Overcoming challenges in minimally invasive gynecologic surgery

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Abstract: Minimally invasive surgery (MIS) has gained widespread use over the past several decades and is now the prevailing surgical approach within gynecology through utilization of hysteroscopy, cystoscopy, laparoscopy, and vaginal surgery. A minimally invasive technique offers a number of benefits to patients, including improved postoperative recovery and superior cosmetic outcomes, and is becoming an increasingly recognized essential skill for all gynecologists. With appropriate precautions and preoperative planning, MIS has been shown to be a safe and effective option for gynecologic procedures. Certain patient populations may present specific challenges to the minimally invasive surgeon. In this article, we discuss commonly encountered challenges in gynecologic MIS. Given the effect that laparoscopy and positioning may have on organ physiology, we review preoperative planning and optimization for medically complex patients. Additionally, we discuss the approach to surgically complex patients, such as those with obesity, pregnancy, prior surgeries with associated scarring and adhesions, and other anatomic abnormalities. As MIS continues to be a growing and evolving field, we highlight novel surgical technologies and discuss the learning curve associated with adoption of new techniques. Through surgeon preparedness and experience, common pitfalls within the field of MIS may be avoided and patients may be provided with optimal care.

Keywords: Minimally invasive surgery (MIS); gynecology; laparoscopy; obesity; comorbidities; challenges

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Introduction

Minimally invasive surgery (MIS) is currently the most popular method of surgical intervention in gynecology. MIS is a surgery during which surgical incisions are minimized to reduce trauma to the body and is widely used in gynecology through multiple techniques including hysteroscopy, cystoscopy, vaginal surgery, and laparoscopy. These techniques together comprise the majority of cases performed by gynecologists today, rather than traditional open abdominal techniques. However, with the rapid evolution of techniques comes a unique set of challenges that must be overcome to optimize MIS.

MIS has continuously evolved since its modern inception in the 1970s when the first laparoscopic appendectomy was performed by a German gynecologist. The use of video cameras revolutionized MIS by allowing for improved posture and visualization during surgery. The first laparoscopic hysterectomy was performed in 1988 in Pennsylvania (1). Robotic surgery was introduced and heavily marketed to gynecologists in 2000 when the da Vinci Surgical System was approved by the Food and Drug Administration.

Hysterectomy has rapidly become one of the most common MIS surgeries performed in the US. The American College of Obstetricians and Gynecologists

(ACOG) states that laparoscopic hysterectomy is preferred over open abdominal hysterectomies to improve patient outcomes (2). When compared with open abdominal surgery, MIS procedures have been shown to have decreased postoperative hospital stay length and shorter recovery times (2). Minimally invasive hysterectomy options have led to decreased rates of open abdominal hysterectomy from 65% in 1998 to 54% in 2010, with a correlating increase in MIS, specifically in laparoscopic and robot-assisted hysterectomies (3).

Now, ten years later, US Obstetrics and Gynecology residents perform the vast majority of their hysterectomy cases through an MIS approach, implying that the number of minimally invasive hysterectomy cases has continued to increase. The Accreditation Counsel on Graduate Medical Education (ACGME) in collaboration with ACOG recently adjusted the required number of hysterectomy cases for graduating US residents to compensate for this increase in MIS by drastically decreasing the required number of total abdominal hysterectomies while increasing the total number of hysterectomies required (4). Thus, MIS is becoming an increasingly recognized essential skill for all gynecologists.

On the other hand, MIS brings unique challenges. As the global population becomes more obese, an increasing number of health problems will plague our patients. These conditions can make MIS, particularly laparoscopy, more challenging. Many of these situations can be addressed with careful preoperative planning. In this review, we aim to outline common challenges encountered with MIS and discuss how these can be addressed during and prior to laparoscopic gynecologic surgery.

Comorbid conditions

As with any surgery, prior to proceeding with MIS it is the responsibility of the provider to assess a patient for candidacy. A thorough evaluation of comorbid conditions must be conducted to understand the surgical risks and benefits for each individual. The American Society of Anesthesiologists (ASA) Physical Status Classification System groups patients into one of four categories ranging from an ASA I (a "normal healthy" patient) to ASA IV (a patient with "severe systemic disease that is a constant threat to life") and can stratify patients' preoperative risk based on existing comorbidities (5). Other tools incorporate existing comorbidities with the type of surgery to provide a risk estimate for adverse outcomes, such as the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) Surgical Risk Calculator (6)

Once a patient has been determined to be an appropriate surgical candidate, the surgeon must optimize the patient prior to their surgery. Guidelines such as the National Institute for Health and Excellent Care (NICE) Routine Preoperative Tests for Elective Surgery can aid surgeons in determining appropriate preoperative testing (7). However, general guidelines may fall short of addressing the individual needs of a complicated patient. Such patients often benefit from risk assessment with their primary care doctor or disease-specific specialist. Preoperative evaluation by an anesthesiologist may also be warranted. Postoperatively, while the opportunity for ambulatory surgery is often possible with MIS, the presence of comorbid conditions may warrant additional observation including overnight admission.

