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Anesthetic Management of Nonobstetric Surgery during Pregnancy

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Abstract

Purpose of Review This article reviews several controversial aspects of management of nonobstetric surgery during pregnancy, including the optimal timing for nonurgent surgery, when to perform intraoperative fetal monitoring, modifications to anesthetic techniques to account for the physiologic changes of pregnancy, and management of maternal cardiac arrest.

Recent Findings There have been several advances in the management of nonobstetric surgery during pregnancy, including the increased use of laparoscopic techniques, an improved understanding of the importance of adequate pain management, and new initiatives to improve the maternal cardiac resuscitation algorithm. Traditional dogma regarding aspiration prophylaxis during pregnancy and concerns about abortifacient and teratogenic properties of diagnostic imaging and anesthetic agents have also recently been reevaluated.

Summary Urgent and emergent surgeries should proceed without delay during pregnancy in order to ensure optimal outcomes for both the mother and fetus. Anesthetic management may require several modifications to account for physiologic changes of pregnancy. In general, uteroplacental perfusion is best maintained by avoidance of maternal hypoxemia, hypotension, hyper- and hypocapnia, temperature extremes, and stress.

Keywords Pregnancy · Physiologic changes of pregnancy · Nonobstetric surgery during pregnancy · Teratogenicity · Preterm labor · Intraoperative fetal monitoring · Left uterine displacement · General anesthetics in pregnancy · Deep sedation during pregnancy · Regional anesthesia · Neuraxial anesthesia · Laparoscopic surgery · Maternal cardiac arrest · Perimortem delivery

Introduction

Up to 2% of pregnant individuals may require surgery at some stage during pregnancy. [1] In the USA, this translates into an estimated 80,000 surgeries unrelated to delivery each year; the true number, though, is likely higher, as patients may be unaware that they are pregnant at the time of surgery. [2] Most of these surgeries are for conditions that are common to women of childbearing age: appendicitis, cholecystitis, breast and ovarian disorders, trauma, and pregnancy-related complications (e.g., cervical incompetence and, increasingly, fetal conditions that require surgical intervention). However, almost every type of surgery, including complex neurosurgical and cardiopulmonary bypass surgeries, has been performed during pregnancy.

Management of pregnant patients undergoing nonobstetric surgery presents a challenge for all health care providers involved. Common, largely unsubstantiated concerns include the likelihood of pregnancy loss, teratogenicity, and preterm birth. [3••] Practical concerns include appropriate diagnostic imaging, the optimal timing of non-elective, nonurgent surgery, feasibility of intraoperative fetal heart rate (FHR) monitoring, prevention of preterm labor, and the course of action if the mother or fetus develops life-threatening complications. Management can be further complicated by challenges distinguishing new-onset pathologic conditions from pregnancy-related conditions, different baseline laboratory indices in pregnant and nonpregnant individuals, and physiologic and anatomic changes of pregnancy.

This article reviews perioperative anesthetic management of pregnant patients presenting urgently or emergently for nonobstetric surgery, with a focus on optimization of maternal

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well-being to minimize the risk of adverse maternal and fetal outcomes. It addresses several specific challenges that commonly present when caring for these patients, including FHR monitoring, fetal and uterine effects of anesthetic agents, the feasibility and safety of laparoscopic techniques, and postoperative pain management options. Despite meticulous attention to maternal and fetal well-being, women exposed to surgery and anesthesia during pregnancy may experience major complications, such as pneumonia, sepsis, venous thromboembolism (VTE), and death, [4•] as well as fetal loss, preterm labor, and low birth weight infants. Many of these complications may be attributable to the underlying maternal condition requiring surgery and can be exacerbated by diagnostic and therapeutic delays.

Physiologic Changes of Pregnancy

An understanding of the central nervous system (CNS), respiratory, gastrointestinal, cardiovascular, and hematologic adaptations to pregnancy can aid in determining the most appropriate anesthetic technique, as well as facilitate intraoperative optimization of maternal hemodynamics. Although no anesthetic technique has been shown to result in improved fetal outcomes, local and regional anesthetic techniques are preferred, when appropriate, to avoid manipulation of a potentially difficult airway, to minimize respiratory complications, and to reduce unnecessary fetal exposure to anesthetic agents. Both general and regional techniques, however, can be safely performed during pregnancy. Regardless of the anesthetic technique, avoidance of maternal hypoxemia, hypotension, acidosis, hyperventilation, and stress results in optimal outcomes for both the mother and the developing fetus.

