversion to laparotomy.

### Patient Positioning

Patient positioning is the most critical step in safely performing the minimally invasive gynecologic surgery. Especially for robotic surgery, the steep Trendelenburg position is required to visualize the pelvis. Unfortunately, this positioning is increasingly difficult to maintain in the obese patient, due to the excess weight and skin laxity that permits slippage on the operating table. Many devices are available to assist with obese patient positioning, including vacuum-molded bean bags, gel pads, convoluted (egg crate) and memory foam mattresses, OR table extenders, and shoulder supports.

Positioning begins with the patient in dorsal supine position. The authors prefer a convoluted or memory foam mattress compared with a beanbag, as the use of a beanbag precludes the use of a fixed retractor system (i.e., Bookwalter) should the case be converted to laparotomy. If permitted by the anesthesia team, the head extension is placed at the foot of the bed and the patient is placed farther down the operating table prior to induction of anesthesia. This reduces the distance the patient must be moved to position the perineum at the edge of the table and thus the risk of injury to staff. An upper body wedge is used by the anesthesia team if needed for intubation and then removed. After induction of anesthesia, the patient is placed in low lithotomy position with appropriately rated stirrups with the buttocks hanging at the edge of the break in the table. The arms are then tucked in neutral position at the patient's sides using a draw sheet and convoluted foam padding where needed to protect the ulnar nerve and hands. OR table extenders are used if increased width is needed to support the arms. In rare cases, the arms are unable to be tucked and require the use of arm boards for support. In these cases, the shoulders are abducted only as much as necessary,

padded, and secured with self-adherent wrap. Once the arms are positioned, shoulder supports are placed superioposteriorly against the scapula in order to minimize brachial plexus injury. A chest strap may also be placed across or above the padded breasts; however, the authors avoid its use to minimize any restriction to ventilation.

Once the patient is positioned, a tilt test is advisable to allow troubleshooting prior to draping. Importantly, the tilt test permits the evaluation of the patient's tolerance to the Trendelenburg position. The maintenance of normotension and the maximum peak inspiratory pressures of < 40 mmHg predict adequate tolerance of the steep Trendelenburg [47]. However, this procedure should be repeated after insufflation to ensure pneumoperitoneum does not compromise ventilation. If the panniculus shifts significantly with a change in position, it is advisable to secure redundant tissue caudally to prevent excess tension on the trocars and abdominal wall fascia. This can be accomplished prior to the procedure by fixing the panniculus to the thighs using cloth tape or Ioban Incise Drape (3M, St. Paul, MN). Fixing the panniculus intraoperatively should be avoided but can be accomplished using either penetrating towel clamps in the skin or a urinary catheter that is passed through the abdominal wall and inflated, either of which is affixed caudally to the operating table with a rolled bandage or similar.

### Intraperitoneal Access

It is important to consider the distortion of anatomic relationships in the obese patient. The dependency of the panniculus often results in inferior displacement of the umbilicus such that normal landmarks for port placement can be misleading. Thus, the bony structures should be used to estimate appropriate trocar placement. Often, a supra-umbilical incision is required for camera port placement to maintain appropriate triangulation and distance from the operative field.

There are myriad methods of entry to the peritoneum, which overall have been shown to be statistically similar in terms of safety [48]. Thus, the operator should be familiar with multiple entry sites and techniques should the need arise. Traditionally, the umbilicus represents thinnest part of the abdominal wall and thus the safest and simplest point to introduce pneumoperitoneum. Furthermore, given that the umbilicus is caudally displaced beneath the aortic bifurcation in obese patients, risk of vascular injury is minimized. Therefore, the authors prefer a direct Veress needle entry at the umbilicus in a patient without prior abdominal surgery. With this technique, the insufflator is attached and activated prior to Veress needle insertion. With the patient flat on the table, the needle is then placed directly into the base of the umbilicus at a 90° angle. The needle is advanced with attention paid to the pressure reading on the insufflator; an acute drop in pressure and increased flow rate signal successful

entry. The right upper quadrant is then percussed and the abdomen observed for uniform distension to assess for possible intraluminal insufflation. Once pneumoperitoneum is established, the supra-umbilical port is placed and the remainder of trocars are placed under direct visualization.

In patients with prior laparoscopic or abdominal surgery, the use of Palmer's point is encouraged [49]. With an orogastric tube in place to decompress the stomach, the Veress needle is introduced two fingerbreadths below the costal margin in the midclavicular line. This approach is also recommended after three failed attempts at transumbilical insufflation.

Once pneumoperitoneum is established and the patient is ventilating stably, the remainder of the trocars can be placed under direct visualization in order to maximize maneuverability and reach within the abdomen. The authors prefer a sunrise pattern, with the peak of the arch in the midline at the umbilicus for routine cases, or several centimeters cephalad for uteri greater than 18 weeks in size. Under direct visualization with the camera in place, the paramedian ports are then placed laterally and slightly inferiorly with care to avoid the epigastric vessels. Finally, the lower quadrant ports are placed laterally and inferiorly. The robotic system can then be docked. The authors prefer the Prograsp™ (Intuitive Surgical, Sunnyvale, CA) forceps in the LLQ, fenestrated bipolar in the left paramedian, and monopolar scissor in the RLQ. The right paramedian port is reserved for the 12-mm assistant port, which allows for the passage of suture and larger manual instruments such as bowel fans that may be required to improve visualization. While port utilization is subject to operator comfort and preference, the authors recommend a central docking approach to maximize the reach of the robotic instrument in obese patients. However, with the flexibility of the latest robotic platform (Da Vinci Xi, Intuitive Surgical), the issue of docking location is less critical.

### Uterine Manipulation

While its use may be severely limited in the obese patient, the uterine manipulator remains critical to the safe completion of the hysterectomy. Redundant perineal tissue or large uteri will equally limit the ability to maneuver the uterus within the abdomen. However, the integrated KOH ring on modern manipulators continues to provide surgical landmarks and ureteral protection, even in obese patients. Thus, the authors routinely use a uterine manipulator and KOH ring for all patients. Even if the uterus cannot be lateralized, cephalad traction will increase the distance of the uterine arteries and cervicovaginal junction from the ureters and increase the margin of safety when using thermal energy. Further manipulation in these cases is accomplished with a combination of the fourth robotic arm (Prograsp) and the bedside assistant.