Although very few conditions serve as absolute contraindications to surgery, the decision to proceed with surgery in a patient with comorbidities requires proper counseling and shared decision-making. The remainder of this section will detail the impact of laparoscopic MIS in commonly occurring conditions.

Pulmonary

In laparoscopy, abdominal insufflation causes increased intraabdominal pressure (*Table 1*) (8-10). The diaphragm is pushed cephalad resulting in a number of changes in pulmonary function: decreased lung compliance and functional residual capacity, as well as increased airway pressures and degree of V/Q mismatch. Trendelenburg positioning potentiates these respiratory effects.

Pulmonary disease is commonly encountered in candidates for gynecologic MIS. Obstructive lung diseases such as asthma and chronic obstructive pulmonary disease (COPD) affect 330 million and 210 million people worldwide, respectively. Restrictive lung disease is less common but when present requires close attention in a surgical candidate. While routine use of imaging and pulmonary function tests are not recommended prior to surgery, careful assessment of existing symptoms and treatment of overlying respiratory infection or exacerbation when identified is warranted (11).

A retrospective study by Galvis *et al.* evaluated patients who underwent laparoscopic hysterectomy and compared outcomes between patients with and without COPD (12). Patients with COPD were three times more likely to suffer

Table 1 Physiologic effects of abdominal insufflation and Trendelenburg position on organ system function (8-10)

Organ system	Decreased	Increased
Cardiac	Venous return	Systemic vascular resistance
	Cardiac output	
Pulmonary	Compliance	Peak pressure
	Lung volume	Plateau pressure
		V/Q mismatch
Renal	Glomerular filtration rate	
	Urine output	
Neurologic		Intracranial pressure

a postoperative complication (15% *vs*. 5%), including the development of pneumonia, need for reintubation, and extended hospital stay. Similar results have been demonstrated in literature outside of the field of gynecology. Sujatha-Bhaskar *et al.* studied patients with COPD undergoing colectomies and found that a laparoscopic approach was associated with lower rates of respiratory complications than that of an open approach (13). Liao *et al.* evaluated patients with and without COPD undergoing laparoscopic cholecystectomy and found that patients with COPD had longer hospitalizations and increased mortality (14).

If pulmonary status is such that avoidance of both abdominal insufflation and intubation is desired to prevent respiratory compromise, an alternate option is vaginal surgery performed under regional anesthesia. This option circumvents the physiologic changes of increased intraabdominal pressures. The GOSSIP trial demonstrated feasibility of this option in patients with pelvic floor disorders (15). Other studies have also supported the feasibility of spinal anesthesia during vaginal hysterectomy, including Tessler *et al.*, in which no clinically significant difference in operative time was appreciated in patients undergoing vaginal hysterectomy under spinal anesthesia compared to general anesthesia (16).

Cardiac

The cardiovascular system is affected by abdominal insufflation in a phasic manner dependent on the degree of insufflation. At an intraabdominal pressure of <10 mmHg, the increase in pressure causes a rise in venous return due to the expulsion of blood from the splanchnic venous system and inferior vena cava (IVC). This initial rise in circulating blood causes a temporary increase in cardiac output. At intraabdominal pressures of 10–20 mmHg, typical of most gynecologic laparoscopic procedures, the compression of the IVC leads to decreased venous return, increased systemic vascular resistance, and decreased cardiac output (*Table 1*). Similarly, intraabdominal pressures >20 mmHg may have significant effects on venous return with a decrease in cardiac output (8). Neuraxial anesthesia affects the cardiovascular system as well, potentially causing hypotension as a result of vasodilation and blockade of the sympathetic nervous system or bradycardia (17).

