Overview of anesthetic considerations for Cesarean delivery

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Introduction: Physiologic changes of pregnancy uniquely influence anesthesia for Cesarean delivery. Included is a review of current obstetrical anesthesia considerations for Cesarean delivery and recent changes improving maternal care and outcome.

Sources of data: A literature review was conducted using Pubmed and the Cochrane database.

Areas of agreement and controversy: Increased use of neuraxial techniques instead of general anesthesia for Cesarean delivery has improved maternal safety. Recent changes in the prevention of gastric aspiration, hypotension from neuraxial techniques, venous thrombosis and a team approach have improved maternal care. Elective Cesarean deliveries and management of urgent deliveries are areas of discussion.

Areas timely for developing research: Obstetric anesthesia advances have improved maternal outcomes. Current areas of needed obstetric anesthesia research include improved obese patient care, the impact of anticoagulation on neuraxial techniques in pregnancy, long-term neurocognitive effects of neonatal exposure to anesthesia and postoperative pain management.

Keywords: anesthesia/obstetrics/Cesarean delivery

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Morbidity and mortality trends in obstetric anesthesia

Many aspects of perioperative care have evolved to improve outcome in obstetrics. Currently, anesthetically associated obstetric mortality has decreased to seventh on the list of causes for maternal mortality in the USA and remains at rates of ~1–3 maternal deaths per million maternities in both the USA and UK. Maternal mortality decreased significantly during the first half of the 20th century. Further reduction in obstetric mortality was seen after 1980 and is attributed to the increase in neuraxial anesthesia for Cesarean delivery, improved safety of neuraxial technique, as well as algorithms and airway devices to improve safety of general anesthesia.

However, in a retrospective study examining 1.5 million deliveries from 2000 to 2006, the rate of maternal mortality was 10-fold higher with Cesarean delivery compared with a vaginal mode of delivery. It is likely that a significant number of the women who died while undergoing Cesarean delivery may have been in severe distress with the emergent situation requiring general anesthesia rather than neuraxial technique, and these factors may have contributed to the higher rate of mortality associated with Cesarean delivery. Additionally, an examination of US case fatality rates from the Center for Disease Control 1979–90 noted that women undergoing Cesarean delivery with general anesthesia have an 16.7 increase in mortality compared with neuraxial anesthesia. In those cases of mortality from anesthesia, over half primarily died of airway management problems. These included aspiration, failed intubation, inadequate ventilation, and respiratory failure. However, this increased mortality ratio associated with use of general anesthesia for Cesarean delivery has decreased significantly. A recent review examining anesthesia-related maternal deaths from 1991 to 2002 noted maternal mortality rates for general anesthesia were 16.8 per million in 1991–96 decreasing to 6.5 per million in 1997–2002, and regional anesthesia mortality rates remained lower at 2.5 and 3.8 per million, respectively. Thus, the resulting risk ratio for general anesthesia compared with neuraxial in 1997–2002 was only 1.7, a substantial decrease compared with the ratio of 16.7 noted prior to 1990. Additionally, a prospective USA multi-center study of over 37,000 women undergoing Cesarean delivery between 1999 and 2002 noted that neuraxial techniques were used in 93% of cases and there was only one maternal death directly related to the anesthetic procedure. This was secondary to hypoxic cardiac arrest in a case of failed intubation, exemplifying the improved safety of modern obstetrical anesthesia techniques.
Obesity is increasing worldwide and caring for an obese pregnant patient is not infrequent. Obese pregnant women (pre-pregnancy BMI $\geq 30$ kg/m$^2$) have an increased risk of Cesarean delivery, failed neuraxial technique, increased risk of failed intubation, difficult ventilation, increased wound infections, gestational diabetes, thromboembolism and increased mortality with Cesarean delivery.$^{8,9}$ An early anesthesia consultation is highly recommended irrespective of delivery mode in order to optimize care and improve patient outcome.

**Physiologic considerations of pregnancy**

Providing a safe effective anesthetic technique for Cesarean delivery requires a detailed understanding of the physiologic changes associated with pregnancy, labor and delivery. These changes are a result of alterations in the maternal hormone balance, biochemical shifts related to larger metabolic demands of the fetus and placenta, and mechanical forces from the gravid uterus.$^{10,11}$ Although each organ system is affected by pregnancy, the changes to the cardiovascular, respiratory and gastrointestinal systems have specific pertinent anesthetic implications around Cesarean delivery.