### Challenges with General Anesthesia

The impact of anatomic and physiologic changes on oxygenation and airway management in obese patients is an important consideration in the perioperative setting. The increased amount of adipose tissue within the pharyngeal structures protrudes into the airway lumen, which results in narrowing of the lumen [50]. The combination of a large tongue, excessive upper airway soft tissue, and reduced pharyngeal dilator muscle function during periods of somnolence predisposes the obese patients to OSA [51]. Morbidly obese patients, with or without OSA, have been shown to experience frequent episodes of oxygen desaturation following laparoscopic bariatric surgery, despite supplemental oxygen therapy [52]. For these above-mentioned reasons, general anesthesia carries extra challenges in the obese patient population.

Difficulties with tracheal intubation significantly contribute to the morbidity and mortality associated with anesthesia. Oxygen desaturation may occur very quickly during apneic episodes since functional residual capacity is decreased [53]. In order to optimize success, pre-oxygenation before induction must be at least 5 min with a close-fitting face mask. Despite this effort, hypoxemia may still occur in morbidly obese patients. Although increased BMI imposes challenges on intubation, the severity of the patient's comorbidities is equally important. Sharp decrease in lung volume occurs with induction of anesthesia, as well as a decrease in lung compliance, and an increase in airway resistance. Following induction of general anesthesia in morbidly obese patients, the functional residual capacity decreases by approximately 50% compared with pre-anesthetic values. This contrasts with a 20% decrease in non-obese patients. These physiologic changes predispose the morbidly obese patients to rapid oxygen desaturation with the onset of apnea [50].

BMI represents the main risk factor for decreased lung compliance after induction of anesthesia and insufflation of pneumoperitoneum. Pneumoperitoneum and the Trendelenburg positioning add to the difficulty of maintaining adequate oxygenation throughout the procedure. Intra-abdominal pressure is significantly increased, usually up to 15 mmHg, during laparoscopic procedures. The increased abdominal pressure coupled with the Trendelenburg positioning compresses the diaphragm, which leads to an increased volume of atelectasis [54]. Obese patients may need to be taken out of the Trendelenburg position and have pneumoperitoneum released in cases of deoxygenation. Therefore, the surgeon and anesthesiologist need to be in close communication throughout the procedure. That being said, obese patients who tolerate induction of anesthesia and supine positioning are likely to tolerate pneumoperitoneum and the Trendelenburg positioning.

Mechanical ventilation and muscle paralysis in the obese patients under general anesthesia have been shown to impair

pulmonary function, lung compliance, and gas exchange as a result of reduced lung volume and atelectasis [50, 55]. As discussed, these changes are further exacerbated by pneumoperitoneum and the Trendelenburg positioning. Special attention should be paid to ventilatory strategies aimed at minimizing pulmonary complications [50]. Volume-controlled ventilation (VCV) has been the most frequently used mode of ventilation during general anesthesia for many years [56, 57]. This mode uses a constant flow to deliver a set tidal volume, but can result in higher airway pressures during laparoscopic procedures due to the counterpressure from pneumoperitoneum [58]. As discussed earlier, pneumoperitoneum results in decreased lung and chest wall compliance and reduced functional residual capacity which impairs alveolar ventilation and leads to ventilator induced lung injury [59]. Pressure-controlled ventilation (PCV) uses a decelerating flow which reaches the highest possible value at the beginning of inspiration, while having a preset maximum pressure with no minimum level for tidal volume. This has been attributed to the decelerating inspiratory flow delivery method, whereby high initial flow rates are delivered to quickly achieve and maintain the set inspiratory pressure followed by rapidly decelerating flow [60]. This high initial rate of flow leads to more rapid alveolar inflation and more homogenous distribution of ventilation to the lung and improving ventilation–perfusion mismatch [61]. However, PCV may result in low tidal volumes during pneumoperitoneum because of increased intra-abdominal pressure limiting inspired volume at a given pressure (i.e., reduced compliance). Using this mode results in low peak pressures and decreases the incidence of barotrauma, especially in obese patients. Therefore, specific ventilation techniques that may be helpful in the setting of morbid obesity include the use of pressure control ventilation [22].

Obese patients have been shown to develop a greater degree of atelectasis both intra- and postoperatively due to previously discussed changes in respiratory mechanics. This is further compounded by slower resolution of airway collapse compared with the non-obese patients [62]. To counteract this, the addition of positive end-expiratory pressure (PEEP) has been evaluated in the prevention of atelectasis and shown to be effective [63].

In a retrospective chart review on obese patients undergoing robotic gynecologic surgery, Wysham et al. evaluated pulmonary and all-cause complication rates and assessed variables that may be associated with pulmonary complications [64]. The ventilator parameters observed in this study were consistent with the recognized ranges for lung-protective intraoperative ventilation [65]. The median tidal volume (TV) was 489 mL, which was essentially within the lung-protective TV goal of 6–8 mL/kg of predicted body weight. Peak inspiratory pressure (PIP) below 30 cm H<sub>2</sub>O is considered lung-protective in the average patient, whereas somewhat higher pressures can also be considered safe when accounting for

decreased chest wall compliance, such as in obese patients, and for increased intra-abdominal pressures, such as in patients with abdominal insufflation for minimally invasive surgery (MIS). The patients in Wysham et al.'s study had a median PIP of 27 cm H<sub>2</sub>O, suggesting that even obese patients can undergo robotic gynecological surgery while maintaining a safe PIP [64]. The authors therefore concluded that pressure control ventilation is better than volume control ventilation in obese patients and that these patients can tolerate lower TV and higher PIP than considered lung-protective and still have minimal perioperative complications [64].

Airway complications and oxygenation issues may present immediately on emergence from anesthesia at the time of extubation, resulting in significant morbidity and mortality [66]. The Analysis of the American Society of Anesthesiologists Closed Claims Project database of causes of death or brain death showed that 17% of the cases (26/156) occurred at time of tracheal extubation and recovery, and 58% of the extubation claims (15/26) were encountered in obese patients [67]. The Difficult Airway Society published guidelines in 2012 for the management of tracheal extubation using a stepwise approach [68]. Patients with obesity and OSA are categorized as “at risk” of a major complication related to extubation. Recommendations for awake tracheal extubation in this patient population include patient optimization (full reversal of neuromuscular blockade and return of protective airway reflexes) and pre-oxygenation, placing the patient in a reverse Trendelenburg or semi-recumbent position, and suctioning of the oropharynx under direct visualization [68]. Logistical factors to be considered include selecting the operating room as the location for extubation and having skilled assistance, equipment (difficult airway trolley), and monitoring (in particular capnography) available. The Difficult Airway Society guidelines also advocate the placement of an airway exchange catheter in patients for whom tracheal reintubation is likely to be difficult [68]. In addition, patients who have been in the Trendelenburg position for a prolonged time during laparoscopic surgery are at increased risk of laryngeal edema [22]. If there is any evidence of this, intubation and sedation should be maintained until the swelling and edema resolve.

