

Anesthesia for Fetal Surgery

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Fetal surgery is an area of rapid and exciting growth. Ex-utero intrapartum therapy (EXIT), fetoscopic procedures, and open, midgestation procedures such as repair of myelomeningocele, congenital cystic adenomatoid malformations of the lung and sacrococcygeal teratoma are now performed at multiple institutions around the world.

Surgical intervention is considered for a fetus with a congenital lesion/condition that can compromise or disturb cardiovascular function or cause severe postnatal morbidity. Surgery is only performed when the risk to the mother is low and the risk of death or severe disability to the fetus outweighs no intervention. Contraindications for these procedures are medical condition in the mother precluding surgery or lethal/disabling genetic defects in the fetus.

Fetal surgical techniques are based on years of animal and clinical research. In contrast, anesthesia for fetal surgery is based on clinical experience, case reports and translation of responses to anesthetics in pregnant sheep. This chapter will review the maternal and fetal anesthetic considerations for each type of fetal surgical procedure.

Indications

Fetal surgery can be divided into three distinct procedure groups.(Table 1) Midgestation hysterotomy is performed on fetuses with well-defined congenital lesions. Surgery on the fetus is performed between 18 – 26 weeks through a hysterotomy. For these procedures, the fetus is exteriorized for surgical intervention and then placed back in the uterus to mature. Correction of these lesions is expected to improve either fetal survivability or enhance post-gestation quality of life. If left untreated, these lesions result in severe disability or death.

Ex-Utero Intrapartum Therapy (EXIT) procedures are hysterotomy based procedures done at or near term on fetuses with expected immediate post-gestation airway or oxygenation compromise. Surgery on the fetus is done after hysterotomy but prior to cord clamping. Surgeons then assess the infant's airway by bronchoscopy and secure the airway via an endo-tracheal tube or tracheotomy prior to complete airway obstruction or ventilation failure. During this time the fetus is oxygenated by placental transfer of oxygen.

Fetoscopic surgery is a minimally invasive technique utilizing small diameter trocars and laparoscopes placed percutaneously to access the uterus. This technique is most commonly used for the evaluation and treatment of twin reverse arterial perfusion sequence, twin-twin transfusion syndromes,

amniotic band syndrome, and bladder outlet obstruction. Surgical devices such as electrocautery and lasers are used to ablate or cauterize vessels or tissue during these procedures. This technique is considered when fetal demise or severe fetal morbidity is imminent or traditional therapeutic measures (e.g. amnioreduction) have failed.

RISK ASSESSMENT

Maternal Anesthetic Considerations

Regional anesthesia is usually the technique of choice for obstetric anesthetic practice. But, because the uterine relaxation required for hysterotomy based fetal surgery is best provided by high concentration potent volatile agents, general anesthesia is the technique of choice for fetal surgery.

The maternal physiologic changes during pregnancy contribute to increased anesthetic risk for both the mother and fetus. Pregnant patients undergoing general anesthesia are at increased risk for aspiration pneumonitis. Thus, a rapid sequence induction is always performed for endotracheal intubation.

Pregnancy affects maternal pulmonary function. The cephalad encroachment of the gravid uterus reduces functional residual capacity, particularly the volumes of the lower lobes, and oxygen consumption increases to meet the increased demands of both the mother and the fetus. These factors increase the risk of hypoxia during a rapid sequence induction. Decreases in capillary oncotic pressure and increases in capillary permeability increase the risk of pulmonary edema, especially postoperatively when magnesium sulfate is used for tocolysis.

The cardiovascular system is affected by pregnancy. A decrease in preload during supine positioning (supine hypotension syndrome), due to compression of vena cava, can cause maternal hypotension and fetal hypoxia. It is important to position the mother with left uterine displacement to displace the uterus from the inferior vena cava.

The parturient's central nervous system is also affected by pregnancy. Sensitivity to anesthetics is increased and MAC is significantly decreased during pregnancy and sensitivity to muscle relaxants is increased. Thus, lower doses of volatile anesthetics and muscle relaxants are needed for surgery.

Fetal Anesthetic Considerations

The primary concern of anesthetic management is maintenance of placental circulation and fetal cardiovascular stability. The combination of immature organ function and cardiovascular compromise

predispose the fetus to anesthetic difficulty. The fetal cardiovascular system is less able to compensate for hypoxia and hypovolemia than a full term infant. Lacking a functional pulmonary system to increase oxygen tension, the fetus relies on increased umbilical blood flow and cardiac output and blood flow redistribution to improve oxygen delivery to the vital organs. The Starling curve is shifted down in a fetus compared to a neonate resulting in less cardiac output for a given stroke volume (figure 1) Thus, cardiac output is more dependent on heart rate. Because of high vagal tone and low baroreceptor sensitivity, the fetus responds to stress with a decrease in heart rate.