**Maternal cardiovascular changes**

Maternal hypotension frequently occurs with supine positioning, because the gravid uterus can compress the aorta and vena cava, decreasing cardiac preload and output. In addition, significant supine hypotension occurs in up to 15% of pregnant women (defined as a decrease in mean arterial pressure (MAP) $>15$ mmHg with increase in heart rate (HR) $>20$ bpm).$^{12}$ The aortoiliac artery compression by the gravid uterus can further reduce uterine perfusion independent of maternal blood pressure. The vena caval compression contributes to increased lower extremity edema, varices and risk of venous thrombosis despite increased collateral venous return via the azygous, vertebral venous plexus and epidural veins. The increased dilation of the epidural veins during pregnancy increases the likelihood of unintentionally entering a vein during placement of neuraxial anesthesia.

In order to minimize hypotension, supine positioning is avoided with any anesthetic administration after mid-gestation. Both neuraxial and general anesthetic techniques decrease sympathetic tone and may further exacerbate the degree of hypotension from the aortocaval compression. The constellation of diaphoresis, nausea, vomiting and changes in cerebration frequently accompany supine hypotension. Even
with a healthy uteroplacental unit, prolonged maternal hypotension can significantly decrease uterine blood flow and lead to progressive fetal acidosis.\textsuperscript{13} The use of lateral table tilt or hip elevation with a wedge is employed until delivery.

During pregnancy there is a disproportionate increase in plasma volume (45\% at term) compared with erythrocyte volume (20\% at term) resulting in a physiologic anemia of pregnancy. The total intravascular volume is increased from 1.0 to 1.5 l at term. Cardiac output increases throughout gestation, reaching a 40–50\% increase by the third trimester. The largest increase in maternal cardiac output occurs immediately after delivery, with the relief of the aortocaval compression and contraction of the uterus.

At term, uterine blood flow increases to \(\sim 0.7 \text{l/min} \) (10\% cardiac output). The uterine arteries have minimal autoregulation to preserve blood flow with decreased uterine perfusion pressure, as they are nearly maximally dilated under normal pregnancy conditions. Arterial hypotension, supine positioning and uterine tachysystole can all decrease the uterine perfusion pressure and associated blood flow.

During pregnancy, blood is hypercoagulable with increases in numerous clotting factors. This aids in reducing surgical blood loss, but increases the risk of deep venous thrombosis. A Cesarean delivery doubles the risk of venous thromboembolism (\(\sim 1 \text{per 500} \)) compared with vaginal delivery in an otherwise healthy patient.\textsuperscript{14} Data from randomized trials are not adequately powered to determine the benefit of prophylactic anticoagulation, however a prudent approach often includes the use of pneumatic compression devices and/or subcutaneous heparin.\textsuperscript{15} Following Cesarean delivery, 0.8–1.0 l of blood is typically lost, but the contracting uterus autotransfuses \(\sim 0.5 \text{l} \) blood. With Cesarean delivery, the need for blood transfusion is infrequent. In a prospective multicenter observational study of over 57 000 women undergoing primary or repeat Cesarean delivery, rates of blood transfusion were 3.2 and 2.2\%, respectively.\textsuperscript{16}

**Maternal airway and respiratory changes**

During pregnancy, the airway has significantly increased tissue edema and friability throughout the pharynx, larynx and trachea. These changes increase the risk of obstruction during positive pressure ventilation and both laryngoscopy and intubation are more difficult. Smaller diameter endotracheal tubes are selected for general anesthesia as arytenoids and vocal cords are typically engorged. In addition, the increased venous pressure from pushing in the second stage of labor,
and co-morbidities such as preeclampsia and upper respiratory tract infections all further worsen airway tissue edema.\textsuperscript{17}

Maternal respiratory changes associated with term gestation include increased minute ventilation (50%), increased oxygen consumption (20%) and decreased functional residual capacity (20%). This combination of increased oxygen consumption and decreased oxygen reserve promote rapid desaturation during periods of apnea. The changes in airway anatomy and respiratory physiology increase the difficulty of ventilation, intubation and the risk of complications. The administration of 100\% oxygen (preoxygenation) is critical for increasing the margin of safety prior to the induction of general anesthesia.