## Postoperative Considerations

Successful completion of a minimally invasive approach significantly reduces operative risk, such that many patients are now discharged on the day of surgery after increasingly complex operations. However, morbidly obese patients carry significantly increased perioperative risk and it is prudent to observe these patients in an inpatient setting for at least 23 h. Due to decreased baseline respiratory function, obese patients are at particularly high risk of

respiratory complications. This is particularly relevant to patients with OSA or OHS as the risk of pulmonary complications is increased in the setting of fluid shifts and anesthetic and narcotic administration associated with surgery [69, 70]. Moreover, a high suspicion for undiagnosed OSA is required, as over half of patients with OSA undergoing surgery have yet to be diagnosed [71]. For patients that undergo prolonged weaning from the ventilator or difficult extubation, monitoring in an ICU setting is mandatory. In obese patients with routine extubations, a floor setting is appropriate; however, the duration of oxygen therapy and post-anesthesia care unit (PACU) monitoring may be necessarily lengthened. However, care should be taken to avoid excessive  $\text{FiO}_2$  to prevent hypercapnia due to hypoventilation. If available, continuous pulse oximetry monitoring should be used to monitor respiratory status overnight. If continuous positive airway pressure (CPAP) therapy is used at home, it should be continued during admission. CPAP can also be applied postoperatively in patients who demonstrate hypoxemia, hypoventilation, or obstruction, though this may be technically challenging in some hospital settings. Additionally, aggressive pulmonary toilet and incentive spirometry should be used to minimize atelectasis. A semi-recumbent position is recommended to prevent worsening of OSA and improve oxygen exchange [72]. As in all patients, early ambulation should be encouraged to increase respiratory function and decrease the risk of VTE.

Choice of anesthesia has also been shown to impact postoperative recovery in the obese patient. A systematic review of 11 randomized controlled trials evaluating postoperative recovery in patients with morbid obesity showed that recovery was significantly longer with desflurane than with propofol anesthesia or with sevoflurane or isoflurane anesthesia. There were no significant differences in postoperative pain scores, PACU discharge time, or incidence of postoperative nausea and vomiting [73]. Moreover, caution should be used with opiate analgesia due to an increased risk of respiratory depression. Wherever possible, an opioid-sparing analgesia regimen should be used, including the use of neuraxial analgesia via epidural if feasible. If necessary, low doses of short-acting, lipophilic opioid such as fentanyl or hydromorphone may reduce the risk of respiratory depression and hypoxia.

Overall, morbidly obese patients receive the greatest risk reduction in perioperative morbidity with the successful completion of a minimally invasive operation. The obesity-related risks of upper airway obstruction, aspiration, and impaired cardiopulmonary physiology are predictable and can be mediated with well-orchestrated multidisciplinary team involving the surgical, anesthesia, respiratory therapy, and nursing teams.

## Surgical Outcomes for Robotics in Morbidly Obese

Despite the possible challenges of robotic surgery in obese patients, current data support the feasibility and safety of robotic surgery in this population [43, 74–78]. During early experiences with robotics, our group conducted a retrospective chart review of 442 women who underwent robotic-assisted laparoscopic hysterectomy for benign and malignant conditions over a 4-year period at an academic and community teaching hospital [43]. Of the 442 patients, 257 (58%) were obese or morbidly obese. Overall, the median estimated blood loss was 100 mL, the operative time was 135 min, and the length of stay was 1 day. These did not differ significantly by BMI groups. Overall, 11.9% of patients experienced complications (7.9% minor, 4.1% major), and this did not differ significantly across BMI groups. The conclusion from this study was that RTH can be performed safely in obese and morbidly obese patients, with surgical outcomes and complication rates similar to those in non-obese patients [43]. Particularly in gynecological oncology patients, robotic surgery has been shown to be feasible. Besides, robotics offers additional benefits of decreased blood loss, fewer transfusions, lower conversion rate to laparotomy, and shorter operative time over traditional laparoscopy [18, 79–81].

One outcome measure of robotic surgery in obese patients is the rate of conversion to laparotomy. Initial experience with laparoscopy/robotics in obese women suggested that increasing BMI may potentially lead to higher rates of conversion [7]. With the surgeon's increasing experience in laparoscopy, the conversion rates have been reported to decline [81–83]. In a retrospective chart review of 1032 obese patients by Wysham et al., 34% of patients had class I obesity, 28% had class II, and remaining 37% had class III obesity with a BMI greater than  $40 \text{ kg/m}^2$  [64]. The rate of conversion to laparotomy in this study was 4%. Only 6 patients (0.6%) required conversion due to failure to the Trendelenburg positioning, as measured by low tidal volumes or low oxygen saturation. The low conversion rates have been repeatedly reported by ours and other groups with studies including obese and morbidly obese patients [75, 81, 84].

Longer operative time has always been a criticism against laparoscopic approach when staging endometrial cancer patients. Along these lines, El Sahwi et al. compared the outcomes of 155 endometrial cancer patients who had robot-assisted surgical staging to 150 open cases [75]. In this retrospective chart review wherein mean BMI was  $34.5 \text{ kg/m}^2$ , the mean operative time was 127 min in the robotic arm and 141 min in the open arm ( $P=0.0001$ ). The adequacy of surgical staging was also compared. The mean lymph node counts were 20.3 in the robotic arm and 20 in the open arm ( $P=0.567$ ). Similarly, the incidence of postoperative complications was lower with the robotic approach. Specifically, the

incidence of postoperative ileus (0.6% vs. 10.7%,  $P = 0.0001$ ), infections (5.2% vs. 24%,  $P = 0.0001$ ), anemia/transfusion (1.3% vs. 7.7%,  $P = 0.005$ ), and cardiopulmonary complications (3.2% vs. 14.7%,  $P = 0.003$ ) was significantly lower in the robotic arm vs. the open arm [75]. The authors were able to demonstrate the benefits of MIS without compromising the adequacy of surgical staging in this obese patient population with endometrial cancer.

Surgical outcomes and complication rates are another important measure that requires discussion in this context. In a large retrospective chart review on obese patients who underwent robotic gynecological surgery, the primary outcome was pulmonary complications and the secondary outcome was all-cause complications [64]. Of 1032 patients, 146 patients (14%) had any complication, whereas only 33 patients (3%) had a pulmonary complication. The median body mass index was 37 kg/m<sup>2</sup>. Only age was significantly associated with a higher risk of pulmonary complications ( $P < 0.01$ ). Older age, higher estimated blood loss, and longer case length were associated with a higher rate of all-cause complications ( $P < 0.0001$ ,  $P < 0.0001$ , and  $P < 0.004$ , respectively). The authors reported that robotic-assisted gynecological surgery can be safely completed in obese patients, including those with class II–III obesity, without significant pulmonary or other complications [64].