Fetal circulating blood volume is relatively low; the midgestation fetus has an estimated fetoplacental blood volume of 50-70 ml (110 ml/kg). Therefore, a small amount of surgical blood loss can precipitate hypovolemia. Inhalation anesthetics also destabilize the fetal cardiovascular system by causing direct fetal myocardial depression, vasodilation and changes in arterio-venous shunting.

Because of incomplete myelination and less synaptic activation, the fetus is more sensitive to volatile inhalation agents. This increased sensitivity results in a decreased MAC when compared to pregnant adults. Sensitivity to analgesics and muscle relaxants is also greater in the fetus compared to the neonate.

Fetal cutaneous heat and evaporative losses require warm ambient temperatures during fetal exposure. Limiting fetal surgical time and the use of warm irrigation fluids can prevent hypothermia.

Altered coagulation factors predispose to bleeding and cause difficulty in surgical hemostasis during fetal surgical manipulation. The small blood volume of the fetus compounds this problem. Fetal hemoglobin can be assessed intraoperatively via a central or percutaneously obtained fetal blood samples.

Utero-placental anesthetic considerations

Uterine and umbilical artery blood flow and placental barriers to diffusion influence fetal oxygen delivery. Maternal systemic blood pressure and myometrial tone directly correlate with uterine artery blood flow. Volatile anesthetics decrease myometrial tone and tend to decrease maternal blood pressure and maternal placental blood flow. This can result in a decrease in fetal oxygenation. Umbilical artery blood flow is influenced by fetal cardiac output and vascular resistance, both intrinsic and extrinsic (e.g.

compression by a “nuchal cord”). Thus, maintenance of a patent umbilical artery and a near-baseline maternal arterial pressure is critical (maternal systemic pressure within 10% of baseline).

Control of myometrial tone by general inhalation anesthesia is necessary for open fetal surgery to provide optimal operative exposure. Epidural anesthesia alone does not provide uterine relaxation. However, epidural anesthesia may help prevent premature labor in the postoperative period. Magnesium sulfate, terbutaline, nifedipine and indomethacin are also used alone or in combination to maintain uterine quiescence in the postoperative period.

MANAGEMENT

Open Fetal Surgery: Preoperative Evaluation and Preparation

In preparation for surgery, the operating room is warmed to 80°F (26.7°C), type specific packed red blood cells for the mother and O negative packed red blood cells for the fetus are made available. Monitors include two pulse-oximeters (maternal and fetal) and an arterial pressure transducer. Epinephrine 10mcg/kg, atropine 20mcg/kg, vecuronium 0.2mg/kg, and fentanyl 10-20mcg/kg, prepared sterilely in 1 cc syringes for possible fetal IM administration. After assuring NPO status, a single large bore intravenous catheter is inserted. Sodium bicarbonate PO and metoclopramide IV are administered to the mother to decrease the risk of aspiration pneumonia. An indomethacin suppository is administered for postoperative tocolysis. A lumbar epidural is inserted and tested. The parturient is then positioned on her left side or the OR table is tilted to the left side to minimize supine hypotension syndrome.

Intraoperative Management

A rapid sequence induction using sodium thiopental IV and succinylcholine IV is performed followed by tracheal intubation. General anesthesia is maintained with 0.5 MAC volatile anesthetic (isoflurane or desflurane) and 50% nitrous oxide. A radial arterial catheter, second intravenous catheter, nasogastric tube and Foley catheter are inserted. Fetal status is monitored by sterile intraoperative echocardiography. Intravenous fluid is restricted (500cc total) to reduce the risk of postoperative pulmonary edema.

Open hysterotomy procedures require low uterine tone to maintain fetal perfusion and optimize fetal exposure. Before the maternal skin incision, nitrous oxide is turned off to improve fetal oxygenation and the inhalation agent is increased to 2.0 MAC to provide uterine relaxation and fetal anesthesia by the

time of uterine and fetal incision. Ephedrine 5-10mg IV or phenylephrine 1-2mcg/kg IV is administered as necessary to maintain maternal systolic blood pressure within 10% of baseline.