**Maternal gastrointestinal changes**

Women past mid-gestation are at increased risk of regurgitation and pulmonary aspiration following induction of anesthesia. The gravid uterus displaces the stomach and pylorus cephalad, and places the intra-abdominal portion of the esophagus intrathoracic. This decreases the competence of the esophageal sphincter, with further reductions in tone from increased progesterone and estrogen levels. Gastric pressure is increased by the enlarged uterus, and gastrin secreted by the placenta stimulates stomach acid secretion, reducing the gastric pH in pregnancy. Maternal acid reflux increases with the duration of the pregnancy and affects the majority of pregnant women.\textsuperscript{18} In addition, gastric emptying is decreased during labor, increasing the risk of aspiration with induction of general anesthesia in a patient who has been laboring. In retrospective analysis of patients undergoing general anesthesia, mortality from an aspiration event can range from 5 to 15\%.\textsuperscript{19,20} Consequently, a reduction in aspiration risk is necessary and appropriate precautions need to be taken with anesthetic induction. These typically include the use of a non-particulate antacid (sodium citrate), rapid-sequence induction, cricoid pressure and use of a cuffed endotracheal tube to secure and protect the airway. A recent Cochrane review examining strategies to reduce the risk of maternal aspiration pneumonitis suggests that a combination of antacids plus H\textsubscript{2} antagonists is more effective than no pharmacologic intervention, and superior to antacids alone in raising gastric pH.\textsuperscript{21} However, no studies have specifically examined potential adverse effects of these additional pharmacologic interventions, and neuraxial anesthesia is therefore recommended to avoid airway manipulation required with general anesthesia. Additionally, there are no studies to date evaluating the risk of increasing gastric volume with non-particulate antacids which could potentially result in microaspirations and increased vomiting.
ASA guidelines for obstetric anesthesia state, ‘Before surgical procedures (i.e. Cesarean delivery, postpartum tubal ligation), practitioners should consider the timely administration of non-particulate antacids, H2 receptor antagonists and/or metoclopramide for aspiration prophylaxis’.22

Decision tree

Prior to Cesarean delivery, every patient should undergo an evaluation by an anesthesiologist to determine any co-morbidities that would impact the anesthetic plan. Even in an emergent situation, an abbreviated examination and adequate preparation are critical for providing a safe anesthetic with appropriate monitoring.

Proceeding to Cesarean delivery in obstetrics can result from several scenarios. Although the majority of women deliver vaginally, Cesarean delivery is a necessary surgical alternative in cases where vaginally delivery is not possible. The risks and morbidity of the procedure depend on the level of urgency.23 In the continuum, the elective Cesarean delivery is the least time sensitive from decision to incision. The majority of these deliveries are typically approached with a single-dose spinal anesthetic technique.24 In cases where the obstetrician expects the length of the procedure to go beyond \(\sim 2\) h, a neuraxial catheter-based technique (epidural or combined spinal–epidural) may be utilized. In the absence of contraindication to neuraxial anesthesia, it is rare that general anesthesia is induced for an elective Cesarean delivery in most developed countries.

The urgent Cesarean delivery requires the more rapid progression from decision to delivery. In this situation, there is concern for either maternal or fetal well-being and the mother is remote from delivery, negating use of either forceps or vacuum assisted vaginal delivery. Clear and open communication between the obstetrician, anesthesiologist, nurse and midwife is paramount in these situations. Although delivery must be expeditious, a neuraxial technique is often preferred if time allows for placement of a spinal anesthetic or dosing of an existing epidural catheter. A non-reassuring fetal HR pattern in itself does not preclude the use of a neuraxial technique.25 However, in certain emergent circumstances induction of general anesthesia is needed. These situations occur when the obstetrician must deliver the baby immediately for maternal and/or fetal indications and there is insufficient time to induce neuraxial anesthesia or concern of neuraxial failure. In these cases, general anesthesia provides the most rapid and reliable form of anesthesia for prompt delivery.
Neuraxial anesthetic techniques

Neuraxial anesthesia has the benefit of an awake mother at delivery and minimal anesthetic exposure to the neonate. Additionally, it allows for placement of neuraxial opioids to decrease post-operative pain and avoids the risks of maternal aspiration and difficult airway associated with general anesthesia. Typical neuraxial techniques for Cesarean delivery include: (i) single-shot spinal technique, (ii) epidural catheter technique or (iii) combined spinal–epidural (CSE) technique. There are advantages and disadvantages to each of these techniques.

Single-dose spinal

Placement of a spinal anesthetic is technically easier than an epidural blockade. It is more rapid in onset and more reliable in providing surgical anesthesia from the mid-thoracic level to the sacrum with a failure rate of <1%. The risk of profound hypotension is higher with spinal anesthesia than with epidural anesthesia, because the onset of the sympathectomy is more rapid and dosing is not titrated. Maternal hypotension and fetal outcome are improved with avoidance of aortocaval compression (left uterine displacement), hydration and appropriate use of vasopressors. A Cochrane review of strategies to decrease hypotension from spinal anesthesia noted that the use of either crystalloid or colloid administration reduced the incidence of hypotension.