CNS

Pregnant patients experience alterations in pain perception and pain threshold, decreased anesthetic requirements, and an increased reliance on the sympathetic nervous system (SNS). The minimum alveolar concentration (MAC) for volatile agents decreases by 28% at 8–12 weeks' gestation, [5] reaches 40% of nonpregnant levels as pregnancy progresses, and returns to baseline by postpartum day 3. [6] The routine use of low concentrations of volatile agents for cesarean delivery under general anesthesia, however, has contributed to a relatively high incidence of intraoperative recall in pregnant patients (0.26%) compared to other surgical patients. [7] Therefore, reduced dosing is generally not recommended. Local anesthetic (LA) requirements for both peripheral and neuraxial procedures (primarily intrathecal) are also reduced in pregnancy, as a result of a combination of anatomical, mechanical, and biochemical changes. Dosing requirements for thiopental (no longer available in the USA) are decreased, while propofol requirements are likely unchanged [8] or reduced. [9]

Increased dependence on the SNS as pregnancy progresses may result in severe hemodynamic changes and increased vasopressor requirements after initiation of spinal anesthesia. A compensatory downregulation of the parasympathetic nervous system (PNS) at term gestation attenuates the maternal hemodynamic response to spinal-induced sympathectomy and mitigates bradycardia after spinal blockade for cesarean delivery. In the absence of contraindications, active management of hemodynamic changes with vasopressors and intravenous fluids during and after neuraxial blockade in pregnant women undergoing nonobstetric surgery may be necessary. Historically, ephedrine was the vasopressor of choice during pregnancy, but more recent studies have found that it has a more marked effect on the fetal pH compared with phenylephrine. [10] In current clinical practice, phenylephrine is the preferred vasopressor for treatment of spinal-induced hypotension during cesarean delivery, with very low doses of norepinephrine (e.g., 5–6 mcg bolus) also being well tolerated. [11••] Ultimately, maintenance of maternal hemodynamic stability during nonobstetric surgery is the priority, with any of these vasopressors.

Respiratory

Changes in the maternal airway start early in pregnancy, become more pronounced at term gestation and during labor and delivery, and resolve several days postpartum. Fat deposition with maternal weight gain, fluid retention, increased airway connective tissue, and capillary engorgement result in oropharyngeal swelling, mucosal friability, and a smaller supraglottic aperture compared with nonpregnant patients. [12] Full dentition in women of childbearing age, enlarged breasts, and the presence of comorbidities, such as obesity and preeclampsia (after 20 weeks' gestation), can also complicate management of the pregnant airway.

Anesthesia-related maternal deaths are decreasing in incidence, but airway complications can still occur at any stage in the perioperative period, especially in the postoperative period. [13] Optimal patient positioning, adequate preoxygenation (with 100% oxygen per face mask for 3–5 min or, alternatively, several vital capacity breaths), access to video laryngoscopes and other airway adjuvants (including short-handle laryngoscopes), immediate availability of additional experienced anesthesia providers, the use of regional blockade in lieu of general anesthesia, when appropriate, and continued vigilance in the recovery period may help minimize or avoid airway catastrophes in pregnant patients undergoing obstetric and nonobstetric surgery.

Anatomic and hormonal changes, as well as increased metabolic demands, result in several alterations in respiratory mechanics during pregnancy. Because of upward uterine displacement of the diaphragm and related decreases in expiratory reserve volume (ERV) and residual volume (RV),

functional residual capacity (FRC) drops considerably after 5 months' gestation, reaching 80% of the prepregnancy value by term gestation. [14] Assuming the supine position, the induction of general anesthesia and comorbidities, such as sepsis or obesity, further decrease FRC, accelerating airway closure and maternal oxygen desaturation. The combination of decreased FRC and increased oxygen consumption (to meet the growing metabolic demands of the fetus and maternal weight gain) results in rapid oxygen desaturation during periods of apnea.