Oncological outcomes are as important as surgical outcomes when robotic surgery is performed in the gynecologic oncology patient population. Menderes et al. evaluated the impact of body mass index (BMI) on the short- and long-term outcomes of patients with endometrial cancer who underwent robotic-assisted staging [81]. In this retrospective chart review of 364 patients with endometrial cancer, the mean (SD) BMI was 34.8 (10.1) kg/m<sup>2</sup>. Conversions from laparoscopy to laparotomy were in 3 (0.8%) of 364 cases. The mean (SD) operative time was 162.3 (54.6) min and the mean (SD) postoperative hospitalization was 1.6 (1.9) days. Although these results compared favorably with the landmark LAP2 study, they were in line with results from similar endometrial cancer laparoscopic staging studies [7, 76, 83, 85]. More interestingly, recurrence rates were consistently lower for patients with BMI greater than 30 kg/m<sup>2</sup> when compared with patients with BMI less than 30 kg/m<sup>2</sup> [81]. The promising oncological outcome data from this paper will hopefully continue to encourage gynecologic oncologists to offer MIS staging approaches for obese patients.

The favorable outcomes of MIS operations in obese patients have been consistent across other surgical specialties. Sundi et al. evaluated operative and pathologic outcomes of laparoscopic radical prostatectomy (LRP) and robot-assisted radical prostatectomy (RARP) in men with progressive changes in BMI category [86]. Of 987 patients, a total of 57% (563/987) of patients were overweight and 19.6% (193/987) were obese. There were no differences in estimated blood loss,

complications, pathologic stage, or recurrences across BMI categories [86]. Higher BMI was a significant predictor of longer operative time. The authors therefore concluded that obese man can safely undergo LRP or RARP and expect perioperative and early oncologic outcomes comparable with those of normal weight men without an increased risk of perioperative complications [86]. Similar encouraging results supportive of MIS in obese patients have been replicated in many other surgical specialties, including general surgery and bariatric surgery [87–91].

## Summary of Tips and Tricks

### General

- The proportion of obese women undergoing gynecologic surgery in the USA is on the rise.
- A woman with BMI > 30 kg/m<sup>2</sup> is at increased risk of diabetes mellitus, hypertension, and many other comorbidities.
- Obese patients are at greater risk of perioperative complications.
- Many of the perioperative risks of surgery in obese patients have been ameliorated with the advent of laparoscopic surgery.
- Body composition, rather than weight-to-height ratio alone, is a better predictor of obesity-related cardio-metabolic risk factors.

#### Physiologic changes in obese patients

- Oxygen consumption and carbon dioxide production are more pronounced.
- Chest wall compliance is decreased by excess body weight around the chest and under the diaphragm.
- General anesthesia and the steep Trendelenburg positioning reduce functional residual capacity.
- Cardiovascular changes occur in the form of larger stroke volume, increased cardiac output, decreased vascular resistance, and overall increased cardiac work.
- VTE is a serious perioperative concern in obese patients.

### Preoperative considerations

- A comprehensive medical history and physical examination should include assessment of a patient's exercise tolerance as well as OSA screening questions.
- A baseline electrocardiogram should be obtained in obese persons of any age undergoing major abdominal surgery since arrhythmias are common.
- Current medications should be carefully reviewed and all medications that increase the potential for bleeding should be discontinued.

### Positioning

- Use of an anti-skid material such as convoluted foam, gel pad, or surgical bean bag should be strongly considered in order to minimize downward shifting on the OR table.
- If a surgeon prefers to use the shoulder blocks, they should be placed over the acromioclavicular joint.
- Success with tucking both arms can be optimized with the use of bed extenders or arm boards.

### Anesthesia considerations

- Pre-oxygenation before induction of anesthesia must be performed for at least 5 min with a close-fitting face mask since oxygen desaturation occurs quickly after apneic episodes. Addition of PEEP should also be considered to prevent atelectasis.
- Pressure control ventilation is preferred in obese patients since it improves the lung ventilation–perfusion ratio, generates higher instantaneous flow peaks, and may enable better alveolar recruitment.
- Patients with obesity and OSA are at high risk of major complication during extubation. It is highly recommended that these patients are extubated once they are awake.

### Surgical considerations

- We do not recommend mechanical bowel preparation or enema since there is no convincing evidence to support its use.
- As BMI and central adiposity increase, the umbilicus migrates caudally with respect to the aortic bifurcation. Therefore, umbilical port should be placed at a right angle to the anterior abdominal wall.
- Effective communication between surgical and anesthesia teams is of paramount importance.
- The patient might need to be taken out of the Trendelenburg position for a period of time in order to improve oxygenation.
- A redundant rectosigmoid colon may be managed using a puppet stitch placed through the epiploic appendices, which is then attached to anterior abdominal wall.

### Postoperative considerations

- Obese patients who undergo robotic surgery should be observed for at least 23 h postoperatively since they are at increased risk for pulmonary and metabolic complications.
- Continuous pulse oximetry monitoring should be used to monitor respiratory status overnight.
- If continuous positive airway pressure (CPAP) therapy is used at home, it should be continued during admission.

- Aggressive pulmonary toilet and incentive spirometry should be used to minimize atelectasis.
- Early ambulation should be encouraged to increase respiratory function and decrease the risk of VTE.
- Caution should be used with opiate analgesia due to an increased risk of respiratory depression.
- Fluid resuscitation should be used judiciously in order to prevent volume overload.

### Compliance with Ethical Standards

**Conflict of Interest** Gulden Menderes, Stefan Gysler, Nalini Vadivelu, and Dan-Arin Silasi declare no conflict of interest.