More recent randomized controlled trials found colloid is significantly more effective than a crystalloid preload, and co-loading with colloid has been shown to be equally effective as pre-loading of colloid in the prevention of hypotension. Historically, ephedrine was recommended as the vasopressor of choice for treating hypotension from a neuraxial block. However, more recent data confirms that use of phenylephrine for treatment of spinal hypotension, or using phenylephrine as a prophylactic infusion at the time of spinal placement, is effective in preventing hypotension, and is associated with less fetal acidosis compared with ephedrine. Data also suggest that spinal anesthesia can be safely used for patients with preeclampsia. A typical spinal anesthetic includes a local anesthetic such as bupivacaine or ropivacaine for the surgical anesthesia with morphine added for post-operative pain control. However, a large variety of other combinations of local anesthetics and opioids are frequently used.

Although either isobaric or hyperbaric preparations of local anesthetic can be placed intrathecally for a spinal anesthetic, hyperbaric solutions containing 8% dextrose are typically used to facilitate anatomic and gravitational control of the block distribution. The medication will
flow along the spinal curvature to a position providing a T4 anesthetic level that is not significantly affected by a patient’s height. The duration of a single shot spinal is variable (and depends on the agents used), but normally provides adequate surgical anesthesia for >90 min. Bupivacaine is frequently used for Cesarean delivery spinal anesthesia with typical doses between 10 and 15 mg. Although successful Cesarean deliveries have occurred with doses <5 mg, logistic regression studies examining doses of intrathecal bupivacaine that provided a 95% rate of effective anesthesia (ED95) for Cesarean delivery when combined with fentanyl (10 mcg) and morphine (0.2 mg) were 11.2 and 13.0 mg for hyperbaric and isobaric bupivacaine, respectively. These doses were determined in an academic setting where the mean surgical duration was >60 min and the uterus was exteriorized (greater stimulation) during a portion of the surgery. Although the use of lower bupivacaine doses (<10 mg) can provide satisfactory anesthesia, there is an increased risk of intraoperative pain or failed spinal with a need for general anesthesia. For most practitioners even a 5% rate of failure would likely be considered too high.

Continuous spinal catheters

A continuous spinal anesthetic technique with deliberate subdural catheter placement is a rarely used alternative, as prior use of intrathecal microcatheters (<27 g) was associated with cauda equina syndrome and banned by the Food and Drug Administration (FDA) in 1992. Placement of a large bore catheter intrathecally is sometimes chosen in cases of accidental dural puncture during attempts to place an epidural catheter, or with a combination of unique circumstances and comorbid conditions (e.g. urgent delivery with severe preeclampsia and morbid obesity). This allows the advantage of a titratable, reliable, dense anesthetic, but carries the risks of high spinal if the intrathecal catheter were mistaken for an epidural catheter and inappropriately dosed. The rates of rare complications such as meningitis or neurologic impairment from local anesthetic toxicity with the use of a spinal catheter theoretically may be somewhat higher than the other neuraxial techniques, however, currently there are no data to determine the rates of these rare complications. A more recent randomized controlled trial of 400 laboring patients, comparing the use of a continuous spinal catheter to epidural catheters, noted no permanent neurologic changes in the 300 patients with spinal catheters. It should be noted that although a 24-g spinal catheter has recently received FDA approval for use in obstetrics, the 28-g microcatheter used in this study remains non-FDA approved and is currently not clinically available in the USA. Given the small sample size
the risk of neurologic damage can only be statistically assessed at <1%. Data suggest that leaving a spinal catheter in place for 24 h after delivery decreases the risk of post-dural puncture headache.\textsuperscript{42,43}

**Epidural catheter**

Epidural neuraxial anesthesia is a catheter-based technique used to provide continuous analgesia during labor or surgical blockade during Cesarean delivery. When this technique is used as labor analgesia, the \textit{in situ} catheter can also be used for Cesarean delivery when necessary. In those cases, the local anesthetic is changed to one that provides more rapid onset and a denser anesthetic block for surgical anesthesia. A rapid onset local anesthetic (e.g. 3% 2-chloroprocaine) given through a newly placed epidural catheter will take \(\approx 10\) min for an appropriate surgical block.\textsuperscript{44} However, extension of a preexisting T10 level of analgesia to a T4 level of surgical anesthesia can reliably be accomplished in...

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**Fig. 1** Technique of epidural catheter placement: (1) the desired epidural space L2–L4 is identified. Following infiltration with local anesthetic a hollow epidural needle (Tuohy) is seated with the tip in the intervertebral ligaments. A syringe is connected to the epidural needle allowing the degree of resistance to be assessed using constant or periodic pressure on the plunger. As the needle tip is passed from the high degree of resistance in the ligaments to the low resistance in the epidural space, a sudden loss of resistance is noted by the anesthesiologist and advancement is stopped. (2) An epidural catheter is passed through the needle into the epidural space. Following a ‘test dose’, anesthetic medications are administered through the catheter to achieve a surgical block for Cesarean delivery (from Eltzschig HK, Lieberman ES, Camann WR. \textit{Regional anesthesia and analgesia for labor and delivery}. \textit{N Engl J Med} 2003;\textbf{348}:319–32, with permission).
<5 min with alkalinized 3% 2-chloroprocaine or alkalinized 1.5 or 2% lidocaine.\textsuperscript{45} The addition of preservative-free morphine may be given in the epidural catheter for postoperative pain control.

Epidural catheter placement involves insertion of a specialized needle and catheter (Fig. 1) between vertebral spinous processes into the epidural space. Following standard sterile technique, the needle is commonly inserted at lumbar space L3/4 or in the region between L2 and L5. In performing a single shot spinal or CSE technique, it is likely best to place the needle below L3 as case reports of neurologic damage are published where the placement of the spinal needle injured the conus medullaris and the use of Tuffier’s line can be an unreliable method of identifying the lumbar interspaces, with anesthesiologists commonly selecting a space or more higher than they assume.\textsuperscript{46,47} The epidural needle traverses the skin and subcutaneous tissues, supraspinous ligament, interspinous ligament, the ligamentum flavum and is advanced into the epidural space. The tip of the needle does not penetrate the dura, which forms the boundary between the intrathecal or subarachnoid space and the epidural space. To locate the epidural space, a tactile technique termed ‘loss of resistance’ is used. The resistance noted with pressure on the plunger of an air or saline-filled syringe dramatically decreases as the tip of the needle is advanced through the

![Fig. 2 Technique of CSE placement: (1) Following epidural needle placement into the epidural space, (2) a spinal needle (24–26 gauge) is passed through the epidural needle and past the tip into the subarachnoid space. (3) Correct spinal needle placement is confirmed by free flow of the cerebral spinal fluid. A bolus of anesthetic medication is given through the spinal needle. (4) Following spinal needle removal, an epidural catheter is advanced through the Tuohy into the epidural space. The epidural catheter can be used for continuation neuraxial anesthesia for Cesarean delivery (from Eltzschig HK, Lieberman ES, Camann WR. Regional anesthesia and analgesia for labor and delivery. N Engl J Med 2003;348:319–32, with permission).](http://bmb.oxfordjournals.org/ at U Colorado AMC Health Sciences Library on June 18, 2012)
ligamentum flavum (high resistance) into the epidural space (no resistance). The space has an average depth of about 5 cm (in the range of 3–8 cm in 90% of individuals) from the skin. Once the needle is properly positioned, a catheter is inserted through the needle into the epidural space and the needle then removed. The catheter is secured with tape and adhesive dressings, and used with intermittent or continuous injections. Once the catheter is placed, labor analgesia or anesthesia for Cesarean delivery is achieved by administration of local anesthetics and/or opioids. In selected circumstances, the use of a CSE technique offers the advantage of a spinal anesthetic with rapid onset of a dense block, as well as the ability to administer additional anesthetics through the epidural catheter. This technique can be used when the total operative time is expected to take longer than allowed for with a typical spinal anesthetic dose, e.g. third or fourth Cesarean delivery or combined with an additional procedure. For a CSE technique, after placement of the epidural needle but before insertion of the epidural catheter, a longer spinal needle is passed through the indwelling epidural needle puncturing the dura, and the spinal dose of local anesthetic and/or opioid is administered (Fig. 2).

**Neuraxial considerations and contraindications**

Certain conditions contraindicate neuraxial procedures. These include patient refusal, infection at the needle insertion site, significant coagulopathy, hypovolemic shock, increased intracranial pressure from mass lesion and inadequate provider expertise. Other conditions such as systemic infection, neurologic disease and mild coagulopathies should be evaluated on a case-by-case basis. A consensus conference regarding guidelines for the timing of neuraxial techniques in patients receiving anticoagulation therapy were recently published regarding the general patient population, but future research is needed regarding pregnant patients and the elevated doses frequently used in this population. In addition, a recent review provides a summary of current guidelines from different international anesthetic societies for neuraxial anesthetic practice in patients receiving anticoagulant and antithrombotic drugs.

According to a Cochrane review, in order to prevent vertical transmission of human immunodeficiency virus (HIV) from mother to child, the evidence supports elective Cesarean delivery rather than vaginal delivery for women with HIV not taking antiretrovirals or taking only zidovudine. Fortunately, HIV infection is not a contraindication to neuraxial technique. Therefore, women undergoing Cesarean delivery for prevention of HIV transmission to the child may undergo neuraxial
technique for Cesarean delivery, rather than needing to incur the risks associated with general anesthesia.

Infrequent but occasionally life-threatening complications can result from administration of neuraxial anesthesia. The most serious complications are from accidental intravenous (IV) administration of local anesthetics or administration of an overdose of local anesthetic intrathecally (total spinal) from unintentional subarachnoid placement or migration of an epidural catheter.

A prospective multicenter study of 145,550 epidurals in the UK placed between 1987 and 2003 noted unintended intravascular injection rates of 1 in 5000 and high spinal rates of 1 in 16,000.\(^5^3\) A prospective USA multi-center study of over 34,600 women undergoing Cesarean delivery with neuraxial techniques between 1999 and 2002 noted high spinal in 23 cases (0.07%) and no cases of meningitis, neuraxial abscess or central nervous system hematoma.\(^7\)

An unintended bolus of IV local anesthetic causes dose-dependent consequences ranging from minor side effects (e.g. tinnitus, perioral tingling, mild blood pressure and HR changes) to major complications (seizures, loss of consciousness, severe arrhythmias and cardiovascular collapse). The severity depends on the dose, type of local anesthetic and preexisting condition of the woman. A high spinal can result in severe maternal hypotension, bradycardia, loss of consciousness and blockade of the motor nerves to the respiratory muscles.\(^5^4\)

Measures that minimize the likelihood of accidental intravascular or intrathecal injection include careful aspiration of the catheter before injection, test dosing and incremental administration of therapeutic doses. If an IV overdose of local anesthetic occurs, consider the use of a 20% IV lipid emulsion to decrease local anesthetic toxicity.\(^5^5\) Successful resuscitation and support of the mother will reestablish uterine blood flow and provide adequate fetal oxygenation, allowing time for excretion of local anesthetic from the fetus.

Treatment of complications resulting from both intravascular injection and high spinal is directed at restoring maternal and fetal oxygenation, ventilation and circulation. Advanced cardiac life support algorithms, which include left uterine displacement for reduction of aorto-caval compression, intubation, vasopressors and fluids may be required. In any situation of maternal cardiac arrest with unsuccessful resuscitation, the fetus should be emergently delivered by Cesarean, if the mother is not resuscitated within 4 min of the arrest. This guideline for emergent Cesarean delivery increases the chances of survival for both the mother and neonate.\(^5^6,5^7\)

In addition, a variety of less severe complications and side effects can occur with neuraxial blockade. The retrospective rates of inadequate epidural analgesia or inadequate CSE analgesia requiring catheter
replacement were 7 and 3%, respectively, at a US academic center.\textsuperscript{58} The rate of accidental dural puncture during epidural catheter placement is 1.5%, and approximately half of these will result in a severe headache,\textsuperscript{59} which is typically managed with analgesics or a blood patch if necessary. Hypotension (decrease in systolic BP >20%) secondary to sympathetic blockade is the most common complication of neuraxial blockade for labor analgesia with rates between 10 and 24%.\textsuperscript{60} Treatment of hypotension consists of further uterine displacement, IV fluids and vasopressor administration. Small boluses of either phenylephrine or ephedrine can be used to treat hypotension.\textsuperscript{32,61} If treated promptly, brief periods of maternal hypotension do not lead to fetal depression or neonatal morbidity.

Other potential side effects from neuraxial blockade include pruritus (if opioids are used), nausea, shivering, urinary retention, motor weakness, elevated temperature and a prolonged block. More serious complications of meningitis, epidural hematoma and nerve or spinal cord injury are extremely rare. A retrospective Swedish study of severe neurologic complications from neuraxial blockade included 200 000 obstetric epidurals and 50 000 obstetric spinals. Rates of serious neurologic events (i.e. neuraxial hematoma or abscess, nerve or cord damage) were 1:29 000 for obstetric epidurals and 1:25 000 for obstetric spinal procedures.\textsuperscript{62}

**General anesthesia**

General anesthesia is typically used for Cesarean delivery when neuraxial anesthesia is contraindicated or for emergent situations because of its rapid and predictable effect. As with neuraxial techniques, appropriate preparation and a working knowledge of difficult airway techniques and algorithms are essential for delivering a safe anesthetic. The sequence of events for general anesthesia for Cesarean delivery may vary slightly by provider, but critical components are described below. After administration of a non-particulate antacid (sodium citrate) and/or H\textsubscript{2} blocker, preoxygenation, confirmation of surgical readiness, a ‘rapid-sequence induction’ in which an IV induction agent is followed immediately by a rapid onset muscle relaxant (succinylcholine) with simultaneous cricoid pressure, is typically performed. Mask ventilation is not normally provided between induction and laryngoscopy to prevent unwanted insufflation of the stomach that would increase the aspiration risk. Clear communication between the anesthesia and obstetric providers is essential, as surgical incision should only occur after a cuffed endotracheal tube is secured and adequate ventilation confirmed.
If intubation attempts fail, the Cesarean delivery may proceed only when the anesthesiologist communicates that she or he can reliably ventilate the mother with either facemask or laryngeal mask airway (LMA). Although an LMA may not reliably prevent aspiration of stomach contents, it should be viewed as a rescue device for failed intubation and mask ventilation. It has a high rate of successful ventilation with first attempt placement and was used without incident of hypoxia or noted aspiration in a prospective study of 1067 patients undergoing elective Cesarean section.

A number of different drugs are used by anesthesiologists to rapidly induce general anesthesia. The most common are propofol, thiopental, etomidate and ketamine. Propofol and sodium thiopental are commonly used for induction and render the patient unconscious in less than a minute. Etomidate and ketamine have a rapid onset of action, but unlike thiopental and propofol, have minimal effects on the cardiovascular system, making either an ideal choice for a pregnant woman in hemodynamic compromise. Succinylcholine remains the neuromuscular blocking drug of choice for obstetric anesthesia because of its rapid onset (30–45 s) and short duration of action. Because it is highly ionized and poorly lipid soluble, only small amounts cross the placenta. It is normally hydrolyzed in maternal blood by the enzyme pseudocholinesterase and does not generally interfere with fetal neuromuscular activity. Rocuronium (or vecuronium, if rocuronium is unavailable) is an acceptable alternative if succinylcholine is contraindicated. It provides adequate intubating conditions in <60 s at larger doses. Unlike succinylcholine it has a much longer duration of action, decreasing maternal safety in the event the anesthesiologist is unable to intubate or ventilate the patient. However, the recent advent of sugammadex (a cyclodextrin, able to rapidly reverse profound rocuronium neuromuscular blockade) may provide an alternative for reversal of rocuronium in the future, although it is currently not approved for use in the USA and additional research is needed regarding placental transfer and neonatal outcomes.

Uterine smooth muscle is not affected by neuromuscular blockade. Under normal circumstances non-depolarizing relaxants (i.e. succinylcholine) do not cross the placenta in amounts significant enough to cause neonatal muscle weakness.

Anesthetic goals during the Cesarean delivery include an appropriate anesthetic level to optimize surgical conditions and minimize maternal recall; adequate perfusion and oxygenation of the mother and neonate; minimal transfer of anesthetic agents to the neonate and minimization of uterine atony following delivery. Anesthesia is typically maintained by administration of a halogenated inhaled agent in combination with nitrous oxide, sedative-hypnotics, opioid analgesics and/or benzodiazepines. By using multiple classes of anesthetics synergistically, such that
the whole anesthetic provides benefits from each of the classes, the halogenated agent can be reduced. This is important in obstetrics because all halogenated anesthetic agents (i.e. isoflurane, sevoflurane, etc.) promote uterine atony. The levels needed for surgical anesthesia with a halogenated vapor as the sole agent may increase blood loss at delivery despite use of uterotonics (oxytocin). During general anesthesia for Cesarean delivery, opioids and benzodiazepines are typically administered after the baby is delivered to avoid placental transfer of these agents to the neonate. Prior to delivery of the baby, the primary anesthetic for the incision and delivery is the induction agent, as there is little time for uptake and distribution of the inhaled halogenated agents into either the mother or fetus. If a significantly prolonged length of time occurs between induction of general anesthesia and delivery, cardio-respiratory depression and decreased tone of the infant should be anticipated. These are a result of greater transfer of anesthetic agents rather than asphyxia and respond easily to assisted ventilation of the anesthetized infant to assist excretion of the anesthetic vapor. Although some animal studies demonstrate cognitive impairment in adult animals after neonatal anesthetic exposure, there are currently no data to extrapolate these findings to humans, but additional human research is ongoing. In a retrospective review of a population-based birth cohort of children delivered vaginally, the use of neuraxial analgesia during labor and vaginal delivery was not independently associated with learning disabilities. Epidemiological data have also suggested no difference in learning disabilities in children whose mothers underwent cesarean delivery with general anesthesia compared with cohorts delivered by cesarean using neuraxial anesthesia. It is interesting to note that in this study children delivered by cesarean regardless of anesthetic technique (neuraxial or general anesthesia) had less learning disabilities than their matched cohort who were born vaginally.

A Cochrane review of 16 studies comparing neuraxial blockade vs. general anesthesia in otherwise uncomplicated Cesarean deliveries found that ‘no significant difference was seen in terms of neonatal Apgar scores of 6 or less and of 4 or less at 1 and 5 min and need for neonatal resuscitation’. The authors concluded that there was no evidence to show that neuraxial anesthesia was superior to general anesthesia for neonatal outcome. As previously stressed, the preference of neuraxial techniques is to improve the safety of the mother. Placement of prophylactic epidural catheters in high-risk patients and replacement of poorly functioning labor analgesia catheters decreases the need for general anesthesia in urgent deliveries.
Elective Cesarean delivery and trial of labor

There are generally two varieties of Cesarean delivery: the primary Cesarean delivery and the repeat Cesarean delivery. For the elective primary Cesarean delivery, a woman typically has a medical indication such as breech presentation of the fetus or prior surgical scar on the uterus. However, a subset of primary elective Cesarean deliveries are performed for non-medical indications such as maternal request or ease of planning. A Cochrane review on this subject has found an absence of trials to adequately assess the risks and benefits of Cesarean delivery for non-medical indications. The authors stress the need for additional research in order to determine guidelines for this practice. There is no consensus among obstetric providers regarding evidence to support primary elective caesarian delivery at maternal request. Currently, data indicate that rates of neonatal respiratory distress increases with Cesarean delivery. However, there is some data, although limited, to support increased rates of urinary incontinence among women who have undergone vaginal delivery initially, but not when followed out several years. Additionally, it is evident that in women with previous cesarean scars, there is an increased incidence of placental previa and accreta in subsequent pregnancies. These abnormal placental implantations carry the associated risk of substantial hemorrhage and consequent morbidity. In cases of women who have previously undergone a Cesarean delivery there is evidence supporting a trial of labor. The guidelines require that women have previously had a low transverse Cesarean delivery, which means the active segment of the uterus is intact. The risk of uterine rupture in these women may be as low as 0.01% or up to 0.9%. The success rate of vaginal birth after Cesarean delivery (VBAC) is between 60 and 80%. Regardless of the success rates of VBAC, Cesarean delivery is increasing in the USA in part by hospitals unable to accommodate women who would like to attempt a trial of labor after Cesarean delivery (TOLAC). A facility must be able to provide emergent Cesarean delivery in order to care for women desiring a TOLAC. This requires that both an obstetrician and anesthesiologist are ‘immediately available’. Research is needed examining barriers to access for TOLAC and factors affecting the course of labor and its clinical management.

Adjuvants for neuraxial analgesia

The use of both epidural clonidine and neostigmine have been evaluated for Cesarean delivery examining prolongation of the neuraxial block during surgery and postoperative pain relief. Although both
may be appropriate for epidural administration, intrathecal clonidine and neostigmine are not advocated for future patient use, as clonidine results in profound hypotension and neostigmine produces refractory nausea and vomiting. Currently, the use of epidural neostigmine is being evaluated in clinical trials and not recommended as standard practice. Epidural clonidine may be administered as an adjuvant to local anesthetic in epidurals for cesarean delivery and has demonstrated improved duration of postoperative analgesia without increased side effect rates. Epidural clonidine currently carries a black box FDA warning which states that it is ‘not recommended for obstetrical, post-partum or peri-operative pain management as the risk of hemodynamic instability (e.g., hypotension, bradycardia) may be unacceptable in this population’. Monitoring recommendations related to the black box data state that in ‘a rare obstetrical, post-partum or perioperative patient, potential benefits may outweigh possible risks’.

The transabdominis plane block (TAP) block has also been studied for postoperative pain control after Cesarean delivery. It appears that in the cases where intrathecal morphine is given there is no added benefit of the TAP block, however there is a benefit when intrathecal morphine is not used. The TAP block results in decreased post-operative IV morphine use in these patients. Therefore, the TAP block may be a beneficial option for patients undergoing general anesthesia for Cesarean delivery when intrathecal morphine is not an option. There may also be benefits of the TAP block in the prevention of chronic pain following Cesarean delivery if used as a pre-emptive approach. This is an area for future research.

Summary

The safety and care of women in obstetrics requires a multidisciplinary team approach. Major advances in obstetric anesthesia have resulted in improved maternal outcomes. As women are delaying child bearing, and both obesity and Cesarean delivery rates continue to rise in developed countries, research must continue to reduce maternal mortality and improve peri-partum care for mother and child. Providing safe peri-operative care for cesarean delivery requires a detailed understanding of the physiologic changes associated with pregnancy with particular attention to changes in airway, cardiovascular, respiratory and gastrointestinal systems. Neuraxial anesthesia for cesarean delivery is preferred to general anesthesia because it minimizes the risk of failed intubation, ventilation and aspiration. As we move forward in this field, multimodal analgesia regimens after cesarean delivery for prevention of chronic pain would benefit from additional research. In addition, lack of hospitals
able to meet current guidelines and accommodate women who would like to attempt TOLAC represents a barrier to equal access to women’s health care and is a necessary focus for further study.

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