Cardiovascular disease is one of the most common conditions among adults and a leading cause of deaths worldwide (18). The 2014 American College of Cardiology/American Heart Association Guideline on Perioperative Cardiovascular Evaluation provides an algorithm and summary of recommendations regarding preoperative cardiac evaluation (19). Patients with known cardiac disease, age 65 years and older, or ASA class III or higher may benefit from undergoing an electrocardiogram (ECG) prior to surgery (20). However, it is not unreasonable to consider ECG for any patient except those that are asymptomatic and undergoing a low risk surgery (19). Additional preoperative assessment of patients with known heart disease or at risk for heart disease should include exercise tolerance testing, as poor performance during testing correlates with increased postoperative complications (20). Patients with poor functional capacity, who cannot perform exercise tolerance testing, may benefit from pharmacologic stress testing and evaluation of left ventricular function. A patient requiring revascularization should undergo such a procedure with ample time preceding elective gynecologic surgery.

Patients with new or recently worsened congestive heart failure were retrospectively studied by Speicher *et al.* to compare open and laparoscopic procedures (appendectomy, colectomy, small bowel resection, splenectomy, and ventral hernia repair) (21). Laparoscopy was associated with a decreased 30-day mortality risk (adjusted OR 0.45; 95% CI, 0.21–0.95. P=0.04) and shorter postoperative hospital stays. While morbidity was high in both laparoscopic and open surgery, the authors conclude that laparoscopy is a viable alternative to open surgery in patients with CHF.

Consistent with the high rate of morbidity and mortality identified above, a retrospective study found that patients with newly diagnosed or decompensated CHF undergoing elective laparoscopic cholecystectomy had an increased risk of pneumonia, reintubation, and death compared to those without CHF (odds ratio 3.9, 4.1, and 8.2, respectively) (22). Although gynecologic data is lacking, such results suggest the need for careful selection of surgical candidates and optimization of cardiac disease prior to gynecologic MIS.

Renal

Increases in intraabdominal pressure with insufflation result in decreased blood flow to the renal system (8). This subsequently causes a decrease in glomerular filtration rate (GFR) and urinary output (*Table 1*). Careful fluid management during laparoscopic procedures may help maintain adequate renal perfusion. Neuraxial anesthesia rarely affects renal physiology in a clinically significant manner.

Chronic kidney disease affects 11–13% of people worldwide and can range from mild disease (stage 1) to end stage renal disease (ESRD; stage 5) based on GFR (23). A routine basic metabolic panel is not recommended in healthy patients undergoing low-risk surgery. Patients ASA class II or higher may benefit from measurement of renal function, as many patients undergoing surgery are at risk for development of renal injury (20). Renal disease may also contribute to electrolyte disturbances, anemia, and platelet dysfunction which may be corrected prior to surgery (24).

In a series of five patients with ESRD on hemodialysis who underwent laparoscopic hysterectomy for abnormal uterine bleeding (25), none of the patients experienced additional organ failure, infection, heavy bleeding, or death within the perioperative period. While data on gynecologic MIS in patients with renal disease is limited, ESRD patients undergoing laparoscopic bariatric procedures had a low overall 30-day mortality rate (0.7%).

Hepatic

Liver disease accounts for two million deaths worldwide each year (26). Hepatic dysfunction affects multiple organ systems, leading to hematologic and electrolyte abnormalities. Additionally, ascites, varices, portal vein thromboses, portal hypertension, encephalopathy, and renal failure may be seen in patients with liver disease. Multiple scoring systems have been designed to classify the severity and mortality associated with liver disease, including the Child-Pugh and Model for End-stage Liver Disease (MELD) classification systems. The Child-Pugh score predicts postoperative mortality rates: 10% for class A, 30% for class B, and 76–82% for class C (27). Despite the morbidity of liver disease, preoperative testing of liver function is generally not indicated in asymptomatic patients without liver disease (20).

While surgical outcomes in patients with cirrhosis are historically quite poor, advances in medical management and surgical techniques may have improved outcomes. A 2012 retrospective study of patients undergoing laparoscopic cholecystectomies demonstrated morality rates as low as 0.12% for Child-Pugh class A and 0.97% for class B (28). Thus, gynecologic MIS may be an option for carefully selected patients with liver disease. Elective surgery is generally acceptable in a patient with Child-Pugh class A cirrhosis or a MELD score less than 10 (29). If possible, patients with acute liver disease should generally have non-urgent surgery deferred until resolution.

Neurologic

Abdominal insufflation and Trendelenburg position are both associated with increases in intracranial pressure (*Table 1*) (8-10). Both intraocular pressure and ocular nerve sheath diameter have been shown to correlate with intracranial pressure and are increased with steep Trendelenberg positioning (30,31). Neuraxial anesthesia, while generally without notable direct effect to the central nervous system (CNS), comes with risk of dural puncture and leakage of cerebral spinal fluid, potentially affecting CNS pressure equilibrium.