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

### References

Papers of particular interest, published recently, have been highlighted as:

- Of importance
- Of major importance

1. Hales CM, Carroll MD, Fryar CD, Ogden CL. Prevalence of obesity among adults and youth: United States, 2015–2016. *NCHS Data Brief*. 2017;(288):1–8.
2. Jensen MD, Ryan DH, Apovian CM, Ard JD, Comuzzie AG, Donato KA, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and The Obesity Society. *J Am Coll Cardiol*. 2014;63(25 Pt B):2985–3023. <https://doi.org/10.1016/j.jacc.2013.11.004>.
3. Shah DK, Vitonis AF, Missmer SA. Association of body mass index and morbidity after abdominal, vaginal, and laparoscopic hysterectomy. *Obstet Gynecol*. 2015;125(3):589–98. <https://doi.org/10.1097/AOG.0000000000000698>.
4. Park DA, Yun JE, Kim SW, Lee SH. Surgical and clinical safety and effectiveness of robot-assisted laparoscopic hysterectomy compared to conventional laparoscopy and laparotomy for cervical cancer: a systematic review and meta-analysis. *Eur J Surg Oncol*. 2017;43(6):994–1002. <https://doi.org/10.1016/j.ejso.2016.07.017>.
5. Park DA, Lee DH, Kim SW, Lee SH. Comparative safety and effectiveness of robot-assisted laparoscopic hysterectomy versus conventional laparoscopy and laparotomy for endometrial cancer: a systematic review and meta-analysis. *Eur J Surg Oncol*. 2016;42(9):1303–14. <https://doi.org/10.1016/j.ejso.2016.06.400>. **A thorough meta-analysis demonstrating the benefits of robotic hysterectomy compared with open and laparoscopic approaches.**
6. Silasi DA, Gallo T, Silasi M, Menderes G, Azodi M. Robotic versus abdominal hysterectomy for very large uteri. *JLS*. 2013;17(3):400–6. <https://doi.org/10.4293/108680813X13693422521755>.
7. Walker JL, Piedmonte MR, Spirtos NM, Eisenkop SM, Schlaerth JB, Mannel RS, et al. Laparoscopy compared with laparotomy for comprehensive surgical staging of uterine cancer: Gynecologic Oncology Group Study LAP2. *J Clin Oncol*. 2009;27(32):5331–6. <https://doi.org/10.1200/JCO.2009.22.3248>.

8. Franzosi MG. Should we continue to use BMI as a cardiovascular risk factor? *Lancet*. 2006;368(9536):624–5. [https://doi.org/10.1016/S0140-6736\(06\)69222-2](https://doi.org/10.1016/S0140-6736(06)69222-2).
9. Romero-Corral A, Montori VM, Somers VK, Korinek J, Thomas RJ, Allison TG, et al. Association of bodyweight with total mortality and with cardiovascular events in coronary artery disease: a systematic review of cohort studies. *Lancet*. 2006;368(9536):666–78. [https://doi.org/10.1016/S0140-6736\(06\)69251-9](https://doi.org/10.1016/S0140-6736(06)69251-9).
10. Yusuf S, Hawken S, Ounpuu S, Bautista L, Franzosi MG, Commerford P, et al. Obesity and the risk of myocardial infarction in 27,000 participants from 52 countries: a case-control study. *Lancet*. 2005;366(9497):1640–9. [https://doi.org/10.1016/S0140-6736\(05\)67663-5](https://doi.org/10.1016/S0140-6736(05)67663-5).
11. Romero-Corral A, Somers VK, Sierra-Johnson J, Thomas RJ, Collazo-Clavell ML, Korinek J, et al. Accuracy of body mass index in diagnosing obesity in the adult general population. *Int J Obes*. 2008;32(6):959–66. <https://doi.org/10.1038/ijo.2008.11>.
12. Medeiros LRF, Rosa DD, Bozzetti MC, Fachel JMG, Furness S, Garry R, et al. Laparoscopy versus laparotomy for benign ovarian tumour. *Cochrane Database Syst Rev*. 2009;15(2):CD004751. <https://doi.org/10.1002/14651858.CD004751.pub3>.
13. Eltabbakh GH, Shamonki MI, Moody JM, Garafano LL. Hysterectomy for obese women with endometrial cancer: laparoscopy or laparotomy? *Gynecol Oncol*. 2000;78(3 Pt 1):329–35. <https://doi.org/10.1006/gyno.2000.5914>.
14. Gomel V. Operative laparoscopy: time for acceptance. *Fertil Steril*. 1989;52(1):1–11.
15. Tozzi R, Malur S, Koehler C, Schneider A. Analysis of morbidity in patients with endometrial cancer: is there a commitment to offer laparoscopy? *Gynecol Oncol*. 2005;97(1):4–9. <https://doi.org/10.1016/j.ygyno.2004.12.048>.
16. Eisenhauer EL, Wypych KA, Mehrara BJ, Lawson C, Chi DS, Barakat RR, et al. Comparing surgical outcomes in obese women undergoing laparotomy, laparoscopy, or laparotomy with panniculectomy for the staging of uterine malignancy. *Ann Surg Oncol*. 2007;14(8):2384–91. <https://doi.org/10.1245/s10434-007-9440-6>.
17. Obermair A, Manolitsas TP, Leung Y, Hammond IG, McCartney AJ. Total laparoscopic hysterectomy versus total abdominal hysterectomy for obese women with endometrial cancer. *Int J Gynecol Cancer*. 2005;15(2):319–24. <https://doi.org/10.1111/j.1525-1438.2005.15223.x>.
18. Boggess JF, Gehrig PA, Cantrell L, Shafer A, Ridgway M, Skinner EN, et al. A comparative study of 3 surgical methods for hysterectomy with staging for endometrial cancer: robotic assistance, laparoscopy, laparotomy. *Am J Obstet Gynecol*. 2008;199(4):360 e1–9. <https://doi.org/10.1016/j.ajog.2008.08.012>.