Physiologic changes in minute ventilation (MV), attributable primarily to an increase in tidal volume and, secondarily, to an increased respiratory rate, also have anesthetic implications. The arterial pressure of carbon dioxide ($PaCO_2$) decreases to 30 mmHg early in pregnancy. The kidneys excrete additional bicarbonate to compensate for the maternal respiratory alkalosis, but the pH remains slightly more alkalotic than the nonpregnant state (7.4–7.44). Clinically, it is important to attempt to maintain these baseline indices. The goal end-tidal carbon dioxide pressure ($ETCO_2$), which closely reflects the PaCO2 during pregnancy, should approximate 30–35 mmHg during mechanical ventilation. Optimally, maternal $ETCO_2$ should be maintained at 32–34 mmHg during laparoscopic surgery. Hypoventilation resulting in high levels of maternal CO_2 may result in fetal acidemia and myocardial depression; extreme hyperventilation to a $PaCO_2$ below 23 mmHg can decrease uterine blood flow and fetal oxygenation. [15]

The combination of decreased FRC and increased MV can result in more rapid uptake of volatile anesthetics during pregnancy and a faster rate of induction of anesthesia.

Cardiovascular

Systemic vascular resistance (SVR) decreases early in pregnancy because of the potent vasodilating effects of progesterone and prostacyclin and the presence of a low-resistance placenta. Cardiac output (CO) begins to increase at 5–8 weeks' gestation and continues to rise until it peaks at 28–32 weeks' gestation and, again, during the second stage of labor. The highest CO occurs in the immediate postpartum period.

Maternal positioning and the induction of anesthesia can compromise pregnancy-induced changes in CO. Supine hypotensive syndrome, which results from uterine compression of the inferior vena cava and, rarely, the aorta, affects some women as early as 18–20 weeks' gestation. [16] At term gestation, aortocaval compression may result in a 30% decrease in CO. [2] The initiation of either general or neuraxial anesthesia decreases sympathetic tone and compromises the normal physiologic response to aortocaval compression. Profound maternal hypotension and additional decreases in cardiac preload and output can ensue. Although recent data challenge whether the routine practice of left uterine displacement (LUD) impacts fetal indices, particularly if vasopressor agents are used appropriately, [17•] it is still common practice to place the patient in a left tilt (e.g., with a wedge under the patient's right flank) as early as 20 weeks' gestation for the duration of surgery and until the patient is fully awake in the post-anesthesia recovery room (PACU). [18] Recent studies have suggested that a 30° tilt may be necessary to alleviate aortocaval compression, but this may not be compatible with surgical requirements. [19] The lateral recumbent position or a knee chest position, elevating the lower extremities, or placing the patient in the Trendelenburg position after initiation of spinal anesthesia can also improve venous return and help maintain CO.

Gastrointestinal

Many hormonal and mechanical changes predispose pregnant patients to gastroesophageal reflux (GERD) and, possibly, a higher risk of aspiration when compared with nonpregnant surgical patients. Early in pregnancy, high levels of plasma progesterone contribute to laxity of lower esophageal sphincter (LES) tone. Later, increased abdominal pressure and upward displacement of the stomach also contribute to the high incidence of symptomatic GERD. In contrast to traditional dogma, however, recent studies have found that gastric motility (and, relatedly, gastric volume) remains unchanged until the onset of labor and/or the administration of systemic or, to a lesser extent, neuraxial opioids. [20] Gastric pH also likely remains unchanged during pregnancy. [21]

Although definitive guidelines are lacking, by the mid to late second trimester and throughout the remainder of pregnancy, full stomach precautions should be adhered to when managing pregnant patients. Until then, it is reasonable to follow standard fasting and pharmacologic aspiration prophylaxis recommendations [22] and treat pregnant patients in a manner similar to nonpregnant patients. Additional prophylactic measures may be required on a case-by-case basis, with consideration of last oral intake and the presence of symptomatic GERD, motility disorders, and other risk factors for aspiration. While no specific intervention has been shown to mitigate the risk of pulmonary aspiration, the incidence of this untoward complication is low in current clinical practice. A recent retrospective study of over 60,000 pregnant women in the first or second trimester who received deep sedation with propofol reported no cases, despite the lack of routine use of antacids and cricoid pressure. [23] All patients in the study maintained a natural airway except a small percentage who received laryngeal mask airways (0.2%) and one patient who received endotracheal intubation.