Gynecologic MIS in patients with known intracranial lesions should be individualized with close discussion with a neurologist regarding risk of herniation and other adverse outcomes (28,32). Proceeding with surgery may be reasonable in patients with minimal to no risk of herniation.

Obesity

Numerous studies have refuted the previously held perspective that laparoscopic surgery was not safe for the obese population (33). Gynecologic MIS is now considered a superior option relative to open abdominal surgeries regarding postoperative outcomes for both obese and non-obese patients (34). Compared to the laparoscopic approach, open abdominal hysterectomies have shown a five-fold increase in wound dehiscence and infection risk in the obese population (35). Even compared to vaginal hysterectomy in obese patients, laparoscopic hysterectomy has shown to have decreased hospital length of stay, lower blood loss, and higher likelihood of obtaining desired removal of adnexal structures, with both approaches having similar operative times (36).

Robot-assisted surgery is also feasible in an obese population, although increasing obesity class has been associated with increasing rates of converting to open laparotomy (37). By any surgical approach, each phase of the surgical process should consider a patient's body mass index (BMI) to minimize the significant risk of morbidity in these patients (38).

Preoperative considerations

Obese patients, defined by the Center for Disease Control as BMI ≥30 kg/m^2, are at increased surgical risk in part due to their higher likelihood of having comorbid conditions within multiple organ systems including pulmonary (obstructive sleep apnea, obesity hypoventilation syndrome), endocrine (diabetes, metabolic syndrome), and cardiac (coronary artery disease, hypertension,) disease (38). Preoperative screening for underlying disease is recommended (hemoglobin A1c, ECG, STOP BANG questionnaire) (39). If results are abnormal, referral to the appropriate subspecialty, including anesthesiology for those at risk for respiratory compromise, is recommended prior to surgery. Otherwise, outside referral for preoperative risk assessment is not indicated.

Intraoperative considerations

Although the laparoscopic approach is feasible and widely accepted, the obese patient presents significant technical challenges. One of the main obstacles is the patient's thick abdominal wall leading to a high baseline intraabdominal pressure. This increased pressure can be displaced onto the patient's chest when positioned in Trendelenburg for adequate visualization of pelvic structures in laparoscopic or robot-assisted surgery. Further, obtaining adequate pneumoperitoneum may be limited due to the patient's baseline restrictive pulmonary status secondary to body habitus. Thus, steep Trendelenburg and higher insufflation pressures, although preferable from a visualization standpoint, may need to be minimized to prevent ventilation difficulties.

Wysham *et al.* performed a large respective study showing no difference in perioperative pulmonary complications (desaturations) or all-cause complication rates across different obesity classes in robotic gynecologic surgeries, although the class III obesity (BMI >40) subgroup analysis trended towards significance (40). Fuentes *et al.* showed that obese patients were seven times more likely to require open laparotomy due to failure to be able to initiate laparoscopic surgery (41). However, a different study found that conversion to laparotomy was more commonly a result of failure to remove an enlarged uterus due to its size more so than failure to tolerate Trendelenburg positioning (40).

Visualization during laparoscopic surgery on an obese patient is further compromised by excess visceral and preperitoneal adipose, redundant colon, and poor surgeon ergonomics. The frequency of complications, including conversion to open laparotomy, was higher in more technically challenging cases, including patients with prior surgeries and those of higher obesity class (41). The frequency of this complication is decreased with greater level of experience in the surgeon. The enhanced dexterity of the robotic 'wrists' allowing for increased operative mobility, 3D visualization, and reduced surgeon fatigue are several advantages of robot-assisted surgery within this patient population (42). The robotic approach has been shown to be safe despite the increased need for steep Trendelenburg compared to laparoscopy (40).

Obesity distorts anatomic landmarks typically used in gynecologic MIS since gravity deflects the patient's pannus caudally. Relative to the non-obese patient, trocars should be placed more laterally and cephalad to compensate. Given the malposition of the umbilicus and that standard Veress needle placement is associated with higher rates of false entry and preperitoneal insufflation in this population, alternative techniques such as left upper quadrant entry, Hassan, or optical trocars may aid in successful laparoscopic entry (43). If the Veress needle is used at the umbilicus, the longer 150 mm needle should be considered and introduced at a 90-degree angle to the patient's abdominal wall. The patient should be appropriately positioned using bariatric equipment, including bed extenders, anti-skid pad, shoulder support, bariatric stirrups, and ample padding at all sites that may be damaged by pressure sore or nerve injury. Fascia at all trocar sites greater than 10 mm should be closed given the increased risk of herniation, especially with risk of expansion of fascial openings during difficult trocar placement (44).

Postoperative considerations

While obesity is not an independent contraindication to same-day discharge, additional monitoring may prevent postoperative complications seen more commonly in the obese population, such as pulmonary, thromboembolic, and glycemic-control complications (45). Intravenous fluids should be minimized to prevent volume overload which can lead to pulmonary edema (38). Narcotics should be minimized to prevent exacerbation of hypoventilation and subsequent hypoxia, especially in patients with sleep apnea. Administration of weight-adjusted heparin has been proven to decrease the risk of venous thromboembolism (VTE) in this population (46). Early ambulation is encouraged to decrease the risk of atelectasis and VTE. Patients with diabetes should have careful glucose monitoring given the adrenergic response seen postoperatively, as tighter glycemic control may decrease the risk of surgical site infections (47).

Non-obstetric surgery during pregnancy

Surgery is commonly indicated during pregnancy, with up to 2% of pregnant patients undergoing non-obstetric surgery (48). Reluctance or deferral of necessary surgery in the antenatal period due to pregnancy status is not only considered outdated, but poor practice. The historical perspective that surgery may cause unwanted obstetric outcomes was born of low-quality data and is misleading, serving only to disadvantage pregnant women with surgical disease (49). The relative safety of necessary diagnostic imaging and general anesthesia has been established (50,51). Effects on children born after maternal surgeries in pregnancy have not been well studied, but thus far no long-term effects have been shown (52).

The specific hypothetical concern for abdominal laparoscopic surgery is in regard to the intraperitoneal pressure from insufflation. This causes increased thoracic pressure, potentially inducing maternal hypercapnia leading to negative fetal effects: hypercapnia, tachycardia, and hypertension. There is also the concern that the increase in intraperitoneal pressure will decrease uterine blood flow and maternal venous return. In reality, these effects have not manifested, but the Society of American Gastrointestinal and Endoscopic Surgeons still recommends utilizing decreased insufflation pressures of 10–15 mmHg (53).

Left upper quadrant entry or ultrasound can be used to avoid uterine injury during initial trocar placement. Laparoscopy may have the added benefit of less uterine manipulation, thus reducing potential disruption of the pregnancy relative to laparotomy. Laparoscopy also offers an improved postoperative course including less pain and subsequent narcotic use, which is especially favorable from a fetal standpoint. A retrospective study from Japan examined commonly performed surgeries during pregnancy and showed a decreased likelihood of adverse fetal events in the laparoscopic group compared to the laparotomy group (54).

Thus, while elective surgery should be avoided during pregnancy, indicated surgical procedures should not be delayed, and a laparoscopic approach is considered a safe surgical option. Special considerations regarding changes in maternal physiology should be carefully accounted for by surgical and anesthesia providers (55). The most common non-obstetric MIS procedures performed in pregnancy (appendectomy and cholecystectomy) are not performed by gynecology and thus will not be reviewed in this article (56,57). Rather, we will focus on specific challenges for gynecologic MIS during pregnancy. Of note, all studies involving postoperative pregnancy-related outcomes are confounded by the underling condition necessitating surgery.

Abdominal cerclage

A widely accepted treatment of prior cervical insufficiency is cervical cerclage placement, with transvaginal cerclage (TVC) placement much more commonly used than transabdominal cerclage (TAC). TAC is more invasive, with higher bleeding and complication risk than compared to TVC. As such, TAC is utilized only when TVC fails or is not possible due to lack of cervical tissue, such as in women with prior cervical excision procedures (58). While interval placement between pregnancies offers multiple advantages, often patients require TAC during pregnancy. While both abdominal and laparoscopic approaches are considered safe obstetrically, laparoscopic TAC was associated with lower complication rates, including hemorrhage and infection, and required a shorter hospital stay. Also, laparoscopic TAC was found to be associated with higher rates of delivery beyond 34 weeks gestation (59).

When a TAC is performed during pregnancy, there is higher likelihood of uterine manipulation and bleeding leading to greater risk of conversion to laparotomy compared to pre-pregnancy procedures (60). This risk is possibly due to post-conception cervical inflammation or shortening. Further, careful technique to place the suture between the uterine vessels and cervical stroma may be more difficult without the use of a uterine manipulator to twist the uterus for improved visualization (58).

Lastly, robot-assisted laparoscopic TAC, although more rarely performed, has been shown to be feasible during pregnancy. While surgical times are longer in robot-assisted laparoscopic TAC than in traditional laparoscopic cases, robotic technology offers the potential for improved visualization of cervical vascularity and tissue, including the concomitant use of indocyanine green dye with the near-infrared camera system or simultaneous display of transvaginal ultrasound (61).

Adnexal masses

Incidental adnexal masses are commonly found during first trimester ultrasounds (1–5% of patients), with the majority being corpus luteal cysts (70%) which typically resolve by the second trimester, followed by dermoid cysts and serous cystadenomas (62). The most common indication for surgical management of adnexal masses in pregnancy is ovarian torsion followed by removal for persistent mass which may be symptomatic or concerning for malignancy (63,64). A retrospective cohort study looking at obstetric outcomes for laparoscopic adnexal surgery in the first versus second trimester showed that both trimesters are relatively safe. However, the trimesters are somewhat difficult to compare given that far more surgeries were performed urgently for ovarian torsion in the first trimester and that baseline pregnancy loss rates are much higher in the first trimester. The authors of this study further observed that undesired obstetrical outcomes (fetal loss, preterm birth) were multifactorial, as most occurred in patients with other risk factors such as uterine anomalies, artificial reproductive technology, twin gestation, or preterm rupture of membranes (65). In comparing laparoscopic and open abdominal cases, a metanalysis including 985 patients showed no difference in fetal loss or operative time, but did show a lower incidence of preterm birth, decreased blood loss, and shorter hospital stays in patients who underwent laparoscopic adnexal surgery (66).

Urgent surgeries in the third trimester

It is preferable that indicated adnexal surgery be performed in the first half of pregnancy to avoid the difficulty of decreased visualization while avoiding injury to the enlarged gravid uterus. Data on laparoscopic surgeries beyond the second trimester are limited. Special precautions recommended in third trimester surgeries include positioning the patient with leftward tilt to offset the weight of the gravid uterus from the IVC and placing the trocars cephalad as needed. No robust studies to aid formal guidelines have been performed. Thus, the Society of American Gynecologic and Endoscopic Surgeons does not make formal recommendations.

Cohen *et al.* described a case series of twelve pregnant patients presenting with acute abdomen undergoing urgent surgery between 27–39 weeks gestation (7 appendicitis, 4 ovarian torsions, and 1 diagnostic) (67). All twelve cases had continuous external fetal heart rate monitoring throughout surgery. Trocar placement location was determined based on fundal height and intended surgery (left upper quadrant used in 4 cases), and entry approach was mostly with Hasson (9 cases) rather than Veress. No complications due to trocar placement occurred. One case with ruptured appendicitis at 30 weeks gestation required conversion to laparotomy for better visualization. Immediate postoperative obstetric complication occurred in one patient (prelabor rupture of membranes) which was potentially physiologic as the patient was at term. All patients were monitored postoperatively and only one patient received nifedipine for preterm contractions. Fetal and obstetrical outcomes did not appear to be directly affected by the surgeries, as the two preterm deliveries observed in this case report occurred in the late preterm period, many weeks after surgery. Thus, laparoscopy is feasible in all trimesters and may be preferable to open abdominal surgery to limit maternal morbidity and adverse fetal outcomes.

Challenges for trocar placements

As with all surgery, the location of surgical incisions can have a direct impact on the ease and length of surgery. MIS typically requires multiple ports, and a surgeon may vary the location of ports based on characteristics of the patient and the specific surgery, allowing for freedom in managing anatomic or scar considerations.

Anatomic

The presence of an umbilical hernia is a commonly encountered anatomic consideration in gynecologic MIS, as initial entry is usually achieved through umbilical entry. Because abdominal contents may be present within the umbilicus when a hernia is present, preoperative evaluation is critical to determine if entry at the umbilicus is possible. This requires an abdominal exam and may involve additional imaging or consultation with a general surgeon for consideration of simultaneous hernia repair. After this evaluation, the primary surgeon can decide whether initial entry at the umbilicus is possible, potentially with combined hernia repair. Alternatively, entry at the left upper quadrant followed by umbilical port placement under direct visualization may help minimize the risk of injury to abdominal organs (68).

Additionally, large pelvic masses and enlarged uteri can now be removed using MIS with fewer complications than open surgery (69-74). Careful preoperative planning with an abdominal exam can aid in avoiding unintentional rupture of large ovarian masses or laceration of an enlarged uterus during trocar placement. Preoperative imaging studies such as CT scan or MRI to assess masses can aid in guiding planned trocar placements and help risk-stratify for neoplasm.

Masses or enlarged uteri that encroach upon the umbilicus can potentially be avoided with initial trocar entry at the midline above the mass or in the left upper quadrant, similar to entry during pregnancy as previously discussed. Ou *et al.* described three separate entry techniques for large cystic adnexal masses; each technique was based on the location of the adnexal mass and the possibility of drainage of the mass prior to trocar placement (69). For drainable cystic structures, a 2–3 cm open umbilical incision was made, the cyst was drained, and an umbilical port was placed for laparoscopic cystectomy or oophorectomy to follow. For masses that were within 4 cm of the umbilicus, a port was placed in the right upper quadrant (for which a left upper quadrant port could be substituted) and laparoscopic cystectomy was performed. For masses greater than 4 cm below the umbilicus, standard trocar placement at the umbilicus was utilized for initial entry. The latter two techniques can be applied to solid masses or enlarged uteri, allowing MIS procedures to be considered for most gynecologic complaints.

Previous surgeries

Previous abdominopelvic surgeries can increase the rate of complications during MIS, particularly those associated with initial entry (75). Previous umbilical surgery has been shown to result in umbilical adhesions in over 20% of women, leading to the surgical recommendation of initial entry at an alternative site such as the left upper quadrant (76). Previous abdominopelvic surgery can also increase the risk of having pelvic adhesions, with potential increased operating times or conversion to open procedures (77). However, laparoscopy can still be safely performed even for a patient with a history of multiple previous abdominal surgeries and is preferred to open procedures to minimize postoperative complications.

Previous abdominoplasty presents potential unique challenges for entry due to anatomic distortion of the abdominal wall. In the literature, several possible methods have been utilized for entry during laparoscopic procedures. In breast cancer patients who have had flap breast reconstruction, Tsahalina and Crawford describe a lateral modified Hassan entry at the abdominoplasty scar for subsequent gynecologic MIS (78). Saber *et al.* used the left upper quadrant as the initial entry location for laparoscopic gastrectomy after abdominoplasty without any additional complications (79). Cassaro and Leitman described a modified Hassan technique for initial abdominal entry in patients undergoing laparoscopic cholecystectomy after abdominoplasty with fascial plication (80). Thus, after examining the patient and discussing the implications of further scarring, the surgeon can approach gynecologic MIS with any of the above entry points in a patient with previous abdominoplasty.

Another complicating factor with previous abdominoplasty procedures is fibrotic scarring of the abdominal wall. This leads to decreased compliance which constrains operating space. This may be of significance in patients with comorbidities limiting the ability to use steep Trendelenburg placement or high intraabdominal pressure (>19 mmHg) or morbid obesity as discussed previously, and thus may limit visualization of pelvic structures during MIS.

Combined cases

MIS is a common approach for most surgical specialties. Therefore, it is unsurprising that patients may request that additional surgical procedures be performed concurrently. Several factors must be taken into consideration when assessing the feasibility of a combined surgery, including surgeon availability for both specialties as well as infection risk and surgical approach. Some of the potential co-performed non-gynecologic abdominal surgeries are cholecystectomy, appendectomy, and umbilical hernia repair. In addition, patients are more frequently requesting plastic surgery procedures, such as abdominoplasty or breast augmentation/reconstruction, which can be performed during the same OR session but may impact the surgical approach (81-83).

For any combined case, particularly those that require abdominal incisions, careful preoperative planning is recommended to ensure the best outcome for all procedures. Ideal trocar placements can be discussed between surgeons prior to the case, minimizing the number of incisions required. The patient should be counseled prior to the surgery that she may have more total incisions than either individual surgical procedure would require. For patients undergoing MIS procedures such as bilateral salpingo-oophorectomy for cancer risk reduction, the potential for breast reconstructive procedures requiring flap should be assessed. When possible, the breast surgeon should be involved in the discussion regarding planned trocar placements to ensure minimal impact on future tissue harvesting. Similarly, a plastic or general surgeon should participate in determining ideal trocar placements for a patient with a simultaneous or upcoming abdominoplasty procedure.

Technical challenges

MIS requires a unique technical skill set. Experience reduces operative time and complications, especially in complex patients such as those with a history of prior abdominal surgeries (84,85). Adoption of new techniques and surgical approaches requires a learning curve to gain proficiency and optimize outcomes. As such, surgeons must develop their preferred technique and consider new technologies and approaches carefully prior to incorporation into surgical practice.

Laparoscopic suturing and knot-tying

Laparoscopic skills, such as suturing and knot-tying, may be a daunting task for the novice surgeon. Many tools are available for simulation, such as laparoscopic box trainers. Simulations have been shown to improve laparoscopic skills of trainees and use of such should be encouraged (86,87). Additionally, advances in laparoscopic devices may aid in surgical practice. Automatic suturing devices may decrease operative time and overall cost in laparoscopic hysterectomies (88). Innovative users have also noted a role for automatic suturing devices in transvaginal sacrospinous ligament fixations (89,90).