19. Bell MC, Torgerson J, Seshadri-Kreaden U, Suttle AW, Hunt S. Comparison of outcomes and cost for endometrial cancer staging via traditional laparotomy, standard laparoscopy and robotic techniques. *Gynecol Oncol*. 2008;111(3):407–11. <https://doi.org/10.1016/j.ygyno.2008.08.022>.
20. Wright JD, Ananth CV, Lewin SN, Burke WM, Lu YS, Neugut AI, et al. Robotically assisted vs laparoscopic hysterectomy among women with benign gynecologic disease. *JAMA*. 2013;309(7):689–98. <https://doi.org/10.1001/jama.2013.186>.
21. Kral JG. Morbidity of severe obesity. *Surg Clin North Am*. 2001;81(5):1039–61.
22. Scheib SA, Tanner E 3rd, Green IC, Fader AN. Laparoscopy in the morbidly obese: physiologic considerations and surgical techniques to optimize success. *J Minim Invasive Gynecol*. 2014;21(2):182–95. <https://doi.org/10.1016/j.jmig.2013.09.009>.
23. Roberts WC, Won VS, Vasudevan A, Guileyardo JM. Causes of death and heart weights in adults at necropsy in a tertiary Texas hospital, 2013–2015. *Am J Cardiol*. 2016;118(11):1758–68. <https://doi.org/10.1016/j.amjcard.2016.08.059>.
24. Mandal R, Loeffler AG, Salamat S, Fritsch MK. Organ weight changes associated with body mass index determined from a medical autopsy population. *Am J Forensic Med Pathol*. 2012;33(4):382–9. <https://doi.org/10.1097/PAF.0b013e3182518e5f>.
25. Kortelainen ML, Porvari K. Extreme obesity and associated cardiovascular disease verified at autopsy: time trends over 3 decades. *Am J Forensic Med Pathol*. 2011;32(4):372–7. <https://doi.org/10.1097/PAF.0b013e318219cd89>.
26. Rocha AT, de Vasconcellos AG, da Luz Neto ER, Araujo DM, Alves ES, Lopes AA. Risk of venous thromboembolism and efficacy of thromboprophylaxis in hospitalized obese medical patients and in obese patients undergoing bariatric surgery. *Obes Surg*. 2006;16(12):1645–55. <https://doi.org/10.1381/096089206779319383>.
27. Hamad GG, Chohan PS. Enoxaparin for thromboprophylaxis in morbidly obese patients undergoing bariatric surgery: findings of the prophylaxis against VTE outcomes in bariatric surgery patients receiving enoxaparin (PROBE) study. *Obes Surg*. 2005;15(10):1368–74. <https://doi.org/10.1381/096089205774859245>.
28. Wang LY, Cerny FJ. Ventilatory response to exercise in simulated obesity by chest loading. *Med Sci Sports Exerc*. 2004;36(5):780–6.
29. Saliman JA, Benditt JO, Flum DR, Oelschlager BK, Dellinger EP, Goss CH. Pulmonary function in the morbidly obese. *Surg Obes Relat Dis*. 2008;4(5):632–9; discussion 9. <https://doi.org/10.1016/j.soard.2008.06.010>.
30. Zavorsky GS, Murias JM, Kim DJ, Gow J, Sylvestre JL, Christou NV. Waist-to-hip ratio is associated with pulmonary gas exchange in the morbidly obese. *Chest*. 2007;131(2):362–7. <https://doi.org/10.1378/chest.06-1513>.
31. Vaughan RW, Cork RC, Hollander D. The effect of massive weight loss on arterial oxygenation and pulmonary function tests. *Anesthesiology*. 1981;54(4):325–8.
32. Singendonk M, Kritas S, Omari T, Feinle-Bisset C, Page AJ, Frisby CL, et al. Upper gastrointestinal function in morbidly obese adolescents before and 6 months after gastric banding. *Obes Surg*. 2018;28(5):1277–88. <https://doi.org/10.1007/s11695-017-3000-3>.
33. Cote-Daigneault J, Leclerc P, Joubert J, Bouin M. High prevalence of esophageal dysmotility in asymptomatic obese patients. *Can J Gastroenterol Hepatol*. 2014;28(6):311–4.
34. Jaffin BW, Knoepflmacher P, Greenstein R. High prevalence of asymptomatic esophageal motility disorders among morbidly obese patients. *Obes Surg*. 1999;9(4):390–5. <https://doi.org/10.1381/09608929976552990>.
35. Suter M, Giusti V, Calmes JM, Paroz A. Preoperative upper gastrointestinal testing can help predicting long-term outcome after gastric banding for morbid obesity. *Obes Surg*. 2008;18(5):578–82. <https://doi.org/10.1007/s11695-007-9341-6>.
36. Sugerma HJ. Effects of increased intra-abdominal pressure in severe obesity. *Surg Clin North Am*. 2001;81(5):1063–75 vi.
37. Glance LG, Wissler R, Mukamel DB, Li Y, Diachun CA, Salloum R, et al. Perioperative outcomes among patients with the modified metabolic syndrome who are undergoing noncardiac surgery. *Anesthesiology*. 2010;113(4):859–72. <https://doi.org/10.1097/ALN.0b013e3181eff32e>.
38. Valentijn TM, Galal W, Tjeertes EK, Hoeks SE, Verhagen HJ, Stolker RJ. The obesity paradox in the surgical population. *Surgeon*. 2013;11(3):169–76. <https://doi.org/10.1016/j.surge.2013.02.003>.
39. Abhyankar S, Leishear K, Callaghan FM, Demner-Fushman D, McDonald CJ. Lower short- and long-term mortality associated with overweight and obesity in a large cohort study of adult intensive care unit patients. *Crit Care*. 2012;16(6):R235. <https://doi.org/10.1186/cc11903>.
40. Chung F, Subramanyam R, Liao P, Sasaki E, Shapiro C, Sun Y. High STOP-Bang score indicates a high probability of obstructive

