SPECIAL ARTICLE

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Anesthesia for Maternal–Fetal Interventions: A Consensus Statement From the American Society of Anesthesiologists Committees on Obstetric and Pediatric Anesthesiology and the North American Fetal Therapy Network

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Maternal–fetal surgery is a rapidly evolving specialty, and significant progress has been made over the last 3 decades. A wide range of maternal–fetal interventions are being performed at different stages of pregnancy across multiple fetal therapy centers worldwide, and the anesthetic technique has evolved over the years. The American Society of Anesthesiologists (ASA) recognizes the important role of the anesthesiologist in the multidisciplinary approach to these maternal–fetal interventions and convened a collaborative workgroup with representatives from the ASA Committees of Obstetric and Pediatric Anesthesia and the Board of Directors of the North American Fetal Therapy Network. This consensus statement describes the comprehensive preoperative evaluation, intraoperative anesthetic management, and postoperative care for the different types of maternal–fetal interventions. (Anesth Analg 2021;132:1164–73)

GLOSSARY

AS = aortic stenosis; **ASA** = American Society of Anesthesiologists; **BPS** = bronchopulmonary sequestration; **CCO** = combined cardiac output; **CDH** = congenital diaphragmatic hernia; **CHAOS** = congenital high airway obstruction syndrome; **CPAM** = congenital pulmonary airway malformation; **EEG** = electroencephalogram; **ETT** = endotracheal tube; **EXIT** = ex utero intrapartum treatment; **FHR** = fetal heart rate; **Fr**, French; **FTC** = fetal therapy center; **HLHS** = hypoplastic left heart syndrome; **IT** = information technology; **IUT** = intrauterine transfusion; **MFM** = maternal-fetal medicine; **MRI** = magnetic resonance imaging; **NAFTNet** = North American Fetal Therapy Network; **PUBS** = percutaneous umbilical blood sampling; **Rh** = Rhesus; **SCT** = sacrococcygeal teratoma; **sIUGR** = selective intrauterine growth restriction; **SIVA** = supplemental intravenous anesthesia; **TAPS** = twin anemia polycythemia sequence; **TRAP** = twin reversed arterial perfusion; **TTTS** = twin-to-twin transfusion syndrome

Over the last 3 decades, significant progress has been made in the field of maternal–fetal surgery.[1,2] Technological advances in prenatal fetal imaging and genetic diagnosis have allowed a better understanding of the disease progression and pathophysiology of several fetal anomalies. Concurrently, refinements in surgical techniques and instrumentation have resulted in a wide range of maternal–fetal interventions being performed at fetal therapy centers (FTCs) worldwide. The goals of these maternal–fetal interventions range from complete prenatal cure to reduction of otherwise irreversible organ damage and

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successful transition to extrauterine life.[3] The anesthetic techniques for these maternal–fetal interventions have evolved over the years. This document is a consensus statement on anesthesia for maternal–fetal interventions from a collaborative workgroup of the American Society of Anesthesiologist (ASA) Committees on Obstetric and Pediatric Anesthesia and the Board of Directors of the North American Fetal Therapy Network (NAFTNet). This document describes the perioperative anesthetic considerations for maternal–fetal interventions and details the role of the anesthesiologist in the multidisciplinary fetal therapy team.

CONSENSUS STATEMENT

A collaborative workgroup developed this consensus statement with representatives from the ASA Committees on Obstetric and Pediatric Anesthesia, consisting of practicing anesthesiologists with significant clinical experience in FTCs in the United States. The consensus statement was developed using a multistep process. First, original published research studies from peer-review journals within each area of comment were reviewed. A manuscript was then developed and independently reviewed by each member of the collaborative workgroup. In case of any disagreement, a consensus was reached through discussion between members of the workgroup. Before submission for publication, the consensus statement was approved by all members of the 2019 ASA Committees on Obstetric and Pediatric Anesthesia and subsequently approved by the Board of Directors of NAFTNet and ASA leadership.

Table 1. Different Types of Fetal Interventions and Their Common Indications

Fetal Interventions	Common Indications
Minimally Invasive Fetal Interventions	
Ultrasound-guided procedures	
Percutaneous umbilical blood sampling	Fetal genetic testing
Intrauterine blood transfusion	Fetal anemia, Rh isoimmunization, TAPS
Balloon valvuloplasty	Critical AS with evolving HLHS
Radiofrequency ablation	TTTS, TRAP sequence, selective IUGR
Cord coagulation ± transection	TTTS, TRAP sequence, selective IUGR
Interstitial laser coagulation	Feeder vessel for BPS, SCT, TRAP
Thoracoamniotic shunt	CPAM, fetal hydrothorax/chylothorax
Vesicoamniotic shunt	Bladder outlet obstruction
Fetoscopic interventions	
Laser photocoagulation	TTTS, TAPS, sIUGR
Fetoscopic endoluminal tracheal occlusion	CDH
Amniotic band release	Amniotic band syndrome
Ablation of posterior urethral valves	Bladder outlet obstruction
Open Fetal Surgeries	Myelomeningocele repair Pulmonary lobe resection for CPAM Mediastinal mass resection SCT tumor debulking/resection
EXIT Procedures	
EXIT to airway	Cervical teratoma/lymphangioma, CHAOS, laryngeal web/atresia, severe micrognathia
EXIT to resection	CPAM, bronchogenic cyst, SCT

Abbreviations: AS, aortic stenosis; BPS, bronchopulmonary sequestration; CDH, congenital diaphragmatic hernia; CHAOS, congenital high airway obstruction syndrome; CPAM, congenital pulmonary airway malformation; EXIT, ex utero intrapartum treatment; HLHS, hypoplastic left heart syndrome; Rh, Rhesus; SCT, sacrococcygeal teratoma; sIUGR, selective intrauterine growth restriction; TAPS, twin anemia polycythemia sequence; TRAP, twin reversed arterial perfusion; TTTS, twin-to-twin transfusion syndrome.

TYPES OF MATERNAL–FETAL INTERVENTIONS

The 3 main categories of maternal–fetal interventions are minimally invasive maternal–fetal interventions, open maternal–fetal surgery, and ex utero intrapartum treatment (EXIT) procedures[3–11] (Table 1). Minimally invasive maternal–fetal interventions are the most commonly performed maternal–fetal interventions and are typically performed in early or midgestation. They include both ultrasound-guided procedures and fetoscopic interventions, which involve ultrasound-guided percutaneous placement of trocar(s) through the uterus into the amniotic cavity.

Open maternal–fetal surgeries are typically performed in midgestation and, currently, the most common indication is fetal myelomeningocele repair. Other less common indications include resection of fetal lung lesions causing mediastinal shift and hydrops, mediastinal masses, and debulking of sacrococcygeal teratomas. After the induction of general anesthesia, a maternal laparotomy is performed to expose the uterus. Profound uterine relaxation is achieved using a combination of volatile and intravenous anesthetic agents, as well as additional tocolytic agents. A hysterotomy is then performed outside the placental margin to expose the desired fetal anatomy. Following the repair of the specific fetal defect, the uterus is closed in multiple layers, and the pregnancy is continued with a goal for delivery at or near term.[4–11]

The EXIT procedure enables securing the fetal airway and performing other life-saving fetal interventions in a controlled fashion, while the fetus remains on placental circulatory support.[12–15] EXIT procedures are performed at or near term gestation because the fetus is delivered at the end of the operation. The most common indication for an EXIT procedure is to secure the airway in fetuses with oropharyngeal masses, neck masses, or severe micrognathia causing airway obstruction. Other less common indications include resection of intrathoracic masses, causing mediastinal compression and debulking of sacrococcygeal teratomas.[12–15]

STRUCTURE OF FTCS

There is substantial variation in the organizational setup of FTCs worldwide. Patient care is typically

coordinated by a multidisciplinary team that includes maternal–fetal medicine (MFM) specialists, pediatric surgeons, neonatologists, anesthesiologists, radiologists, perioperative nurses, social workers, and geneticists. The American College of Obstetricians and Gynecologists and the American Academy of Pediatrics have made recommendations on the general components of an FTC, emphasizing the importance of maternal autonomy, explicit informed consent, multidisciplinary approach, availability of support services, oversight of centers, and collection of outcomes data.[16] Specific recommendations have also been made for complex maternal–fetal interventions, such as open fetal myelomeningocele repair.[17] The International Fetal Medicine and Surgery Society and NAFTNet published a joint opinion statement proposing the necessary components of an FTC, emphasizing the importance of the availability of advanced imaging services, comprehensive obstetric and neonatal care, access to multidisciplinary counseling, and established fetal therapies[3] (Table 2).