Fetal anesthesia and analgesia is provided by a combination of placental passage of volatile anesthetics and intramuscularly administered opioids. Equilibration between mother and fetus with isoflurane and desflurane, reaches approximately 70% and 50% of maternal levels, in one hour. Before fetal incision, the fetus receives fentanyl 20mcg/kg intramuscularly to supplement the anesthesia and provide postoperative analgesia.

Fetal well-being is assessed by both direct and indirect methods. For procedures where a fetal extremity is accessed (congenital cystic adenomatoid malformation and sacrococcygeal teratoma resections), fetal arterial saturation is monitored by pulse-oximetry. The pulse oximeter probe is placed on the fetal hand and wrapped with foil to decrease ambient light exposure. Normal fetal arterial saturation is 60-70%, during fetal surgery values greater than 40% represent adequate fetal oxygenation. Echocardiography is also used to monitor fetal heart rate and stroke volume. Fetal distress, manifested by bradycardia, decreased saturations, or decreased stroke volume, is often a result of partial umbilical cord occlusion. Fetal arterial or venous blood gas samples may be obtained by the surgeons percutaneously or through umbilical or central vessel puncture to help guide therapy during periods of fetal distress. Warm fresh O negative blood can be administered to the fetus to correct anemia through a percutaneous peripheral venous line placed intraoperatively.

Following closure of the uterus, the anesthetic is converted to a regional based technique. As the final stitches are placed in the uterus, the volatile anesthetic is decreased and the epidural catheter is dosed with local anesthetic and opioid. Tocolysis is instituted via a loading dose of magnesium sulfate 6 grams IV followed by a magnesium sulfate IV infusion at 2-3 grams/hour. The patient's trachea is extubated after skin closure and she is then transferred to the obstetric floor for postoperative care.

Postoperative management

Key goals for postoperative management include prevention of premature labor and maintaining maternal comfort. Magnesium sulfate is the drug of choice in the early postoperative period (18-24 hours) for tocolysis while a patient controlled epidural infusion is used for analgesia. A well-functioning epidural may assist in the prevention of preterm labor.

Ex-utero intrapartum therapy (EXIT): Preoperative Management

Anesthetic preparation is the same for the EXIT as for the open procedure with two notable exceptions: no tocolytics, and one additional operating room for direct postdelivery care and possible surgery of the newborn. Tocolytics are unnecessary since the procedure ends in delivery. Resuscitation equipment, neonatologists and a second operating room are all made available for post-delivery care of the neonate.

Intraoperative Management

The risk of aspiration and supine hypotensive syndrome are high in the term gestation mother with a large gravid uterus. Thus, after epidural placement, a rapid sequence induction is performed followed by orotracheal intubation. A second intravenous catheter, a nasogastric tube and Foley catheter are placed. The second intravenous line is placed in case the patient requires volume resuscitation for acute blood loss following delivery of the fetus. A maternal arterial cannula is placed when a fetus has end-stage disease manifesting as fetal hydrops due to lability of maternal blood pressure during these cases.

Anesthesia for the EXIT is via an inhalation based technique. Sub-MAC concentrations (0.5 MAC) of volatile agent are used before maternal skin incision and high-level inhalation agent is used thereafter. Ephedrine and phenylephrine are used for maternal blood pressure maintenance. For rapid maternal and neonatal emergence after delivery, the preference of inhalation agent is desflurane because of its low blood-gas solubility.

During hysterotomy it is important for the surgeons to only partially expose the fetus and maintain the uterine volume at an appropriate level for placental perfusion to be maintained. Maternal hyperventilation should be avoided because maternal hypocapnia causes fetal placental vasoconstriction and fetal hypoxia. Fentanyl 20 mcg/kg intramuscularly is given to the fetus to supplement fetal analgesia and provide postoperative analgesia. Fetal status is closely monitored via a pulse-oximeter, sterile echocardiography, and visual inspection. Fetal blood gases are obtained as needed and fresh O negative blood administered if necessary. Direct laryngoscopy and intubation is performed by either the surgeons or anesthesiologist. If the fetus cannot be intubated, partial resection of an obstructive lesion and/or tracheotomy is performed by the surgeons. After securing the airway and assuring adequate fetal oxygenation with manual ventilation, the umbilical cord is clamped and the fetus delivered.