- sleep apnoea. *Br J Anaesth.* 2012;108(5):768–75. <https://doi.org/10.1093/bja/aes022>.
41. Poirier P, Alpert MA, Fleisher LA, Thompson PD, Sugerman HJ, Burke LE, et al. Cardiovascular evaluation and management of severely obese patients undergoing surgery: a science advisory from the American Heart Association. *Circulation.* 2009;120(1):86–95. <https://doi.org/10.1161/CIRCULATIONAHA.109.192575>.
  42. • Mechanick JI, Youdim A, Jones DB, Garvey WT, Hurley DL, McMahan MM, et al. Clinical practice guidelines for the perioperative nutritional, metabolic, and nonsurgical support of the bariatric surgery patient—2013 update: cosponsored by American Association of Clinical Endocrinologists, The obesity society, and american society for metabolic & bariatric surgery\*. *Obesity.* 2013;21(S1):S1–S27. <https://doi.org/10.1002/oby.20461>. **Multidisciplinary guidelines regarding the perioperative management of bariatric patients. Recommendations for perioperative optimizations apply directly to the obese gynecologic population.**
  43. Gallo T, Kashani S, Patel DA, Elshawi K, Silasi DA, Azodi M. Robotic-assisted laparoscopic hysterectomy: outcomes in obese and morbidly obese patients. *JSL.S.* 2012;16(3):421–7. <https://doi.org/10.4293/108680812X13462882735890>.
  44. Winegar DA, Sherif B, Pate V, DeMaria EJ. Venous thromboembolism after bariatric surgery performed by Bariatric Surgery Center of Excellence Participants: analysis of the Bariatric Outcomes Longitudinal Database. *Surg Obes Relat Dis.* 2011;7(2):181–8. <https://doi.org/10.1016/j.soard.2010.12.008>.
  45. Rahn DD, Mamik MM, Sanses TV, Matteson KA, Aschkenazi SO, Washington BB, et al. Venous thromboembolism prophylaxis in gynecologic surgery: a systematic review. *Obstet Gynecol.* 2011;118(5):1111–25. <https://doi.org/10.1097/AOG.0b013e318232a394>.
  46. Güenaga KF, Matos D, Wille-Jørgensen P. Mechanical bowel preparation for elective colorectal surgery. *Cochrane Database Syst Rev.* 2011;(9):CD001544. <https://doi.org/10.1002/14651858.CD001544.pub4>.
  47. Lamvu G, Zolnoun D, Boggess J, Steege JF. Obesity: physiologic changes and challenges during laparoscopy. *Am J Obstet Gynecol.* 2004;191(2):669–74. <https://doi.org/10.1016/j.ajog.2004.05.077>.
  48. Vilos GA, Ternamian A, Dempster J, Laberge PY, Clinical Practice Gynaecology C. Laparoscopic entry: a review of techniques, technologies, and complications. *J Obstet Gynaecol Can.* 2007;29(5):433–47. [https://doi.org/10.1016/S1701-2163\(16\)35496-2](https://doi.org/10.1016/S1701-2163(16)35496-2).
  49. Palmer R. Safety in laparoscopy. *J Reprod Med.* 1974;13(1):1–5.
  50. Murphy C, Wong DT. Airway management and oxygenation in obese patients. *Can J Anaesth.* 2013;60(9):929–45. <https://doi.org/10.1007/s12630-013-9991-x>.
  51. Benumof JL. Obesity, sleep apnea, the airway and anesthesia. *Curr Opin Anaesthesiol.* 2004;17(1):21–30.
  52. Ahmad S, Nagle A, McCarthy RJ, Fitzgerald PC, Sullivan JT, Prystowsky J. Postoperative hypoxemia in morbidly obese patients with and without obstructive sleep apnea undergoing laparoscopic bariatric surgery. *Anesth Analg.* 2008;107(1):138–43. <https://doi.org/10.1213/ane.0b013e318174df8b>.
  53. Juvin P, Lavaut E, Dupont H, Lefevre P, Demetriou M, Dumoulin JL, et al. Difficult tracheal intubation is more common in obese than in lean patients. *Anesth Analg.* 2003;97(2):595–600 table of contents.
  54. Tomescu DR, Popescu M, Dima SO, Bacalbasa N, Bubenek-Turconi S. Obesity is associated with decreased lung compliance and hypercapnia during robotic assisted surgery. *J Clin Monit Comput.* 2017;31(1):85–92. <https://doi.org/10.1007/s10877-016-9831-y>.
  55. Andersson LE, Baath M, Thorne A, Aspelin P, Odeberg-Wernerman S. Effect of carbon dioxide pneumoperitoneum on development of atelectasis during anesthesia, examined by spiral computed tomography. *Anesthesiology.* 2005;102(2):293–9.
  56. Movassagi R, Montazer M, Mahmoodpoor A, Fattahi V, Iranpour A, Sanaie S. Comparison of pressure vs. volume controlled ventilation on oxygenation parameters of obese patients undergoing laparoscopic cholecystectomy. *Pak J Med Sci.* 2017;33(5):1117–22. <https://doi.org/10.12669/pjms.335.13316>.
  57. Sen O, Umutoglu T, Aydin N, Toptas M, Tutuncu AC, Bakan M. Effects of pressure-controlled and volume-controlled ventilation on respiratory mechanics and systemic stress response during laparoscopic cholecystectomy. *SpringerPlus.* 2016;5:298. <https://doi.org/10.1186/s40064-016-1963-5>.
  58. Sprung J, Whalley DG, Falcone T, Warner DO, Hubmayr RD, Hammel J. The impact of morbid obesity, pneumoperitoneum, and posture on respiratory system mechanics and oxygenation during laparoscopy. *Anesth Analg.* 2002;94(5):1345–50.
  59. Adams JP, Murphy PG. Obesity in anaesthesia and intensive care. *Br J Anaesth.* 2000;85(1):91–108.
  60. Davis K Jr, Branson RD, Campbell RS, Porembka DT. Comparison of volume control and pressure control ventilation: is flow waveform the difference? *J Trauma.* 1996;41(5):808–14.
  61. Prella M, Feihl F, Domenighetti G. Effects of short-term pressure-controlled ventilation on gas exchange, airway pressures, and gas distribution in patients with acute lung injury/ARDS: comparison with volume-controlled ventilation. *Chest.* 2002;122(4):1382–8.
  62. Eichenberger A-S, Proietti S, Wicky S, Frascarolo P, Suter M, Spahn D, et al. Morbid obesity and postoperative pulmonary atelectasis: an underestimated problem. *Anesth Analg.* 2002;95(6):1788–92.
  63. Coussa M, Proietti S, Schnyder P, Frascarolo P, Suter M, Spahn DR, et al. Prevention of atelectasis formation during the induction of general anesthesia in morbidly obese patients. *Anesth Analg.* 2004;98(5):1491–5.
  64. Wysham WZ, Kim KH, Roberts JM, Sullivan SA, Campbell SB, Roque DR, et al. Obesity and perioperative pulmonary complications in robotic gynecologic surgery. *Am J Obstet Gynecol.* 2015;213(1):33 e1–7. <https://doi.org/10.1016/j.ajog.2015.01.033>.
  65. Kilpatrick B, Slinger P. Lung protective strategies in anaesthesia. *Br J Anaesth.* 2010;105(Suppl 1):i108–16. <https://doi.org/10.1093/bja/aeq299>.
  66. Cook TM, Woodall N, Frerk C, Fourth National Audit P. Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: anaesthesia. *Br J Anaesth.* 2011;106(5):617–31. <https://doi.org/10.1093/bja/aer058>.
  67. Peterson GN, Domino KB, Caplan RA, Posner KL, Lee LA, Cheney FW. Management of the difficult airway: a closed claims analysis. *Anesthesiology.* 2005;103(1):33–9.
  68. Difficult Airway Society Extubation Guidelines G, Popat M, Mitchell V, Dravid R, Patel A, Swampillai C, et al. Difficult Airway Society Guidelines for the management of tracheal extubation. *Anaesthesia.* 2012;67(3):318–40. <https://doi.org/10.1111/j.1365-2044.2012.07075.x>.
  69. Liao P, Yegneswaran B, Vairavanathan S, Zilberman P, Chung F. Postoperative complications in patients with obstructive sleep apnea: a retrospective matched cohort study. *Can J Anaesth.* 2009;56(11):819–28. <https://doi.org/10.1007/s12630-009-9190-y>.
  70. Kaw R, Chung F, Pasupuleti V, Mehta J, Gay PC, Hernandez AV. Meta-analysis of the association between obstructive sleep apnoea and postoperative outcome. *Br J Anaesth.* 2012;109(6):897–906. <https://doi.org/10.1093/bja/aes308>.
  71. Singh M, Liao P, Kobah S, Wijeyesundera DN, Shapiro C, Chung F. Proportion of surgical patients with undiagnosed obstructive sleep apnoea. *Br J Anaesth.* 2013;110(4):629–36. <https://doi.org/10.1093/bja/aes465>.
  72. Gross JB, Apfelbaum JL, Caplan RA, Connis RT, Cote CJ, Nickinovich DG, et al. Practice guidelines for the perioperative