Table 2. Suggested Components of Fetal Therapy Centers

Component	Function
Prenatal imaging (ultrasonography, fetal MRI, fetal echocardiography)	Accurate diagnosis of fetal anomalies
Maternal–fetal medicine/pediatric surgery, including perinatal nursing	Prenatal consultation, intervention, and postdelivery management
Nurse coordinator	Care coordination, resource, and education
Obstetric anesthesia	Maternal management during fetal interventions
Genetics	Diagnosis and counseling for genetic disease
Neonatology, including nursing	Prenatal consultation, peripartum, and postdelivery care
Pediatric anesthesia	Fetal/neonatal management during fetal interventions
Pediatric cardiology	Prenatal diagnosis, postdelivery care, fetal monitoring during complex procedures
Adult medicine and critical care	Consultation as needed
Social worker and spiritual support	Coordination of social services, patient advocacy, and perinatal loss support
Language interpretation and cultural diversity specialist services	Consultation, consent, and follow-up services
Palliative care	Palliative postdelivery care, perinatal hospice services
Medical ethicist	Consultation and oversight, as needed
Institutional review board	Oversight of experimental and research related interventions
Database and IT support services	Reporting, data collection and sharing, research

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Abbreviations: MRI, magnetic resonance imaging; IT, information technology.

PREOPERATIVE EVALUATION

A multidisciplinary team meeting should be held, and the mother and her family should meet with all specialty teams, individually or in a group setting before any planned maternal–fetal intervention to discuss risks, benefits, anticipated outcomes, and alternatives for both fetus and mother. The anesthesiologist is a critical member of the multidisciplinary team that evaluates the mother's suitability for undergoing a procedure.[4–11] The standard medical, surgical, obstetric, and anesthetic history must be solicited, and a targeted physical examination should be performed, focusing on the airway, cardiopulmonary system, and spine. The anesthesiologist should explicitly discuss the risks of the planned anesthetic, understanding that the mother assumes the surgical and anesthetic risks for the benefit of the fetus(es). If members of the multidisciplinary team identify preexisting maternal comorbidities that significantly increase the maternal risk of perioperative morbidity or mortality, a multidisciplinary discussion should occur to review the maternal risks and potential fetal benefits, and the mother should be given the opportunity to decline the planned procedure.

Standard adult fasting guidelines are applicable.[18] Maternal preoperative laboratory testing is guided by history and physical examination. While a type and screen are adequate for minimally invasive maternal–fetal interventions, a type and cross-match should be ordered for open maternal–fetal surgeries and EXIT procedures. In addition, O-negative, leukocyte-reduced, irradiated, cytomegalovirus-negative blood cross-matched to the patient should be readily available for the fetus.[4–11]

A comprehensive maternal–fetal evaluation should include a review of all fetal imaging studies in a multidisciplinary meeting to evaluate the extent of anatomic and physiologic derangement. Often, serial fetal imaging studies are performed to monitor the growth of pulmonary lesions, progression of heart failure, development of fetal hydrops, worsening of mediastinal shift, and airway compression.[4–11] Fetal genetic studies, including karyotype and microarray at a minimum, must be performed to rule out chromosomal abnormalities, microdeletions, or duplications, which might be a contraindication to perform the fetal intervention.[3] Pertinent information for the anesthesiologist includes gestational age, fetal cardiac function, estimated fetal weight for drug dosing, and placental location, which determines patient positioning and the need to exteriorize the uterus.[4–11]

The multidisciplinary team, including neonatology, should also discuss the plan for the fetus in the event of an intraoperative maternal arrest and/or the need for fetal resuscitation. If the fetus is of a previable gestational age or the patient has elected not to

resuscitate the fetus if born at the time of surgery, planning for emergent cesarean delivery is still needed, as it may be performed for maternal hemorrhage or cardiac arrest. Uterotonics should be readily available in the event of an unplanned cesarean delivery to prevent uterine atony. In the event of fetal distress, in utero fetal resuscitation alone will be performed if the fetus is determined to be nonviable.[19] If the multidisciplinary team and the patient decide that fetal resuscitation would be pursued, then the neonatology and pediatric anesthesia team should be prepared for the possibility of delivery and neonatal resuscitation.

FETAL PHYSIOLOGY AND DRUG TRANSFER

A detailed understanding of fetal physiology and drug transfer is necessary to interpret various modes of intraoperative fetal monitoring, determine appropriate drug dosing, and effectively administer in utero resuscitation.[9,20] More than half of the fetal blood volume resides in the placenta and is approximately 110–160 mL/kg, from the start of the second trimester to term. Fetal cardiac output is mainly a function of fetal heart rate (FHR). This is because the fetal myocardium is less compliant than adult myocardium and less responsive to fluctuations in preload.[21] Right ventricular and left ventricular output are not equivalent in the fetus, so cardiac output is described in terms of the combined cardiac output (CCO) of both ventricles. A normal fetus has a CCO of 425–550 mL/kg/min. During surgical procedures resulting in significant fetal blood loss, the degree of hypovolemia and transfusion end point requires vigilant monitoring of both FHR and intraoperative fetal cardiac function using echocardiography. Fetal lungs are fluid filled, and the pulmonary epithelium secretes approximately 100 mL/kg/d of fluid that exits the fetal trachea to be either swallowed or introduced into the amniotic fluid. Although immature, the fetal liver synthesizes coagulation factors. These coagulation factors do not cross the placenta and are in lower concentration and less effective in forming clots compared to adults. Although fetal hepatic enzymes are less functional than in adults, most medications in the umbilical vein undergo a significant amount of fetal hepatic metabolism (first-pass metabolism) before circulating to the fetal brain or heart. Although these fetal metabolic enzymes are less functional than those of adults, most drugs are still significantly metabolized.

Molecules smaller than approximately 1000 Daltons are primarily exchanged between the maternal and fetal circulation by placental diffusion. The degree and rate of transfer are determined by transplacental concentration gradients, molecular weight, protein binding, ionization, and lipid solubility. All drugs cross the placental barrier to some degree, but a few are significantly restricted. Examples of medications with severely limited maternal–fetal transfer include nondepolarizing neuromuscular blockers, succinylcholine, glycopyrrolate, unfractionated heparin, low-molecular-weight heparins, and insulin. Volatile anesthetics, opioids, benzodiazepines, and atropine readily cross the placenta.

FETAL ANALGESIA

Pain is a subjective phenomenon that is difficult to assess. Although pain typically includes a nociceptive component and reflexive withdrawal response mediated at the level of the spinal cord and brainstem, it also includes affective components that require higher-level cortical processing and can be present without physical stimuli (eg, phantom limb pain).[22] Direct fetal interventions, including the passage of a needle into the fetus, result in a hormonal stress response that is decreased with fetal opioid administration.[23] Although pituitary–adrenal, sympathoadrenal, and nociceptive components of the stress response are present by 19 weeks' gestation allowing a fetus to reflexively withdraw from a noxious stimulus without input from the cerebral cortex,[22,24] thalamocortical connections to the somatosensory cortex allowing the perception of pain are not significantly developed until 24 to 30 weeks' gestation.[22,25] There is evidence to indicate that noxious stimulation can be transmitted to the cortex by 25 weeks' gestation.[26,27] Electroencephalogram (EEG) studies support this timeline. EEG electrical activity is only present 2% of the time at 24 weeks' gestation. By 30 weeks' gestation, EEGs demonstrate patterns of wakefulness and sleep (although not concordant with fetal behavior). By 34 weeks' gestation, EEG electrical activity is present 80% of the time, with wake/sleep patterns similar to adults.[28]

Because it remains uncertain exactly when a fetus has the capacity to feel pain, it is best to administer adequate fetal anesthesia in all invasive maternal–fetal procedures to inhibit the humoral stress response, decrease fetal movement, and blunt any perception of pain, as has been standard practice since the start of maternal–fetal surgery in the early 1980s. In addition, if the fetal stress response is not blunted, there may be significant short- and long-term adverse effects on the developing central nervous system.[23,29] Opioid analgesics can reach the fetal circulation by maternal administration, direct fetal intramuscular administration, or intravenous umbilical cord administration. Fetal movement can be further decreased by intramuscular or umbilical administration of a muscle relaxant. The umbilical cord and placenta have no known pain receptors, so procedures that only involve these tissues (eg, intrauterine transfusion [IUT] or laser ablation for twin-to-twin transfusion syndrome [TTTS]) do not require fetal administration of analgesics. In

these procedures, maternal opioid administration (eg, remifentanil) and subsequent placental transfer can assist with fetal immobility, but this is not always required.[30] For open maternal–fetal procedures, the use of maternal general anesthesia allows the transfer of anesthetics from the mother to the fetus, but direct fetal administration of opioid is still required to blunt the fetal stress response to invasive procedures reliably.

ANESTHETIC TECHNIQUES

The anesthetic technique for any maternal–fetal intervention depends on the planned surgical approach, degree of invasiveness, maternal comorbidities, and patient/surgeon preference.[4–11] Specific resources available at each institution must be taken into consideration when choosing the optimal location for each maternal–fetal intervention. Maternal safety is paramount, and an assessment of fetal/neonatal risks and benefits of each maternal–fetal intervention must be weighed against potential maternal complications. The anesthesia team must have a thorough understanding of maternal and fetal physiology, as well as the planned maternal–fetal intervention. For open maternal–fetal and EXIT procedures, expertise in obstetric and pediatric anesthesia is required.

Anesthesia for Minimally Invasive Maternal–Fetal Interventions

Most minimally invasive maternal–fetal interventions are performed with local anesthetic infiltration, with or without maternal sedation. Some of the less invasive procedures, such as amnioreduction and percutaneous umbilical blood sampling (PUBS), may be performed in ultrasound or procedure rooms without the involvement of an anesthesiologist. Neuraxial techniques or general anesthesia may be necessary depending on the number and size of port sites, anticipated patient position, surgeon preference, and maternal comorbidities, such as aspiration risk, severe anxiety, and inability to tolerate the supine position with uterine displacement for the length of the procedure. An anterior placenta might necessitate the lateral positioning of the patient for the procedure. Only minimal-to-moderate sedation should be used in either monitored anesthesia care or neuraxial anesthesia to preserve airway reflexes and maintain a level of consciousness so the patient can be directed to reposition herself or hold still during the procedure.[31] Although preoperative tocolytics may be administered, profound intraoperative uterine relaxation is not necessary for minimally invasive procedures, and maternal administration of sedatives and analgesics only provides limited fetal analgesia via transplacental transfer. For maternal–fetal interventions on noninnervated tissues such as the umbilical cord (IUT, PUBS) and placenta (laser photocoagulation for TTTS), no additional fetal analgesia is necessary. In the case of an IUT, a nondepolarizing muscle relaxant may be administered to the fetus via the intramuscular route or directly into the umbilical vein to decrease the likelihood of fetal movement that could dislodge the needle or shear the umbilical vein. For more invasive maternal–fetal interventions, such as percutaneous balloon valvuloplasty or fetoscopic endoluminal tracheal occlusion, fetal analgesia is provided using an intramuscular or intraumbilical venous administration of a fetal mixture containing opioid and muscle relaxant, often accompanied with atropine to minimize the risk of fetal bradycardia.

Preoperatively, consider the maternal administration of aspiration prophylaxis medications, including nonparticulate antacids, H_2-receptor antagonists, and/or metoclopramide. Standard ASA monitors should be used.[18] In the past, intraoperative fluid administration was restricted secondary to concerns of maternal pulmonary edema from the absorption of irrigation fluids.[32,33] However, judicious use and close accounting of intrauterine irrigation fluids have mitigated this issue, and routine maintenance fluids should be administered based on the patient's volume status and the duration of surgery. If maternal hypotension occurs, administration of medications such as phenylephrine, ephedrine, and glycopyrrolate may be necessary to maintain adequate uteroplacental blood flow and maternal hemodynamics near baseline levels.[34] Fetal monitoring during minimally invasive maternal–fetal interventions typically involves FHR monitoring using Doppler ultrasonography at the beginning and the end of the maternal–fetal intervention. In many cases, it is also assessed intermittently during the procedure. During maternal–fetal cardiac interventions, continuous fetal echocardiography may be performed by the pediatric cardiologist or MFM specialist. The perioperative considerations for minimally invasive fetal interventions are listed in Supplemental Digital Content, Table S1, http://links.lww.com/AA/D187.

Anesthesia for Open Maternal–Fetal Surgeries

Open maternal–fetal surgeries are typically performed under maternal general anesthesia.[4–11] Preoperatively, a high lumbar (L1–3) epidural catheter is inserted for postoperative analgesia. Secondary to concerns of intraoperative hemodynamic instability, the epidural catheter is frequently not initiated until maternal wound closure but with enough time remaining to ensure adequate analgesia during emergence and extubation. Preoperatively, consider the maternal administration of medications for tocolysis and aspiration prophylaxis. For venous thromboembolism prophylaxis, mechanical or pharmacologic

methods, including low-dose unfractionated heparin or low-molecular-weight heparin, should be administered according to published guidelines, based on maternal comorbidities, current fetal status, concern for reoperation or urgent delivery, and timing of planned catheter removal.[35,36] The patient should be positioned supine with left uterine displacement on the operating table. The presence of all team members and, at a minimum, a repeat assessment of FHR and position should occur before induction. Drugs for fetal intramuscular administration and unit doses of fetal resuscitation drugs (epinephrine and atropine) based on estimated fetal weight should be prepared in a sterile fashion and clearly labeled. After adequate preoxygenation, a rapid sequence induction should be performed to facilitate endotracheal intubation and minimize the risk of aspiration. In addition to standard ASA monitors, maternal large-bore intravenous access should be obtained for volume resuscitation in case of significant acute hemorrhage. Although there is no consensus among FTCs, arterial catheter placement can be considered for close hemodynamic monitoring. Maternal general anesthesia is maintained with either a volatile anesthetic agent or a combination of volatile and intravenous anesthetic agents. Maintaining uteroplacental blood flow is critical, and vasopressors are commonly required to support maternal hemodynamics.[34] If a maternal nondepolarizing muscle relaxant is administered, the degree of neuromuscular blockade should be monitored with a twitch monitor and reversed before emergence.

One of the central tenets of open maternal–fetal surgery is achieving profound uterine relaxation before hysterotomy and maintaining it until uterine closure.[4–11] Traditionally, high doses of a volatile anesthetic agent (up to 2–3 minimum alveolar concentrations) were used to maintain adequate uterine relaxation. However, this technique can be associated with significant fetal cardiac dysfunction and bradycardia.[37] More recently, supplemental intravenous anesthesia (SIVA) using remifentanil infusions with or without propofol in addition to a volatile anesthetic agent for uterine relaxation has allowed the dose of the volatile agent to be lowered during open maternal–fetal surgery, thereby minimizing fetal cardiac dysfunction and maternal hemodynamic instability.[38,39] In addition, boluses or a continuous infusion of nitroglycerin may be administered to augment uterine tocolysis. Currently, no specific anesthetic technique has been proven to be superior to another. Early intraoperative administration of magnesium sulfate infusion for tocolysis can also be considered to reduce the amount of volatile anesthetic required for uterine relaxation during open maternal–fetal surgery.[40] Intraoperative fluid administration is frequently restricted to <2 L to minimize concerns for postoperative maternal pulmonary edema.[11]

Clear communication between the surgery and anesthesia team throughout the procedure and anticipation of intraoperative events are critical to success. After maternal laparotomy and uterine exposure, the placental borders are mapped with a sterile ultrasound probe. After ensuring adequate uterine relaxation, a hysterotomy is performed. A specialized absorbable stapling device may be used to ensure adequate hemostasis. Subsequently, warm crystalloid solution is infused into the uterine cavity to maintain uterine volume, and intrauterine temperature is monitored and maintained near normal. It is important to maintain maternal core temperature using warmed fluids and forced air warmers to ensure appropriate fetal/intrauterine temperature. Following optimal fetal positioning, a fetal intramuscular dose of opioid and nondepolarizing muscle relaxant is administered for fetal analgesia and immobilization. Atropine may also be administered to minimize the chance of fetal bradycardia. Dosing of fetal medications is based on the estimated fetal weight from the most recent ultrasound, taking into account any anatomic fetal abnormalities that may introduce error (eg, hydrocephalus). Although continuous fetal cardiovascular monitoring is not feasible throughout most open procedures, periodic monitoring of FHR, fetal cardiac function, and/or umbilical artery Doppler should be performed using a sterile probe. Following surgical repair of the fetal defect, and hysterotomy closure, any residual maternal neuromuscular blockade should be fully reversed, and prophylactic antiemetic medications should be administered. The epidural catheter may be initiated before the conclusion of the surgery to ensure adequate analgesia during emergence and extubation. The patient is extubated when fully awake and following commands. The perioperative considerations for open maternal–fetal surgeries are listed in Supplemental Digital Content, Table S2, http://links.lww.com/AA/D187.

Anesthesia for EXIT Procedures

The anesthetic management of a mother undergoing an EXIT procedure is similar to that of open maternal–fetal surgery with some key differences.[12–15] While EXIT procedures are typically performed under maternal general anesthesia, they have also been successfully accomplished using maternal neuraxial anesthesia with the administration of a nitroglycerin infusion for uterine tocolysis and remifentanil infusion for fetal immobilization and analgesia.[41,42] The fetus is delivered at the end of the procedure, and uterine relaxation is only needed intraoperatively, so magnesium sulfate is not required to prevent postoperative uterine contractions. The guiding principles

of an EXIT procedure include (1) achieving adequate uterine relaxation to maintain uteroplacental circulation, (2) maintaining uteroplacental blood flow and maternal hemodynamics, (3) preserving uterine volume by partial delivery of the fetus and amnioinfusion, (4) minimizing fetal cardiac dysfunction, and (5) reversal of uterine relaxation after umbilical cord clamping.[12]

After maternal general anesthesia and ensuring adequate uterine relaxation, a hysterotomy is performed to partially deliver the fetus. Fetal analgesia and optimal intubating conditions are obtained by the intramuscular fetal administration of a mixture containing opioid and muscle relaxant, often accompanied with atropine to minimize the risk of fetal bradycardia. Fetal monitoring can occur via continuous fetal echocardiography, or a pulse oximeter may be placed on either fetal hand with an opaque covering to prevent interference from room lights. The normal range for fetal oxygen saturation is 40%–70%, with a significant increase expected following fetal lung ventilation. There is frequent difficulty in measurement, but efforts should be made to obtain a pulse oximetry waveform before securing the airway. Direct laryngoscopy and endotracheal intubation is then typically performed on the fetus. Other advanced airway interventions such as rigid bronchoscopy, retrograde wire intubation, partial mass resection, and/or tracheostomy should be readily available to secure a distorted fetal airway.[12–15,43] Additional equipment for fetal airway management are listed in Table 3.

After confirming the position of the endotracheal or tracheostomy tube with a flexible bronchoscope, end-tidal carbon dioxide tracing, or chest rise, surfactant may be administered if clinically indicated for prematurity or concerns for pulmonary hypoplasia. If additional fetal interventions such as resection of thoracic masses or sacrococcygeal teratoma are planned, a fetal peripheral intravenous catheter may be inserted for fluid and blood administration, if necessary. On completion of the EXIT procedure and clamping of the umbilical cord, intravenous oxytocin should be administered to the mother for the rapid reversal of uterine relaxation. Administration of the volatile anesthetic agent to the mother is reduced or discontinued, and general anesthesia is typically maintained with additional intravenous anesthesia agents such as propofol and opioids. Communication between the surgeons and anesthesiologists is again critical at all stages of an EXIT procedure. The newborn is transferred to an adjoining operating room for further resuscitation and stabilization, as indicated. A separate team consisting of a surgeon, anesthesiologist, neonatologist, respiratory therapist, and nurses must be readily available for completion of surgery on the newborn in the adjacent operating room if necessary. Following the delivery of the placenta, an assessment of the uterine tone should be performed. Atony should be treated with the additional uterotonics, and blood should be immediately available for possible prolonged maternal hemorrhage. The perioperative considerations for EXIT procedures are listed in Supplemental Digital Content, Table S3, http://links.lww.com/AA/D187.

Table 3. Equipment for Fetal Airway Management During an Ex Utero Intrapartum Treatment Procedure

Disposable sterile laryngoscope handle with Miller 1, 0, and 00 blades
ETTs (uncuffed): 2.0, 2.5, 3.0 and 3.5 with stylette
Laryngeal mask airway: sizes 1 and 1.5
Armored endotracheal tubes: 3.0 and 3.5
Tracheostomy tubes: 2.5 and 3.0 Neonatal Bivona, 3.0 Neonatal Shiley
Sterile Mapleson D bag and circuit
Sterile tubing for oxygen administration
Flexible bronchoscope: 2.5 mm
Rigid telescope: 1.9 and 2.5 mm
Hi-definition camera and light cord
ETT tube changer or wires for retrograde intubation
Feeding tubes: 2.5 and 3.0 Fr for surfactant administration
Major neck tray for tracheostomy or mass excision

Abbreviations: ETT, endotracheal tube; Fr, French.

FETAL RESUSCITATION

The fetus depends on uteroplacental support, and during fetal surgeries, preserving the uteroplacental circulation by maintaining maternal hemodynamics, achieving adequate uterine relaxation, preserving appropriate intrauterine fluid volume, and avoiding uterine contractions are critical. Fetal bradycardia is a reliable indicator of fetal compromise that must be addressed immediately.[4–11] The common causes of fetal bradycardia include mechanical compression or kinking of the umbilical cord, uterine contractions, placental separation, maternal hypotension, umbilical artery vasospasm, anemia, or hypoxemia. Less common causes include fetal hypovolemia, hypothermia, and anemia. All efforts to avoid maternal hypothermia should be used. The presence of placental circulation makes the fetal temperature highly dependent on maternal temperature, and maternal hypothermia will result in fetal hypothermia, which is associated with fetal bradycardia.[44,45]

If fetal bradycardia occurs, the anesthesiologist should increase maternal inspired oxygen, administer vasoactive drugs and intravenous fluids to ensure appropriate maternal blood pressure and heart rate, administer additional tocolytic agents or increase the concentration of volatile anesthetic agents in the presence of uterine contractions, and rule out aortocaval compression as a cause of maternal hypotension. The surgeons should rule out mechanical compression of the umbilical cord by repositioning the fetus and increase the amniotic fluid volume. Placental

abruption must also be ruled out. If these initial measures are unsuccessful, fetal resuscitation medications (eg, epinephrine, atropine) should be administered to the fetus via the intramuscular route. Fetal resuscitation may also include the administration of crystalloid or blood products and the performance of chest compressions.

POSTOPERATIVE MANAGEMENT AND CONSIDERATIONS

Postoperative considerations are similar to cesarean delivery (eg, pain management, venous thromboembolism prophylaxis, monitoring for hemorrhage). However, postoperative care of maternal–fetal surgery patients should also include tocolysis and fetal assessment. For minimally invasive procedures such as cordocentesis or IUT, tocolysis is typically not required. For more invasive percutaneous procedures (eg, shunt catheter placement, fetoscopic techniques), preoperative prophylactic tocolytic agents such as indomethacin may be administered, with additional drugs rarely required in the postoperative period.

Following open maternal–fetal surgery, patients often require continuous uterine monitoring for 48 or 72 hours. To decrease the fetal morbidity from postoperative preterm labor and preterm delivery, the magnesium sulfate infusion initiated intraoperatively is continued for ≥24 hours postoperatively. Additional tocolytic agents (eg, indomethacin and/or nifedipine) should also be considered as needed. Indomethacin can cause constriction of the fetal ductus arteriosus. If administered for tocolysis, periodic fetal echocardiography monitoring should be performed to detect premature closure of the ductus arteriosus. This occurs most commonly at gestational ages <32 weeks.

Fetal assessment is dependent on gestational age and parental wishes. Continuous FHR monitoring and periodic ultrasound assessment should be instituted in the postoperative period, with a predetermined plan established for the management of fetal distress. The monitoring plan should be individualized, based on gestational age, fetal condition, procedure, and plan for fetal distress. Examples of fetal morbidity in the postoperative period include infection, heart failure, intracranial hemorrhage, oligohydramnios, and intrauterine demise. The mother should be evaluated for signs of postoperative pulmonary edema. If there is suspicion of pulmonary edema, a chest radiograph should be obtained, with initiation of diuresis and consideration of critical care admission, if present.

Inadequate postoperative pain control can increase the risk of preterm labor.[25,46] For minimally invasive procedures, postoperative analgesia is typically achieved by the administration of oral analgesics such as acetaminophen. For open procedures, postoperative analgesia is typically epidural based using a dilute solution of a local anesthetic and an opioid. Administration of a long-acting neuraxial opioid (eg, preservative-free morphine) may be considered at the time of epidural discontinuation. Intravenous and/or oral opioids and acetaminophen can be used in place of an epidural or after the epidural is discontinued.

After open maternal–fetal procedures, patients are at risk for premature rupture of membranes, preterm labor, infection, and uterine rupture.[47,48] The patient should remain near the FTC for 2–4 weeks after the procedure to facilitate the periodic assessment of the pregnancy and the possibility of preterm delivery. A course of steroids for fetal lung maturity may be administered if there is a concern for preterm delivery and the gestational age is appropriate. Cesarean delivery is typically planned for 37 weeks' gestation following open maternal–fetal surgery but may occur earlier with the onset of preterm labor or other complications necessitating delivery.

SUMMARY

A wide range of maternal–fetal interventions are being performed across FTCs worldwide, and the anesthetic techniques have evolved over the years. Maternal safety is paramount, and the risks to the mother must be balanced against benefits to the fetus. The anesthesiologist plays a critical role and should be involved at all levels in these multidisciplinary maternal–fetal interventions. Anesthetic management should focus on maintaining adequate uteroplacental blood flow, optimizing surgical conditions, and minimizing maternal and fetal risk.

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