Hematologic

Pregnant patients often develop anemia in pregnancy because of the disproportionate increase in plasma volume vis-à-vis

red blood cell mass. The World Health Organization defines anemia in pregnancy as below 11 g/dL, [14] although some clinicians may elect to use a lower threshold (e.g., 10 g/dL). A similar dilutional effect, along with several other mechanisms, commonly results in thrombocytopenia; at term gestation, roughly 12% of women have platelet counts below 150,000/mm^3. [24] Plasma pseudocholinesterase levels also decrease due to a dilutional effect; however, a dose reduction in succinylcholine is generally not indicated, in part because of the increased volume of distribution in pregnancy.

Starting early in pregnancy, the plasma concentration of almost all procoagulants increases. The activity of anticoagulant protein S decreases, while resistance to protein C contributes to an increase in thrombin formation. Proteins that inhibit clot lysis (plasminogen activator inhibitor types 1 and 2) increase dramatically during pregnancy, peaking at term. Overall, pregnancy represents a hypercoagulable state, with increased clotting capacity and decreased anticoagulant and fibrinolytic activity. Pregnant patients are at increased risk of VTE throughout pregnancy and for several weeks postpartum. Pneumatic compression devices should be placed on all pregnant patients undergoing nonobstetric surgery. Pharmacologic thromboprophylaxis may be necessary for patients with additional risk factors (e.g., history of VTE, prolonged immobilization, malignancy, prolonged surgery, etc.).

Diagnostic Imaging During Pregnancy

During pregnancy, as always, the potential risks of diagnostic imaging must be weighed against the benefits of accurate diagnosis or exclusion of disease. With rare exception, the recommendation is usually for pregnant women to proceed with a diagnostic test that is deemed to be vital for maternal health. The potential for adverse fetal effects from ionizing radiation during X-ray, computed tomography (CT), fluoroscopy, and nuclear medicine imaging depends on the total dose of radiation and the type, timing, and site of exposure. A single or limited number of exposures in most cases falls well below the threshold at which potential harmful effects occur. X-ray procedures remote from the maternal pelvic or abdominal areas result in very little fetal exposure to ionizing radiation; exposure can be further reduced with digital radiographic imaging. The risk of carcinogenesis from multiple in utero X-ray studies is unknown but is likely very small.

CT studies of the head and chest result in less fetal exposure than pelvic and abdominal studies. Low-exposure techniques have adequate diagnostic potential and may be used when pelvic CT is performed. Spiral CT results in fetal radiation exposure comparable to conventional CT. If diagnostically feasible, CT with iodinated contrast (i.e., intravenous contrast media) is generally avoided during pregnancy, despite the lack of known harm. [25•] Fluoroscopy exams, such as endoscopic retrograde cholangiopancreatography (ERCP), barium enema, ureteroscopy, and cerebral angiograms, can result in considerable radiation exposure to the fetus. Risks associated with nuclear medicine studies (e.g., pulmonary ventilation-perfusion, bone, thyroid scans) depend on the physical and biochemical properties of the radioisotope "tag" used and, when combined with CT for improved quality of information, the dose of ionizing radiation. While some radioisotopes can be used safely in pregnancy, radioactive iodine is generally contraindicated.

Magnetic resonance imaging (MRI) and ultrasonography, which do not use ionizing radiation, are considered safe during pregnancy. Concerns about the heating effects of radiofrequency pulses and acoustic damage associated with MRI have not been substantiated in the literature. The use of gadolinium contrast, however, is best avoided, when possible, due to uncertainty regarding potential teratogenicity. [25] Lengthy ultrasound studies have the potential to raise tissue temperature, particularly when color Doppler is used, but machines used in the obstetric setting deliver lower temperatures and are considered to be safe. [25]

Available evidence and broad clinical experience suggest that withholding diagnostic testing causes more harm to pregnant patients and their fetuses than performing appropriate imaging tests.

Teratogenicity

Teratogenesis can manifest as structural abnormalities (e.g., growth restriction or congenital malformation) or as functional behavioral or cognitive delays. For structural or functional abnormalities to develop from a teratogenic exposure, the fetus must be genetically susceptible to the adverse effects and exposed to sufficiently large doses at a particular gestational age. Based on available animal research and epidemiologic studies, relatively few agents are known teratogens in human beings (Table 1). Given the impracticality of clinical studies in pregnant patients, it is unlikely that prospective studies will be conducted to determine the effects of commonly used analgesic and anesthetic agents.