- management of patients with obstructive sleep apnea an updated report by the American society of anesthesiologists task force on perioperative management of patients with obstructive sleep apnea. *Anesthesiology*. 2014;120(2):268–86.
73. Liu F-L, Cherng Y-G, Chen S-Y, Su Y-H, Huang S-Y, Lo P-H, et al. Postoperative recovery after anesthesia in morbidly obese patients: a systematic review and meta-analysis of randomized controlled trials Récupération postopératoire après anesthésie chez des patients présentant une obésité morbide: revue systématique et méta-analyse des essais randomisés contrôlés. *Can J Anesth*. 2015;62(8):907–17.
  74. Bernardini MQ, Gien LT, Tipping H, Murphy J, Rosen BP. Surgical outcome of robotic surgery in morbidly obese patient with endometrial cancer compared to laparotomy. *Int J Gynecol Cancer*. 2012;22(1):76–81. <https://doi.org/10.1097/IGC.0b013e3182353371>.
  75. ElSahwi KS, Hooper C, De Leon MC, Gallo TN, Ratner E, Silasi DA, et al. Comparison between 155 cases of robotic vs. 150 cases of open surgical staging for endometrial cancer. *Gynecol Oncol*. 2012;124(2):260–4. <https://doi.org/10.1016/j.ygyno.2011.09.038>.
  76. Tang KY, Gardiner SK, Gould C, Osmundsen B, Collins M, Winter WE 3rd. Robotic surgical staging for obese patients with endometrial cancer. *Am J Obstet Gynecol*. 2012;206(6):513–e1–6. <https://doi.org/10.1016/j.ajog.2012.01.002>.
  77. Subramaniam A, Kim KH, Bryant SA, Zhang B, Sikes C, Kimball KJ, et al. A cohort study evaluating robotic versus laparotomy surgical outcomes of obese women with endometrial carcinoma. *Gynecol Oncol*. 2011;122(3):604–7. <https://doi.org/10.1016/j.ygyno.2011.05.024>.
  78. Acholonu UC Jr, Chang-Jackson SC, Radjabi AR, Nezhat FR. Laparoscopy for the management of early-stage endometrial cancer: from experimental to standard of care. *J Minim Invasive Gynecol*. 2012;19(4):434–42. <https://doi.org/10.1016/j.jmig.2012.02.006>.
  79. Cardenas-Goicoechea J, Adams S, Bhat SB, Randall TC. Surgical outcomes of robotic-assisted surgical staging for endometrial cancer are equivalent to traditional laparoscopic staging at a minimally invasive surgical center. *Gynecol Oncol*. 2010;117(2):224–8. <https://doi.org/10.1016/j.ygyno.2010.01.009>.
  80. Gehrig PA, Cantrell LA, Shafer A, Abaid LN, Mendivil A, Boggess JF. What is the optimal minimally invasive surgical procedure for endometrial cancer staging in the obese and morbidly obese woman? *Gynecol Oncol*. 2008;111(1):41–5. <https://doi.org/10.1016/j.ygyno.2008.06.030>.
  81. Menderes G, Azodi M, Clark L, Xu X, Lu L, Ratner E, et al. Impact of body mass index on surgical outcomes and analysis of disease recurrence for patients with endometrial cancer undergoing robotic-assisted staging. *Int J Gynecol Cancer*. 2014;24(6):1118–25. <https://doi.org/10.1097/IGC.000000000000156>.
  82. Harr JN, Haskins IN, Amdur RL, Agarwal S, Obias V. The effect of obesity on laparoscopic and robotic-assisted colorectal surgery outcomes: an ACS-NSQIP database analysis. *J Robot Surg*. 2018;12(2):317–23. <https://doi.org/10.1007/s11701-017-0736-7>.
  83. Cosin JA, Brett Sutherland MA, Westgate CT, Fang H. Complications of robotic gynecologic surgery in the severely morbidly obese. *Ann Surg Oncol*. 2016;23(12):4035–41. <https://doi.org/10.1245/s10434-016-5340-y>.
  84. Wechter ME, Mohd J, Magrina JF, Cornella JL, Magtibay PM, Wilson JR, et al. Complications in robotic-assisted gynecologic surgery according to case type: a 6-year retrospective cohort study using Clavien-Dindo classification. *J Minim Invasive Gynecol*. 2014;21(5):844–50. <https://doi.org/10.1016/j.jmig.2014.03.016>.
  85. Iavazzo C, Iavazzo PE, Gkegkes ID. Obese patients with endometrial cancer: is the robotic approach a challenge or a new era of safer and more cost-effective management of such patients? *J Robot Surg*. 2016;10(2):183–4. <https://doi.org/10.1007/s11701-016-0566-z>.
  86. Sundi D, Reese AC, Mettee LZ, Trock BJ, Pavlovich CP. Laparoscopic and robotic radical prostatectomy outcomes in obese and extremely obese men. *Urology*. 2013;82(3):600–5. <https://doi.org/10.1016/j.urology.2013.05.013>.
  87. Ackerman SJ, Daniel S, Baik R, Liu E, Mehendale S, Tackett S, et al. Comparison of complication and conversion rates between robotic-assisted and laparoscopic rectal resection for rectal cancer: which patients and providers could benefit most from robotic-assisted surgery? *J Med Econ*. 2018;21(3):254–61. <https://doi.org/10.1080/13696998.2017.1396994>.
  88. Zheng M, Ma J. Advantages and disadvantages of minimally invasive surgery in colorectal cancer surgery. *Zhonghua Wei Chang Wai Ke Za Zhi*. 2017;20(6):601–5.
  89. Ayloo S, Roh Y, Choudhury N. Laparoscopic, hybrid, and totally robotic Roux-en-Y gastric bypass. *J Robot Surg*. 2016;10(1):41–7. <https://doi.org/10.1007/s11701-016-0559-y>.
  90. Tzvetanov I, Bejarano-Pineda L, Giulianotti PC, Jeon H, Garcia-Roca R, Bianco F, et al. State of the art of robotic surgery in organ transplantation. *World J Surg*. 2013;37(12):2791–9. <https://doi.org/10.1007/s00268-013-2244-x>.
  91. Vasilescu C, Procopiuc L. Robotic surgery of locally advanced gastric cancer: a single-surgeon experience of 41 cases. *Chirurgia (Bucharest, Romania : 1990)*. 2012;107(4):510–7.

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.