Use of barbed suture avoids the need for knot-tying. Multiple studies have compared the use of barbed suture to traditional suture for vaginal cuff closure after laparoscopic hysterectomy. Findings of a prospective cohort study by Cong *et al.* showed that barbed suture is associated with decreased operative time with no difference in rate of vaginal cuff dehiscence (91). A retrospective trial by Karacan *et al.* demonstrated similar outcomes (92). A randomized controlled trial by López *et al.* found no difference in surgical times or adverse outcomes in vaginal cuff closure with barbed suture compared to standard suture technique after laparoscopic hysterectomy (93). Such findings suggest that suture technique may be chosen per surgeon preference without impact on patient outcomes.

Robot-assisted laparoscopy

As discussed previously, the development of robot-assisted laparoscopy has expanded the field of MIS within gynecology and allows complex surgeries to be performed in a minimally-invasive manner. However, randomized controlled trials in patients undergoing hysterectomy for benign indications have shown that compared to traditional laparoscopy, robot-assisted laparoscopy is associated with longer operative times and no clinical difference in surgical complications, postoperative pain, or time to return to daily activities and work (94,95). A Cochrane review similarly found no evidence to suggest that a robot-assisted approach improved outcomes compared to other MIS approaches (96). Robotic surgery has also been associated with a higher cost for both hysterectomy and pelvic floor surgery (97,98).

As with any new technology, a learning period is required to become competent in robot-assisted laparoscopy. The average number of cases needed to develop proficiency has not been fully elucidated, and studies suggest that between 33 and 90 robotic hysterectomies are needed (99,100). Prior to that, patients may experience longer operative times and length of hospitalizations. A similar learning curve has been suggested for robotic sacrocolpopexies (101). Additionally, use of the robot requires not only surgical proficiency, but also trained operating room staff with specific knowledge of robotic equipment. Thus, the surgical approach should be determined by the skillset of the provider and surgical team, individual patient characteristics, and desires of an informed patient.

Advances in minimally invasive approach

Developments in technology and technique have been pushing the boundaries of MIS. Single-port surgery (also known as laparoendoscopic single-site surgery) enables an operation to be performed through a single umbilical port. Such an approach may be performed with or without robot assistance. Studies have demonstrated that single-port laparoscopic hysterectomy is safe and feasible, though may be associated with a longer operative time and higher failure rate (additional port placements or conversion to open surgery) compared to a traditional multi-port laparoscopic approach (102,103). A randomized controlled trial by Matanes *et al.* demonstrated that robot-assisted single-port sacrocolpopexy is comparable to a robot-assisted multi-port approach with regard to short-term surgical outcomes but is associated with longer anesthesia time (104).

A transvaginal laparoscopic approach offers a visually scar-free option for gynecologic MIS including ovarian cystectomies, hysterectomies, and sacrocolpopexies (105-107). A randomized controlled trial by Baekelandt *et al.* found that a transvaginal laparoscopic approach to hysterectomy is associated with a shorter postoperative hospitalization than a conventional laparoscopic approach (105).

Gasless laparoscopy is another MIS approach that utilizes a mechanical lift system to elevate the anterior abdominal wall and may be used in patients with a contraindication to pneumoperitoneum. Although this technique has not been widely adopted, feasibility studies have suggested that the use of gasless laparoscopy is safe for myomectomy and other benign gynecologic surgeries (108-110).

A non-technical advancement in gynecologic MIS has been the implementation of the enhanced recovery after surgery (ERAS) pathways, which are a compilation of evidence-based best-practice guidelines that can be applied in the perioperative period to accelerate functional recovery by minimizing the physiologic stress response to surgery (111). This includes allowing for clear fluids up to two hours before surgery, a multimodal analgesic and antiemetic regimen including non-narcotic pain medication prior to surgery, and early ambulation. Its use has also been found to have many benefits including expediting return of bowel function, decreasing cost of care, and reducing hospital stay, without increasing readmission rates (112,113).

Conclusions

MIS is a rapidly evolving field and many technologies will continue to be introduced. These advances have made MIS feasible for a wide range of surgical indications and patient populations, including those with significant medical comorbidities and surgical histories. Indeed, US Obstetrical and Gynecologic resident training has increasingly emphasized gynecologic MIS training over open abdominal surgery, introducing more physicians with MIS-focused training into the US healthcare system. As the number of gynecologic MIS procedures in the US continues to increase, careful preoperative evaluation and planning will help to minimize adverse surgical outcomes.

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