Despite the lack of these high quality studies, commonly used anesthetic agents and adjuvant drugs are currently considered to

Table 1 Known teratogens in humans

Captopril
Carbamazepine
Cocaine
Enalapril
Fluconazole (high dose)
Lithium
Phenobarbital
Retinoic acid
Tetracyclines
Thalidomide
Valproic acid

be safe in clinically relevant doses (i.e., single use or short-term exposure). Some studies have linked in utero exposure to opioids with congenital defects. [26–28] However, a recent systematic review of maternal opioid use during pregnancy concluded that uncertainty remains regarding the potential teratogenicity of opioids, citing flaws in sampling and limitations with outcome and/or exposure measurement, confounders, and lack of power. [29••] Published data do not support the association of in utero exposure to diazepam and fetal cleft palate formation. [30] Midazolam has not been associated with congenital malformations; judicious use of preoperative anxiolysis is appropriate and may serve to reduce circulating catecholamines. [31] Nitrous oxide, which inactivates methionine synthase and inhibits thymidine and DNA synthesis, is weakly teratogenic to rodents after prolonged administration, but it is not clear that these findings can be extrapolated to humans. [32] Concerns about an increased incidence of spontaneous abortions among operating room personnel exposed to nitrous oxide have not been substantiated in the literature. [33]

Over the past nearly two decades, a great deal of animal research has been dedicated to investigating the potential adverse effects of volatile agents and other anesthetic medications on the developing brain. Several studies that demonstrated accelerated apoptosis in animals exposed to anesthetics in utero ultimately led the US Food and Drug Administration (FDA) to issue a warning of the potential risks to pregnant women and children under 3 years of age. [http://www.fda.gov/Drugs/DrugSafety/ucm532356.htm] The Society for Obstetric Anesthesia and Perinatology, American College of Obstetricians and Gynecologists (ACOG), and American Academy of Pediatrics have acknowledged the limitations of available data and reaffirmed that urgent and emergent surgery during pregnancy should not be delayed. [34] While much remains to be elucidated in future research, clinically relevant doses of anesthetic agents in single or short-term exposures are unlikely to result in behavioral abnormalities and development delays. It is reasonable to select the anesthetic regimen based on maternal disease and surgical requirements.

Several adjuvant drugs that may be appropriate for the general surgical population should be avoided during pregnancy. NSAIDs are contraindicated, particularly in late pregnancy, due to concerns for premature closure of the ductus arteriosus. While most antibiotics have a good safety record, including penicillins, cephalosporins, clindamycin, and azithromycin, tetracyclines are avoided because of adverse effects on bone and teeth development.

Optimal Timing for Surgical Procedures During Pregnancy

Elective surgery should be deferred during pregnancy; emergency procedures should proceed without delay, regardless of gestational age. [35] Delaying surgery for acute conditions, such as appendicitis, may result in an increased risk of adverse outcomes for the mother (e.g., appendiceal perforation, generalized peritonitis, and sepsis) and an increased risk of fetal loss.

The early second trimester, when the risks of teratogenicity and preterm labor are lowest and when the uterus is small enough not to interfere with visualization of the operative field, is the preferred time to undertake non-elective, nonurgent surgical procedures, when possible. [35] The period of organogenesis (3–8 weeks' gestation) is most concerning for potential teratogenic exposures. Surgery during the third trimester raises concerns for an increased risk of preterm labor and for exposure of the developing fetal brain to agents that have been associated with behavioral abnormalities and developmental delays in animal studies. [36] However, these findings from animal studies have not been demonstrated in human studies, and a definitive link between preterm contractions, preterm labor, and preterm birth has not been established in the literature. Several factors likely contribute to perioperative labor and delivery outcomes, including the underlying maternal pathology and the timing, type, and location of surgery during pregnancy.

Multidisciplinary planning to address the timing and type of surgery (i.e., laparoscopic versus an open approach), the optimal anesthetic technique (regional or general), and postoperative pain management options may provide the most effective means of minimizing the risk of preterm delivery. Decisions regarding whether a condition that presents in the first trimester can be medically managed until the second trimester, whether surgery can be delayed until the postpartum period, and how perioperative surveillance of uterine contractions may affect management should also be addressed in advance, when possible. Theoretically, laparoscopic surgery (which is associated with less uterine manipulation), the use of volatile agents (which decrease uterine tone), [37] and prophylactic administration of tocolytic agents should help decrease the risk of preterm labor. However, these benefits have not been demonstrated in the literature. Currently, prophylactic tocolytic agents are not recommended.

Although evidence is lacking that the type of anesthetic influences preterm labor, anesthesia providers may elect to avoid certain agents that have been associated, however remotely, with adverse maternal or fetal outcomes. Ketamine increases uterine tone and might best be avoided in patients deemed at high risk for preterm labor unless the benefits outweigh the potential risks (e.g., in a hemodynamically unstable patient with reactive airway disease). Maternal pain and stress are associated with increased uterine irritability and increased levels of plasma catecholamines, which may reduce uteroplacental perfusion. This further emphasizes the need for optimal perioperative maternal analgesia. It is also reasonable to use regional anesthetic techniques, when possible, in lieu of general anesthesia to avoid unnecessary fetal exposure to anesthetic agents and adjuvants.

Intraoperative Fetal Monitoring

Perioperative FHR monitoring requires multidisciplinary planning with members of the obstetrics, surgical, anesthesiology, nursing, and neonatology teams. According to the American College of Obstetricians and Gynecologists (ACOG), the decision to use intraoperative monitoring should be individualized, with consideration of the type of surgery, the gestational age of the fetus, and available personnel and facilities. [35]

At a minimum, preprocedure and postprocedure assessment of the FHR is recommended beginning in the first trimester. Continuous intraoperative fetal monitoring may be appropriate for viable fetuses (i.e., 23–24 weeks' gestation), when technically feasible, and may be performed with the use of an electronic FHR monitor, a Doppler ultrasound, or a transvaginal ultrasound. Some obstetric providers may elect instead to perform continuous electronic fetal monitoring in all pregnant patients regardless of gestational age (including remote from delivery) in order to detect and correct suboptimal fetal conditions related to maternal hemodynamics and oxygenation. [3] In minimally invasive cases (e.g., carpel tunnel release) and procedures performed under peripheral nerve blocks and/or monitored anesthesia care, continuous monitoring may be feasible, but unnecessary. Preprocedure and postprocedure assessment of uterine tone and fetal heart rate generally suffices in these cases.

If continuous monitoring is performed, an obstetric provider with privileges should be available to perform an emergency cesarean delivery, providing that the primary surgery can be safely interrupted. Ideally, informed consent for emergency cesarean delivery should be obtained in advance. A provider familiar with interpretation of the baseline FHR and the anticipated changes associated with general anesthetic agents must be readily available. FHR variability, which may not be uniformly present until 25–27 weeks' gestation, generally declines with exposure to anesthetic agents. The baseline FHR may also decline with maternal exposure to general anesthesia. Prolonged fetal bradycardia should not be categorized as a benign physiologic response to general anesthesia or to adjuvant agents.

Any change in FHR beyond expected physiologic parameters should alert the health care team to the possibility of true fetal compromise and prompt the anesthesiologist to reassess and optimize maternal blood pressure, ventilation and oxygenation status, and positioning. An appraisal of surgical sites for blood loss and for inadvertent compression of uterine blood flow is also warranted before drastic measures, such as an emergency cesarean delivery, are taken. If emergency delivery is performed, additional providers (e.g., neonatology, respiratory therapy, obstetric anesthesiology) may be required to help care for the mother and the neonate, who may require tracheal intubation and mechanical ventilation due to prematurity and residual depressant effects of anesthetic agents and opioids.

Laparoscopic Surgery

Laparoscopic surgery, which can be performed in all trimesters of pregnancy, [38] is being used with increasing frequency for the management of nonobstetric surgery. The benefits for pregnant patients are similar to those in nonpregnant individuals and include lower risk of wound complications, reduced analgesic requirements and improved pain scores, faster return of bowel function, faster return to normal activity, reduced risk of thromboembolic complications, and shorter hospital stay. The laparoscopic approach also results in decreased manipulation of the uterus when compared with open abdominal surgeries and may reduce the risk of preterm labor. Postoperative complications and surgical outcomes with laparoscopic surgery appear to be similar in pregnant and nonpregnant patients. [38]

Several precautions must be taken when performing laparoscopic surgery during pregnancy. Trocar insertion should be performed with caution and may be prohibitive in the late third trimester. An open method for port insertion (i.e., the Hasson technique) may be preferred in advanced pregnancy to avoid injury to the gravid uterus and adjacent organs. High intraabdominal pressure from the pneumoperitoneum may decrease uteroplacental perfusion and can contribute to maternal respiratory compromise, particularly when combined with steep Trendelenburg positioning, an enlarged uterus, and elevated intrathoracic pressure during mechanical ventilation. Maternal and fetal risks can be minimized by maintaining pneumoperitoneal pressure at 10–15 mmHg, slowly adjusting patient positioning, ensuring adequate intravascular volume status, and alleviating aortocaval compression with LUD (Table 2). Maternal end-tidal CO_2 should be maintained between 32 and 34 mmHg, and maternal blood pressure should remain within 20% of baseline.

Table 2 Recommendations to maintain maternal well-being during laparoscopic surgery

Use an open method for port insertion
Apply lower extremity pneumatic compression devices
Maintain LUD throughout
Insufflate and deflate pneumoperitoneum gradually
Keep pneumoperitoneal/intraabdominal pressure below 10–15 mmHg
Maintain maternal end-tidal CO_2 between 32 and 34 mmHg
Adjust maternal positioning (e.g., Trendelenburg) slowly
Maintain adequate volume status
Maintain maternal blood pressure within 20% of baseline
Minimize intrathoracic pressure during positive pressure ventilation

Cardiopulmonary Resuscitation During Pregnancy

Management of perioperative maternal cardiac arrest requires participation from a multidisciplinary team with an understanding of the physiologic changes of pregnancy and familiarity with the maternal resuscitation algorithm. [39] This algorithm deviates from standard nonpregnant resuscitation protocols in its focus on relief of aortocaval compression and preparedness for perimortem delivery. It also encourages consideration of pregnancy- and nonpregnancy-related conditions in the differential diagnosis of maternal cardiac arrest. [40]

Manual LUD must be maintained to relieve aortocaval compression at or beyond 20 weeks' gestation, while high-quality chest compressions (with hand placement over the mid-lower sternum) and adequate oxygenation are continued. If the gestational age is unknown, the fetal age can be estimated by maternal anatomic landmarks: the uterus exits the pelvis at 12-weeks' gestation and reaches the umbilicus at 20 weeks. Each inch above the umbilicus represents an additional gestational week in a singleton pregnancy. During maternal cardiac arrest, the airway should be managed early, preferably by an anesthesiologist with knowledge of pregnancy-induced airway changes. If maternal circulation is not restored within 4 min of cardiac arrest, perimortem delivery at the site of arrest (i.e., without transfer to the operating room) should be performed to improve resuscitative efforts, regardless of fetal viability. Extracorporeal membrane oxygenation (ECMO) or cardiopulmonary bypass should be considered if resuscitative measures are unsuccessful. Pregnant patients, who are generally young and healthy, have a high rate of survival after cardiac arrest with the appropriate and timely initiation of CPR. [39] Simulation exercises are encouraged to enhance team preparedness to respond to maternal cardiac arrest and optimize maternal survival in all health care settings.

Conclusion

Nonobstetric surgery during pregnancy presents several challenges and is best managed with multidisciplinary preprocedure planning to determine optimal timing of the procedure, FHR monitoring, measures to minimize preterm labor, and preparedness for fetal and/or maternal emergencies. For the anesthesia provider, numerous physiologic adaptations to pregnancy may require modifications to the anesthetic technique. These include using regional in lieu of general anesthesia when feasible and relieving aortocaval compression with LUD after 20-weeks' gestation. Avoiding techniques such as controlled hypotension and hyperventilation are also prudent. Ultimately, maintaining adequate oxygenation, hemodynamic stability, and normothermia help to promote optimal outcomes for both the mother and fetus.

Compliance with Ethical Standards

Conflict of Interest R. d'Arby Toledano, Hannah E. Madden and Lisa Leffert declare they have 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.

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- • Of importance
- •• Of major importance

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