Following the delivery it is important to quickly reverse uterine relaxation. Volatile agents are decreased after cord clamping and the epidural catheter is dosed with local anesthetic and an opioid analgesic. Due to the anesthetic induced uterine relaxation, uterine atony and significant blood loss is a risk. Thus, the timing of cord clamping with respect to administration of oxytocin, methergine and prostaglandin $F_{2\alpha}$ must be coordinated between anesthesiologist and surgeon. Blood loss is monitored and cross-matched blood is administered if needed. Epidural analgesia is used for postoperative analgesia and the trachea extubated after surgical closure.

Postdelivery/Postoperative Management:

Following surgery/delivery there are two patients to care for. The mother is brought to a postpartum ward. The immediate disposition of the newborn infant is based on surgical need; a second operating room should be available in case further surgery is needed e.g. for excision of a cervical teratoma. If surgery is not required immediately, a neonatology team resuscitates and transports the neonate to intensive care.

Fetoscopic Surgery: Preoperative management

Patients for fetoscopic surgery are admitted to the hospital the day of surgery. The operating room is prepared as for an open procedure in the rare event a hysterotomy is required for surgical access. In the preoperative area, the mother receives sodium bicarbonate PO, metoclopramide IV and, if at high risk for preterm labor, indomethacin per rectum. Following placement of ASA standard monitors, a lumbar epidural catheter is inserted and tested. The parturient is then positioned with left uterine displacement to prevent supine hypotension syndrome by compression of the inferior vena cava between the gravid uterus and the spine.

Intraoperative management

Anesthetic choice is guided by potential advantages and disadvantages for the mother and the fetus (Table 2). Epidural anesthesia is used for the majority of these cases and has the advantage of minimal effects on fetal hemodynamics, on uteroplacental blood flow, and postoperative uterine activity. The disadvantages include lack of uterine relaxation, lack of fetal anesthesia, and difficulty manipulating the uterus and cord while the fetus may be moving. A balanced inhalation-opioid anesthetic has the advantage of allowing uterine manipulation with an immobile-anesthetized fetus, yet should have less fetal

cardiovascular depression than deep inhalation anesthesia. General anesthesia also eliminates concerns associated with an awake patient such as anxiety, combativeness, nausea and emesis. The potential disadvantage of this technique is an inability to fully relax the uterus to access difficult cord positions. Deep inhalation anesthesia has the advantage of profound uterine relaxation allowing externalization of the uterus and hysterotomy based procedures. The disadvantages of this technique are fetal cardiovascular depression and decreased uteroplacental blood flow.

Postoperative management

As with the open hysterotomy cases, the most important aspect of postoperative management is tocolysis. Epidural catheters are removed after the surgery for these patients, unless they undergo hysterotomy-based procedures. Thus, magnesium sulfate followed by either nifedipine or terbutaline are the mainstay of tocolytic management. Discharge from the hospital on postoperative day 1-2 is expected following these procedures.

Conclusion

Anesthesia for fetal surgery continues to evolve. The anesthetic techniques that have emerged are safe for mother and fetus. Due to the myriad of anesthetic and surgical issues these cases generate, it is essential to have good communication and cooperation between surgeons, anesthesiologists and perinatal physicians. This communication must exist from the preoperative period to the postoperative period. This will allow development of a cohesive anesthetic and surgical plan that can be used for the safe perioperative management of the fetal surgery patient.

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Further Reading

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Table 1: Surgical approaches to fetal lesions: timing and cause for treatment

Surgical Approach	Fetal Lesion/Anomaly	Reason for Treatment	Gestational Age
Open/Hysterotomy	Congenital Cystic Adenomatoid Malformation	Hydrops fetalis, lung hypoplasia	18-25
	Myelomeningocele	Aminotic fluid neurotoxicity	22-26
	Sacroccygeal teratoma	Hydrops fetalis	18-25
Ex-Utero Intrapartum Therapy	Congenital or iatrogenic high airway obstruction	Secure airway	Near term
	Giant fetal neck mass	Secure airway, resect mass	Near term
Fetoscopic surgery	Twin-twin transfusion	Impending fetal demise, hydrops fetalis	Midgestation
	Twin reversed arterial perfusion sequence	Impending fetal demise, hydrops fetalis	Midgestation
	Bladder outlet obstruction	Hydronephrosis and renal hypoplasia	Midgestation

Table 2: Implications of anesthetic technique for fetoscopic surgery

	Fetal Depression	Uteroplacental Blood Flow	Uterine Relaxation
Regional Anesthesia	-	-	-
Balanced General Anesthetic +/- Epidural	+	+/-	+/-
Deep General Anesthetic With Epidural	++	++	++

Figure 1:

