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Chapter 10

Neuro-anesthesiology in pregnancy

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Abstract

Management of the pregnant patient requiring neurosurgery poses multiple challenges, juxtaposing pregnancy-specific considerations with that accompanying the safe provision of intracranial or spine surgery. There are no specific evidence-based recommendations, and case-by-case interdisciplinary discussions will guide informed decision-making about the timing of delivery vis-à-vis neurosurgery, the performance of cesarean delivery immediately before neurosurgery, consequences of neurosurgery on subsequent delivery, or even the optimal anesthetic modality for neurosurgery and/or cesarean delivery.

In general, identifying whether increased intracranial pressure poses a risk for herniation is crucial before allowing neuraxial procedures. Modified rapid sequence induction with advanced airway approaches (videolaryngoscopic or fiberoptic) allows improved airway manipulation with reduced risks associated with endotracheal intubation of the obstetric airway. Currently, very few anesthetic drugs are avoided in the neurosurgical pregnant patient; however, ensuring access to critical care units for prolonged monitoring and assistance of the respiratory-compromised patient is necessary to ensure safe outcomes.

INTRODUCTION

It is estimated that up to 2% of pregnant women will undergo nonobstetric surgery during pregnancy, although most commonly, these procedures are abdominal emergencies, such as acute appendicitis, cholecystitis, or intestinal obstructions, with preterm delivery, preterm labor without delivery, and intrauterine fetal demise after surgery being the most common adverse outcomes after these surgical procedures (Sachs et al., 2017).

Indications for neurosurgery in the pregnant patient include intracranial and spinal surgeries, along with interventional neuroradiology procedures, for management of one of the following: subarachnoid hemorrhage (SAH), intracranial hemorrhage (ICH), arteriovenous malformation (AVM), ischemic stroke, symptomatic intracranial tumor, cerebral abscesses, spinal cord tumors and lesions, and traumatic brain injury (Wang and Paech, 2008). There are no large series describing outcomes of neurosurgery during pregnancy, but tight control of maternal blood pressure, avoidance of maternal hypotension, and continued fetal heart rate monitoring during the surgical procedure are recommended to ensure adequate fetoplacental perfusion and optimized obstetric outcomes (Po et al., 2019).

BASIC CONSIDERATIONS RELATED TO THE PROVISION OF ANESTHESIA IN THE OBSTETRIC PATIENT

With thorough knowledge of all pregnancy-related physiologic changes, obstetric anesthesiologists balance the risks associated with the provision of anesthetic and analgesic medications to the mother, with those involving the fetus. Depending on the surgery, there may be choices, and a multidisciplinary approach allows the weighing of risks and complications to enable decision-making.

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Neuraxial anesthesia

For cesarean delivery, and whenever possible for nonobstetric surgery during pregnancy, neuraxial anesthesia, which includes spinal, epidural, or combined spinal–epidural (CSE) anesthesia, is the preferred anesthetic modality (Fig. 10.1).

Neuraxial anesthesia will not only reduce anesthesia-related morbidity and mortality (Guglielminotti et al., 2019), it also allows (1) avoidance of volatile agent-induced uterine relaxation and uterine atony, (2) prevention of intraoperative recall also referred to as "awareness during anesthesia," (3) enhanced postoperative pain management via long-acting lipophilic opioids, (4) decreased fetal exposure to the potentially toxic effects of general anesthesia, and (5) overall avoidance of airway manipulation, which may be challenging in the obstetric patient (Kinsella et al., 2015).

Spinal anesthesia, typically performed with small-gage pencil-point needles (25–27G), is the preferred and most common technique for cesarean delivery offering rapid onset and reliable surgical block, with overall low doses of local anesthetics and opioids (Fig. 10.2).

Epidural anesthesia is used in women in labor who had received neuraxial labor analgesia, and subsequently will require a cesarean delivery. Titration of the indwelling epidural catheter (19–20G) will achieve a surgical block that will be sufficient for cesarean delivery and may also be used for postcesarean pain relief. The advantage of epidural anesthesia is that it may be titrated slowly, when sudden sympathectomy is undesirable (e.g., women with pulmonary hypertension). CSE anesthesia, typically performed with a large epidural needle (17–18G) through which a small-gage pencil-point needle (25–27G) will be inserted before threading of the epidural catheter (19–20G), allows for a quick, dense block, as well as titration of the local anesthetic over a longer period of time, and may be favored over spinal anesthesia if de novo anesthesia is provided in the operating room.

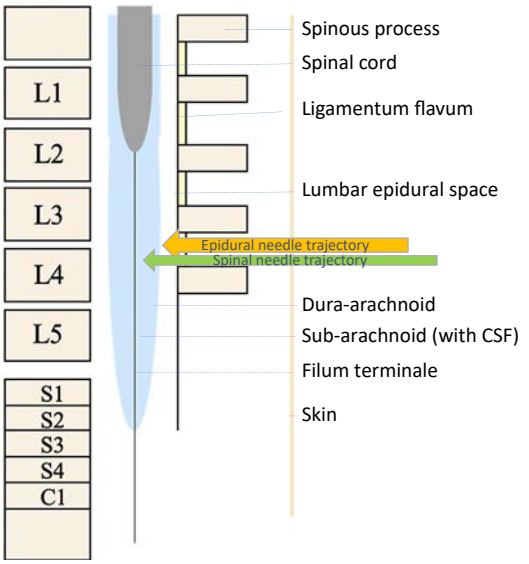

Fig. 10.1. Simplified anatomy of lumbar spinal, epidural, and subarachnoid spaces. The *orange arrow* illustrates the epidural needle trajectory. The *green arrow* depicts dural/arachnoid passage into subarachnoid space (with cerebrospinal fluid).

Fig. 10.2. Needles used for combined spinal–epidural (CSE) applying the needle through needle technique. The 27G spinal needle protrudes through the 17G epidural needle and reaches the subarachnoid space (dural/arachnoid puncture). Epidural needle: Tuohy or Weiss, usually 17G (cutting edge). Spinal needle: Whitacre or Sprotte, usually 25 or 27G (pencil-point edge). Shown here, a 27G Whitacre needle protruding 11 mm through a 17G epidural needle.

Maternal hypotension is the most common side effect of neuraxial blockade, although use of vasopressor infusions (typically phenylephrine) to prevent and manage spinal-induced hypotension is now standard (Kinsella et al., 2018).

Pregnant patients are more sensitive to local anesthetics, likely due to hormonal and anatomical changes. As pregnancy progresses, there is dilation of epidural veins and increased abdominal pressure, which decrease the size of the epidural space and cerebrospinal fluid (CSF) volume in the subarachnoid space. This ultimately improves the spread of local anesthetics in the space.

However, one must consider the complications of high intracranial pressure (ICP) and dural puncture, as a rapid change in CSF pressure may precipitate intracranial hemorrhage and herniation (Leffert and Schwamm, 2013). Epidural injection of medications can also cause an increase in ICP due to compression of the dural sac; therefore slow and incremental injection is recommended if increased ICP is suspected.

Patients with intracranial lesions are often assumed to have high ICP, and the risk of herniation is frequently cited as a contraindication to neuraxial anesthesia. However, women with space-occupying lesions that have no mass effect, no hydrocephalus, and no clinical or imaging findings suggestive of increased ICP are not at increased risk of herniation from a dural puncture (Leffert and Schwamm, 2013). Those at high risk of herniation from a dural puncture have lesions that compress normal brain tissue and cause it to shift across the midline or downward, with or without obstruction to the flow of CSF (Leffert and Schwamm, 2013).

Neuraxial medications at clinically relevant doses are thought not to cross the placenta, and women are informed that medication given epidurally or intrathecally will have minimal to no effect on the fetus/neonate. Contraindications to neuraxial procedures include patient refusal, infection at site, significant coagulopathy or recent administration of thromboprophylaxis (Leffert et al., 2018), hypovolemic shock, and increased ICP. In contrast, common neurological disorders such as multiple sclerosis (MS), epilepsy, and neuromuscular disorders, or unruptured aneurysm or AVMs are not contraindications to neuraxial procedures (see later under specific sections).

General anesthesia

Airway management in pregnancy is more challenging than in the nonobstetric population due to several factors, leading to a higher incidence of failed intubation for general anesthesia (Kinsella et al., 2015). Failed tracheal intubation in the pregnant patient is a dramatic situation as the presence of fetus(es) means that more than one life could potentially be compromised if severe hypoxia occurred during difficult airway management.

The incidence of failed intubation in the obstetric population is eight times higher than that in the general population. It has remained unchanged over the past 4 decades at 1:390 for general anesthesia in the obstetric population and 1:443 for cesarean deliveries (Kinsella et al., 2015). In busy tertiary obstetric centers with higher general anesthesia rates for cesarean deliveries and 24/7 specialist coverage the failed intubation incidence may actually be lower (1:462) (Teoh et al., 2012).

Factors contributing to the challenges of the pregnant airway are airway edema, respiratory and metabolic changes, weight gain and obesity, breast enlargement, gastroesophageal changes, and increased aspiration risk. Increased maternal blood volume and higher estrogen levels result in mucosal edema, capillary engorgement, and increased tissue friability. Hence intubation, insertion of nasal airways, use of orogastric or nasogastric tubes, are each associated with increased bleeding tendency. Epistaxis and soft palate hematoma can occur even after little or minimal unprovoked trauma (Teoh et al., 2013). Edema distorts laryngeal anatomy narrowing apertures and mandates intubation with tracheal tubes having smaller diameters.

Pregnancy causes several changes in the pulmonary system that ultimately lead to decreased oxygen reserve and more rapid desaturation compared with a nonpregnant patient (Guglielminotti et al., 2019). This makes supplemental oxygen and preoxygenation prior to induction of anesthesia a pivotal part of airway management in a pregnant patient. The enlarging gravid uterus pushes the diaphragm cephalad causing 15%–30% reduced expiratory reserve volumes and decreased functional residual capacity. Early airway closure can occur at normal tidal volume breathing exacerbated in supine, Trendelenburg, and pregnant women with high body mass index. Increased oxygen consumption, and potentially the pain and/or stress of labor, potentiates rapid hypoxemia necessitating denitrogenation (administration of a maximal fraction of inspired oxygen (FiO_2) with tight-fitting mask) prior to rapid sequence induction (RSI) to achieve the longest apneic duration before desaturation. This is best achieved by elevating the head of the bed by 25 degrees (Dixon et al., 2005). The standard technique for preoxygenation is to breathe 100% oxygen for 3–5 min of tidal volume (Tanoubi et al., 2009); however, given the emergent nature of general anesthesia in obstetrics, eight deep breaths over 60 s have been shown to provide adequate denitrogenation as measured by end-tidal fractional oxygen concentration (F_{ETO2}) (Chiron et al., 2004).

While RSI has historically implied succinylcholine administration to achieve rapid onset muscle paralysis before endotracheal intubation, succinylcholine is absolutely contraindicated in patients with known or suspected elevated ICP. Alternatives to RSI with succinylcholine in the obstetric population include use of rocuronium (Sharp and Levy, 2009), which may now be reversed at any time point if needed with sugammadex. The Society for Obstetric Anesthesia and Perinatology (SOAP) has provided recommendations on the use of sugammadex in the obstetric patient (https://soap.org/wp-content/uploads/2019/06/SOAP_Statement_Sugammadex_During_Pregnancy_Lactation_APPROVED.pdf).

Mammomegaly in supine pregnant women often impedes the insertion and manipulation of the laryngoscope to achieve good glottic visualization. The "head-ramped" position (where the external auditory meatus is aligned horizontally with the sternal notch) is advocated (El-Orbany et al., 2011).

Although maternal mortality from pulmonary aspiration of gastric contents has declined to negligible rates in the past 3 decades, pregnant women remain at risk for regurgitation and aspiration of gastric contents due to hormonal changes (increased gastrin, decreased motilin, and progesterone-induced relaxation of gastrointestinal smooth muscle decreasing lower esophageal sphincter tone). Historical data identified a threefold higher aspiration risk in women undergoing cesarean delivery, with an overall incidence of aspiration of 1:2131 in the general population undergoing anesthesia vs 1:661 in obstetric patients (Olsson et al., 1986). Pregnant women are therefore considered to have a "full stomach" by second trimester, and prophylaxis with inhibitors of gastric acid secretion or sodium citrate and RSI remain the standard of care.

Preserving hemodynamics is an important goal during surgery to maintain maternal and uteroplacental perfusion. The main cardiovascular changes in pregnancy include an increase in cardiac output, increase in intravascular volume, decrease in systemic vascular resistance, and supine aortocaval compression. Cardiac output increases to about 50% above baseline by the third trimester due to increases in both heart rate and stroke volume. Strategies to maintain perfusion involve maternal positioning with left displacement of gravid uterus, fluids, and vasopressors.

Another important consideration in pregnancy is that anesthetic requirement is reduced by approximately 25% by the first trimester. The volatile anesthetic agents most commonly used to maintain anesthesia in pregnancy are isoflurane and sevoflurane, as they have been shown to reduce cerebral metabolic rate and have the least effect on ICP. However, they also cause uterine relaxation and are often decreased or turned off (switched to intravenous propofol infusion) once the baby is delivered to avoid uterine atony and excessive maternal blood loss.

Overall, general anesthesia for cesarean delivery or nonobstetric procedures is used only when neuraxial technique is contraindicated or when it cannot be avoided. A comprehensive understanding of maternal physiology, its implications regarding anesthesia, and the difficult airway algorithm is crucial in providing a safe general anesthetic to a pregnant patient.

CHRONIC NEUROLOGIC CONDITIONS AND ANESTHETIC MANAGEMENT OF THE PREGNANT PATIENT REQUIRING SURGERY

Numerous neurologic conditions may constitute maternal comorbidities, and some of the more common or more critical conditions that may complicate management of the obstetric patient during pregnancy or at the time of delivery are reviewed here.

Epilepsy

The prevalence of epilepsy in pregnancy is 0.3%–0.7%, making it one of the most common neurologic conditions in pregnancy (Stephen et al., 2019). There is a higher incidence of status epilepticus in pregnant compared with nonpregnant women and increased mortality in epileptic pregnant patients (80 per 100,000 patients) compared with nonepileptic pregnant patients (6 per 100,000) (MacDonald et al., 2015). There are no contraindications to general or neuraxial anesthesia in epileptic parturients, and no routine changes in medications used for anesthetic care are made. Antiepileptic drugs require careful titration during pregnancy, with care taken to minimize teratogenicity for the fetus, although most antiepileptic drugs are teratogenic.

Most cases of status epilepticus in pregnancy are not due to underlying epilepsy, and differential diagnosis should include eclampsia, posterior reversible encephalopathy syndrome, reversible cerebral vasoconstriction syndrome, cortical venous sinus thrombosis, and autoimmune encephalitis. Initial treatment involves stabilizing airway, breathing and circulation, and differentiating eclamptic from noneclamptic seizures (Rajiv and Radhakrishnan, 2019). Eclamptic seizures require management with magnesium sulfate and control of hypertension. Noneclamptic seizures will be managed in the same way as in nonpregnant patients (e.g., benzodiazepines, including lorazepam and midazolam). Midazolam has the added benefit of being titratable, short acting, and available to be administered intramuscularly as well as intravenously.

Fetal care throughout the initial phase of treatment necessitates fetal monitoring, delivery near term after the maternal condition has been stabilized, anticipation of potential premature delivery, administration of betamethasone when indicated, and neonatal ICU involvement and counseling.

Multiple sclerosis

Women with MS who become pregnant usually encounter a "remission" of symptoms particularly during the third trimester, with a risk for relapse in the immediate postpartum period. The mode of delivery, presence or absence of anesthetic, and anesthetic technique do not influence the rate of postpartum relapse (Dorotta and Schubert, 2002; Mankowitz, 2018; Lavie et al., 2019).

Historical concern with neuraxial procedures and specifically spinal anesthesia centered on the potential neurotoxic effect of local anesthetic on demyelinated nerves, with concern that lidocaine may unmask MS symptoms (Stoelting et al., 2008). However, spinal, epidural, and CSE anesthesia have all been administered safely in patients with MS and are not contraindicated (Pasto et al., 2012; Lu et al., 2013; Harazim et al., 2018).

A study of 423 pregnancies in 415 patients with MS at 21 centers in Italy demonstrated no correlation between type of anesthetic care and disease progression at 1 year (Pasto et al., 2012). However, increased disability (defined by higher EDSS score) at conception was correlated with disease progression. This suggests that patients with more disability may benefit from aggressive MS treatment in the postpartum period.

Current obstetric anesthesia recommendations entail no change in practice in women with MS, and CSE for neuraxial labor analgesia and spinal anesthesia for cesarean delivery are routinely offered to pregnant women with MS.

General anesthesia may be necessary during any delivery for failed block, massive hemorrhage and resuscitation, or emergent obstetric indications such as cord prolapse and fetal bradycardia. Preoperative documentation of neurologic examination and symptoms is critical on arrival to the obstetric unit to risk-stratify patients and identify potential new symptoms. Particular attention should be paid to symptoms of chronic aspiration, respiratory muscle weakness, and baseline lower extremity exam. Interactions with medications should be reviewed for potential effects on anesthetic agents (e.g., resistance to nondepolarizing neuromuscular blockade in patients on anticonvulsants, sensitivity with baclofen use) and side effects (e.g., pulmonary fibrosis from cyclophosphamide) (Dorotta and Schubert, 2002). In general, there are no contraindications to intravenous hypnotics or inhalational anesthetics. Succinylcholine is avoided due to potential for hyperkalemia and i.v. lidocaine due to concern for potential disease progression. Stressors such as hyperthermia and anxiety in the surgical period may also lead to disease progression and should be managed in an active manner.

Women with MS warrant particular attention postcesarean delivery due to the potential for hypoventilation as a result of baseline disease and use of epidural or spinal morphine for pain control, and the SOAP guidelines on monitoring for respiratory depression should be followed (Bauchat et al., 2019).

In the event of a postdural puncture headache, epidural blood patches have been safely administered in women with MS, although some advocate for slow injection of blood and somatosensory evoked potential monitoring (Makris et al., 2014).

Myasthenia gravis

While pregnancy may cause myasthenia gravis (MG) flares in 50% of patients, it does not alter the overall course of the disease (Toscano and Thornburg, 2019), which is unpredictable during this period (Hopkins et al., 2014).

Based on the 2016 international consensus statement on management of MG, treatment goals include optimization of disease state with oral pyridostigmine and prednisone as the immunosuppressant of choice, with azathioprine and cyclosporine as back-up options (Sanders et al., 2016).

Vaginal delivery is preferred because surgery itself is a risk factor in MG crisis, although patients with MG have an increased risk of operative vaginal delivery and a cesarean delivery rate of up to 60% due to muscular fatigue (Ducci et al., 2017). Magnesium sulfate is contraindicated in the event of preeclampsia in a woman with MG due to exacerbation of muscle weakness and respiratory depression. Barbiturates or phenytoin may be used instead, and if magnesium sulfate use is required, intubation and ventilatory support must be readily available (Toscano and Thornburg, 2019). Reversal of neuromuscular blockade with sugammadex has been reported in a woman with MG. Neonates born to myasthenic mothers should be carefully observed for signs of weakness due to transplacental passage of antibodies (Mankowitz, 2018).

Anesthetic preparation for gravid myasthenic patients includes a dedicated anesthetic consultation prior to patient presentation on the labor and delivery unit (Hopkins et al., 2014).

MG does not constitute a contraindication for neuraxial anesthesia, and early neuraxial labor analgesia is encouraged to mitigate the potentially crisis-inducing stress of labor and will allow for an assisted second stage. (Varner, 2013) Amide local anesthetic agents should be used in neuraxial preparations as ester local anesthetics are metabolized by pseudocholinesterases, which are rendered less effective by pyridostigmine (e.g., avoid chloroprocaine).

General anesthesia should be avoided if possible, although it may be required for emergent obstetric indications. Myasthenic patients may demonstrate an amplified and prolonged response to nondepolarizing neuromuscular blockers, whereas they may have a diminished response to succinylcholine (Stoelting et al., 2008). Respiratory depression in the postoperative period may be profound and prolonged intubation and monitoring in an ICU may be required.

ACUTE NEUROLOGIC DISEASES THAT MAY REQUIRE ANESTHETIC CARE IN PREGNANT WOMEN

A variety of acute neurologic conditions may affect women during pregnancy, which may either require surgery as a therapeutic intervention or interact with the provision of anesthesia at the time of delivery, whether it be neuraxial labor analgesia or anesthesia for cesarean delivery.

The most common conditions are reviewed here.

Lumbar disc herniation

Lumbar disc herniation (LDH) has been reported to affect 1 in 10,000 pregnant women. Low back pain affects up to 50%–75% of women during pregnancy and may be due to the anterior shift of the center of gravity and subsequent hyperlordosis in response to the growing fetus(es), placenta(es), and uterus.

Failure to treat significant herniation can lead to long-term deficits, and 2% of patients with LDH may develop cauda equina syndrome. Worsening back pain deserves a thorough neurologic exam. Magnetic resonance imaging scan is recommended in pregnant women to confirm a herniated disc or evaluate cauda equina symptoms (Ahern et al., 2019).

Spine surgery

With failure of conservative management, a decompression laminectomy (e.g., microdiscectomy) in the prone or lateral position may be indicated if pain is worsening, with suspected spinal cord compression or with bowel/bladder dysfunction (Di Martino et al., 2017; Hayakawa et al., 2017; Kapetanakis et al., 2017; Ahern et al., 2018; Kovari and Horvath, 2018). General anesthesia will typically be provided, although microdiscectomy in the right lateral position with spinal anesthesia has also been reported (Kovari and Horvath, 2018).

Neuraxial labor analgesia and cesarean delivery anesthesia

With regards to neuraxial labor analgesia or cesarean delivery anesthesia, disc herniation is not an absolute contraindication in the former. However, patients with symptomatic disc disease may have an increased risk for neurologic complications. Relevant for future pregnancies and anticipated neuraxial procedures, prior lumbar discectomy surgery does not alter the efficacy of subsequent neuraxial labor analgesia (Bauchat et al., 2012).

Guillain–Barre syndrome

In the general population, the incidence of Guillain–Barre syndrome (GBS) is about 2/100,000 per year, and there were 2 cases of GBS during pregnancy in the Vaccine Safety Datalink cohort of 2.5 million women of reproductive age in the United States (Myers et al., 2019).

There does not appear to be any significant protection or predisposition of developing GBS in pregnancy, although vaccination (e.g., Zika, flu, H1N1) is associated with GBS (Tomimatsu et al., 2016; Myers et al., 2019).

Treatment during pregnancy should follow the same principles as for nonpregnant individuals (Pacheco et al., 2016). Effective treatment options include plasmapheresis and intravenous immunoglobulin therapy, both of which are considered safe in pregnancy. Respiratory muscle weakness may require mechanical ventilation support, and delivery in the ICU has been reported in such circumstances (Jain et al., 2019). Neuraxial anesthesia is not contraindicated; however, deficits should be documented and rare cases of relapses have been reported (Wiertlewski et al., 2004; Meenakshi-Sundaram et al., 2014). The benefits of neuraxial anesthesia appear to outweigh the risks, bearing in mind that women with GBS may be more sensitive to local anesthetics and may experience an exaggerated sympathetic block, although this has not always been reported to be an issue (Brooks et al., 2000; Kocabas et al., 2007; Kim et al., 2013; Volquind et al., 2013; Bouslama et al., 2017).

There is no contraindication for general anesthesia if required; however, autonomic dysfunction may be present and anesthesia should be carried out carefully depending on the extent of dysfunction. Succinylcholine should be avoided (Feldman, 1990), and nondepolarizing neuromuscular blockers should be used with caution as there is increased sensitivity.

Intracranial mass lesions

Of the intracranial tumors due to neurologic symptoms that have been seen in pregnancy, gliomas represent the majority, followed by meningioma and acoustic neuroma. Tumors such as meningiomas and pituitary adenomas can be hormone responsive and therefore may enlarge during pregnancy. Metastatic intracranial lesions are more common than primary tumors in pregnancy. Symptoms may be confused with other diseases in pregnancy, and careful history and physical exam are imperative.

Major concerns with intracranial tumors include ICP and increased risk for tumor-induced seizures. The decision to proceed with the surgical resection of an intracranial tumor during pregnancy vs after delivery should be based on presenting symptoms and the gestational age (Verheecke et al., 2014; Laviv et al., 2018a, b).

Neurosurgery (craniotomy)

There are scarce reports on the management of pregnant women undergoing tumor resections, most of which took place with general anesthesia for cesarean delivery immediately followed by the tumor resection (Sahu et al., 2010; Kazemi et al., 2014; Khurana et al., 2014). Hyperventilation and osmotic diuresis with mannitol are recommended strategies. Awake craniotomy, usually with dexmedetomidine for sedation, has also been

reported in the obstetric population (Abd-Elsayed et al., 2013; Handlogten et al., 2015; Meng et al., 2016; Hedayat et al., 2017; Kamata et al., 2017; Al Mashani et al., 2018).

Neuraxial labor analgesia and cesarean delivery anesthesia

Neuraxial anesthesia has generally been contraindicated in patients with known increased ICP, and inadvertent dural puncture has been thought to increase the risk of cerebral herniation. If a primary tumor or metastasis is located remotely from CSF pathways, it will likely cause no or inconsequential ventricular compression and have no impact on CSF flow. In contrast, if the lesion partially or completely obstructs CSF flow, then the risk of brain herniation due to either intentional (spinal) or unintentional dural puncture will be increased. Space-occupying lesions that narrow the foramen magnum or are situated in the posterior fossa can place a parturient at significant risk of herniation. This can occur from benign or malignant tumors anywhere in the posterior fossa or at the opening to the foramen magnum. It can also occur from low-lying cerebellar tonsils, due to either a preexisting Arnold–Chiari malformation or intracranial hypotension from a persistent CSF leak.

As previously indicated, injection of medication into the lumbar epidural space (bolus) may also increase ICP due to the upward displacement of CSF into the intracranial compartment (Hilt et al., 1986). However, without evidence of increased ICP or obstructive CSF flow, neuraxial anesthesia can be offered.

The question about whether an epidural procedure might be preferable over a spinal one is valid, although inadvertent dural puncture can occur during epidural placement, even in expert hands, and this would occur with large-gage needle (17 or 18G). Therefore a small-gage pencil-point spinal needle (25 or 27G) might be preferable, and it has been shown to result in shorter duration and minimal CSF leak.

Planned cesarean delivery is preferred to avoid the high ICP associated with Valsalva maneuvers during childbirth; however, assisted vaginal delivery may be feasible with a carefully titrated neuraxial technique.

If general anesthesia is indicated, precautions for increased ICP should be in place. This often requires placement of an intraarterial line to maintain cerebral perfusion pressure. To minimize the hemodynamic responses to laryngoscopy, intubation and extubation are warranted.

Intracranial vascular pathology

Implications for anesthesia management of the pregnant patient with intracranial arterial or vascular pathology requires a thorough understanding of the type of vascular abnormality and the risk of rupture in the peripartum period. For pregnant women with an SAH due to aneurysmal rupture, neurosurgical management should be the same as if she were not pregnant (Roth and Deck, 2019).

Advanced maternal age, African American race, Hispanic ethnicity, hypertensive disorders, coagulopathy, tobacco, drug or alcohol abuse, intracranial venous thrombosis, sickle cell disease, and hypercoagulability are risk factors for pregnancy-related SAH (Bateman et al., 2012).

Neurosurgery (craniotomy/embolization)

There are anecdotal reports of the management of endovascular emergencies during pregnancy, which have reported clipping or coiling (Tarnaris et al., 2012; Kataoka et al., 2013; Kim et al., 2014; Fritzsche et al., 2017).

For patients requiring combined procedures (craniotomy/embolization and cesarean delivery), general anesthesia might be preferable although neuraxial anesthesia for cesarean delivery followed by general anesthesia for the craniotomy may be recommended and offers the advantages of allowing the patient to experience the delivery of her child and have neuraxial analgesic medication for postcesarean pain management.

Neuraxial labor analgesia and cesarean delivery anesthesia

Avoiding neuraxial anesthesia in parturients with intracranial hemorrhage or in the setting of altered intracranial vasculature out of concern for precipitating neurologic complications has historically been advocated. However, risks with general anesthesia in this population and information about the vascular abnormality and its risk of rupture are crucial to making informed decisions about anesthetic management.

Unruptured brain aneurysms have historically been considered an absolute indication for cesarean delivery to avoid prolonged Valsalva maneuvers and expulsive efforts-associated increases in cerebral blood and CSF volume and increases in ICP. However, the risk of aneurysmal SAH was not shown to be increased during pregnancy, labor, or postpartum compared with that in the general population, probably because Valsalva maneuvers with substantial pushing during the second stage of labor may be avoided with effective epidural analgesia and followed by instrumental vaginal delivery, suggesting that vaginal deliveries with “maternal sparing” may be offered to women with unruptured aneurysms (Tiel Groenestege et al., 2009). In addition, a significant proportion of peripartum SAH is likely nonaneurysmal in etiology (Bateman et al., 2012).

For patients with a recent intracranial hemorrhage from an aneurysm or AVM, evaluating the risk of mass effect, ICP, or CSF obstruction is paramount before proceeding with a neuraxial procedure.

For patients with a stable aneurysm who do not require simultaneous aneurysm repair, neuraxial anesthesia is appropriate if hemodynamic stability is ensured.

Stroke

The incidence of maternal strokes, ischemic (IS) or hemorrhagic (HS), was estimated to be 30 in 100,000 pregnancies (Swartz et al., 2017) and includes nontraumatic intracerebral hemorrhage (ICH) and SAH, dural sinus thrombosis, and cerebral venous thrombosis (CVT). Recent data suggests that strokes account for 7.4% of maternal deaths in the United States (Miller and Leffert, 2019). Pregnancy-specific risk factors for stroke include hypertensive disorders of pregnancy via endothelial dysfunction and impaired cerebral autoregulation, gestational diabetes, severe postpartum hemorrhage, and cesarean delivery (Miller and Leffert, 2019). Stroke during pregnancy most often occurs close to the time of delivery although up to 50% occurs in the immediate postpartum period (Swartz et al., 2017; Too et al., 2018).

Pregnant women suspected of having IS or HS should be evaluated for the same therapies as nonpregnant women (Ladhani et al., 2018; Kozberg and Camargo, 2019; Miller and Leffert, 2019; Elgendy et al., 2020), and immediate multidisciplinary care is warranted to avoid any delays in managing the maternal emergency.

Recombinant tissue plasminogen activator (r-tPA) has emerged as a safe treatment option for ischemic stroke in the pregnant patient (Ladhani et al., 2018). If fibrinolysis is contraindicated, catheter-based thrombolysis or thrombectomy are alternative treatment options. Pregnancy should not be considered a contraindication to angiography and endovascular thrombectomy for proximal large vessel occlusions causing acute disabling stroke (Ladhani et al., 2018; Limaye et al., 2019; Szuchy Kristiansen et al., 2019; Watanabe et al., 2019; Wiącek et al., 2019).

Neuraxial labor analgesia or cesarean delivery anesthesia

Anesthetic management will largely depend on the recent administration of anticoagulation/thrombolysis and if ICP is increased.

In the setting of unruptured AVMs and aneurysm, assisted second stage of labor is sometimes advised, and in that case, neuraxial labor analgesia will be beneficial. Occasionally, cesarean delivery is recommended with immediate neurosurgical intervention to follow.

Traumatic brain injury

Domestic/intimate partner violence and motor vehicle accidents (MVAs) are the predominant causes of trauma during pregnancy (Einav et al., 2013; Rossignol, 2016). Pregnant trauma victims have a twofold increased mortality rate compared with their nonpregnant counterparts, whether trauma was violent (homicide, assault) or nonviolent (MVA or accidental fall) (Deshpande et al., 2017).

The Advanced Trauma Life Support® (ATLS) guidelines provide a framework for rapid assessment and management of the injured patient and have been demonstrated to improve patient outcomes. Modifications to ATLS guidelines that may be considered for the pregnant casualty are provision of supplemental oxygen because of maternal susceptibility to hypoxia and desaturation, preference for establishment of intravenous access above the diaphragm, and left lateral positioning of the patient as soon as possible, because of the possibility of reduced venous return secondary to uterine pressure on the vena cava, aortocaval syndrome, or supine hypotensive syndrome (Einav et al., 2013). However, some updates have deemphasized spinal immobilization in favor of restriction of spinal motion in case of spinal cord injury (Galvagno Jr. et al., 2019). Although there is no consensus on the best method of intubation in patients with cervical-spine injury, fiberoptic techniques may be preferable in pregnant patients because of the additional difficulty that may arise from pregnancy and an unstable neck.

FETAL AND NEONATAL CONSIDERATIONS IN THE PREGNANT PATIENT UNDERGOING NEUROSURGERY

Neurosurgical procedures may require anticonvulsant therapy in the perioperative and postoperative periods. All anticonvulsants cross the placenta. The fetal congenital anomaly rate in pregnant women with epilepsy on anticonvulsant drugs is 4%–8% compared with the general population (Chestnut, 2009). Such medications have even coined the broad term of fetal anticonvulsant syndrome consisting of orofacial, cardiovascular, digital malformation, and neural tube defects. These drugs include the following: phenytoin, carbamazepine, phenobarbital, and valproic acid. There is unequivocal data on newer anticonvulsant therapies. For example, felbamate was approved for monotherapy treatment of epilepsy but was later restricted secondary to its association with aplastic anemia and liver failure (Chestnut, 2009). Historically, lamotrigine has been utilized in pregnancy given its relative safety during this period, but it requires complex titration schedules.

Levetiracetam has demonstrated similar safety profiles in the pregnant population. The rate of major congenital malformation associated with exposure to levetiracetam monotherapy is comparable to that in the nonepilepsy population (Koubeissi, 2013). Levetiracetam is very easy to titrate and can be given both orally and intravenously. Frequently, it is used in the perioperative setting for seizure prophylaxis. Regardless, neurologic guidance should be sought as pregnancy-induced changes can alter the clearance, unbound fractions, and half-lives of many anticonvulsant drugs.

Other induction medications appear safe in pregnancy and include short-acting opioids, local anesthetics, and intravenous anesthetic agents. Prior to the advent of propofol, thiopental was frequently used and considered safe in pregnancy. In several countries, propofol was stated to be contraindicated in pregnancy. However, both agents have demonstrated acceptable safety profiles during their use in pregnancy. Of note, intravenous magnesium sulfate (30–60 mg/kg bolus) given after induction is effective in patients with SAH or preeclampsia/eclampsia.

Volatile anesthesia, such as sevoflurane and isoflurane, involves inhalation agents of choice in neuroanesthesia as they decrease the cerebral metabolic rate and provide cerebral protection. During pregnancy, it is important to note that the minimum alveolar concentration of volatile agents is reduced by approximately 25%. Nitrous oxide should be avoided as it increases ICP and cerebral blood flow and cerebral oxygen metabolic rate, impairs autoregulation, and expands air bubbles.

Either total intravenous anesthesia or balanced intravenous and volatile anesthesia and/or solely volatile anesthesia are acceptable maintenance options for surgery during pregnancy. Intraoperative blood pressure maintenance is crucial and often intraarterial blood pressure monitoring is recommended for induction. This is crucial to preserve both cerebral and uteroplacental perfusion.

Intraoperatively, a variety of measures are applied to avoid elevations in ICP. Severe hyperventilation ($PaCO_2 < 25$ mmHg) may cause uterine artery vasoconstriction and leftward shift of maternal oxyhemoglobin dissociation curve (Lars Peter Wang, 2008). Thus it is recommended to keep $PaCO_2$ between 25 and 30 mmHg. Mannitol given to pregnant women can accumulate in the fetus leading to fetal hyperosmolality, reduced fetal lung fluid production and urinary blood flow, and increased plasma sodium concentration. However, mannitol in doses of 0.25–0.5 mg/kg appears safe in pregnancy. There is no data to support the use of hypertonic saline (23.4%) for refractory elevated ICP in pregnant women; in fact, historical studies report on the use of hypertonic saline in medical abortions. A single dose of steroid is not teratogenic and accelerates fetal lung maturity, and antiemetic drugs appear safe to use in pregnancy. Calcium channel blockers have not been shown to increase teratogenic risk and are regarded as safe in pregnancy (Alabdulrazzaq, 2012).

Nimodipine is commonly used to reduce the incidence of intracranial vasospasm, and it has been used in pregnant patients without apparent adverse events in fetal or neonatal outcomes. Esmolol 0.5–1 mg/kg may cause fetal bradycardia and cautious use in pregnancy is advised.

It should be assumed that all postpartum woman will be breastfeeding. Only few drugs are absolutely contraindicated during breastfeeding, and they include some cytotoxic drugs, some immunosuppressive drugs, and radioactive compounds that are rarely implemented during a neurosurgical procedure. Current recommendations no longer involve the "pump and dump" dogma (Dodd and Sharpe, 2018), and women are encouraged to breastfeed after anesthesia (Reece-Stremtan et al., 2017; Martin et al., 2018).

CONCLUSION

Management of pregnant women with acute or chronic neurological conditions may potentially include providing anesthesia for two distinct events: (1) the anesthetic required for a neurosurgical procedure during pregnancy, which might entail, depending on the gestational age, continuous intraoperative monitoring of the fetal heart rate and (2) neuraxial labor analgesia or anesthesia for cesarean delivery at the time of delivery.

Factors to be considered before proceeding with a neuraxial procedure in women with neurological conditions involve the risk of herniation with increased ICP; however, in most instances, if a primary tumor or metastasis is located remotely from CSF pathways, it will likely cause no or inconsequential ventricular compression and have no impact on CSF flow; therefore a multidisciplinary evaluation is recommended to weigh the risks and benefits of providing general vs neuraxial anesthesia, whenever possible.

With general anesthesia, manipulation of the "pregnant" airway carries its own risks, and general anesthesia for cesarean delivery or nonobstetric procedures is used only when neuraxial technique is contraindicated or when it cannot be avoided.

Overall, there are very few anesthetic drugs that should be avoided in the neurosurgical pregnant patient; however, ensuring access to critical care units for prolonged monitoring and assistance of the respiratory-compromised patient is necessary for safe outcomes.

References

Abd-Elsayed AA, Diaz-Gomez J, Barnett GH et al. (2013). A case series discussing the anaesthetic management of pregnant patients with brain tumours. F1000Res 2: 92.

Ahern DP, Gibbons D, Dodds M et al. (2018). Operative management of perinatal lumbar disc herniation and cauda equina syndrome: a case series. Ir Med J 111: 843.

Ahern DP, Gibbons D, Johnson GP et al. (2019). Management of herniated lumbar disk disease and cauda equina syndrome in pregnancy. Clin Spine Surg 32: 412–416.

Al Mashani AM, Ali A, Chatterjee N et al. (2018). Awake craniotomy during pregnancy. J Neurosurg Anesthesiol 30: 372–373.

Alabdulrazzaq F (2012). Fetal safety of calcium channel blockers. Can Fam Physician 58: 746–747.

Bateman BT, Olbrecht VA, Berman MF et al. (2012). Peripartum subarachnoid hemorrhage: nationwide data and institutional experience. Anesthesiology 116: 324–333.

Bauchat JR, McCarthy RJ, Koski TR et al. (2012). Prior lumbar discectomy surgery does not alter the efficacy of neuraxial labor analgesia. Anesth Analg 115: 348–353.

Bauchat JR, Weiniger CF, Sultan P et al. (2019). Society for obstetric anesthesia and perinatology consensus statement: monitoring recommendations for prevention and detection of respiratory depression associated with administration of neuraxial morphine for cesarean delivery analgesia. Anesth Analg 129: 458–474.

Bouslama MA, Brahim A, Kaabia O et al. (2017). Anesthesia for cesarean section in parturient with Guillain Barre syndrome: a case report. Tunis Med 95: 229–232.

Brooks H, Christian AS, May AE (2000). Pregnancy, anaesthesia and Guillain Barre syndrome. Anaesthesia 55: 894–898.

Chestnut D (2009). Chestnut's obstetric anesthesia: principles and practive, fourth edn Mosby/Elsevier, Philadelphia.

Chiron B, Laffon M, Ferrandiere M et al. (2004). Standard preoxygenation technique versus two rapid techniques in pregnant patients. Int J Obstet Anesth 13: 11–14.

Deshpande NA, Kucirka LM, Smith RN et al. (2017). Pregnant trauma victims experience nearly 2-fold higher mortality compared to their nonpregnant counterparts. Am J Obstet Gynecol 217: 590 e591–590 e599.

Di Martino A, Russo F, Denaro L et al. (2017). How to treat lumbar disc herniation in pregnancy? A systematic review on current standards. Eur Spine J 26: 496–504.

Dixon BJ, Dixon JB, Carden JR et al. (2005). Preoxygenation is more effective in the 25 degrees head-up position than in the supine position in severely obese patients: a randomized controlled study. Anesthesiology 102: 1110–1115. discussion 1115A.

Dodd SE, Sharpe EE (2018). Pump and dump; anesthesiologists lead the feed. Anesthesiology 128: 1046–1047.

Dorotta IR, Schubert A (2002). Multiple sclerosis and anesthetic implications. Curr Opin Anaesthesiol 15: 365–370.

Ducci RD, Lorenzoni PJ, Kay CS et al. (2017). Clinical follow-up of pregnancy in myasthenia gravis patients. Neuromuscul Disord 27: 352–357.

Einav S, Sela HY, Weiniger CF (2013). Management and outcomes of trauma during pregnancy. Anesthesiol Clin 31: 141–156.

Elgendy IY, Gad MM, Mahmoud AN et al. (2020). Acute stroke during pregnancy and puerperium. J Am Coll Cardiol 75: 180–190.

El-Orbany M, Woehlck H, Salem MR (2011). Head and neck position for direct laryngoscopy. Anesth Analg 113: 103–109.

Feldman JM (1990). Cardiac arrest after succinylcholine administration in a pregnant patient recovered from Guillain–Barre syndrome. Anesthesiology 72: 942–944.

Fritzsche FS, Regelsberger J, Schmidt NO et al. (2017). Maternal aneurysmal subarachnoid hemorrhage during pregnancy as an interdisciplinary task. Z Geburtshilfe Neonatol 221: 276–282.

Galvagno Jr. SM, Nahmias JT, Young DA (2019). Advanced trauma life support((R)) update 2019: management and applications for adults and special populations. Anesthesiol Clin 37: 13–32.

Guglielminotti J, Landau R, Li G (2019). Adverse events and factors associated with potentially avoidable use of general anesthesia in cesarean deliveries. Anesthesiology 130: 912–922.

Handlogten KS, Sharpe EE, Brost BC et al. (2015). Dexmedetomidine and mannitol for awake craniotomy in a pregnant patient. Anesth Analg 120: 1099–1103.

Harazim H, Stourac P, Janku P et al. (2018). Obstetric anesthesia/analgesia does not affect disease course in multiple sclerosis: 10-year retrospective cohort study. Brain Behav 8: e01082.

Hayakawa K, Mizutani J, Suzuki N et al. (2017). Surgical management of the pregnant patient with lumbar disc herniation in the latter stage of the second trimester. Spine (Phila Pa 1976) 42: E186–E189.

Hedayat H, Felbaum DR, Reynolds JE et al. (2017). Awake craniotomy for the treatment of a cortical pseudoaneurysm in a pregnant patient. Cureus 9: e1921.

Hilt H, Gramm HJ, Link J (1986). Changes in intracranial pressure associated with extradural anaesthesia. Br J Anaesth 58: 676–680.

Hopkins AN, Alshaeri T, Akst SA et al. (2014). Neurologic disease with pregnancy and considerations for the obstetric anesthesiologist. Semin Perinatol 38: 359–369.

Jain R, Rathi PS, Telang K et al. (2019). A case of Guillain–Barre syndrome with pregnancy who delivered in ICU: a rare outcome of rare co-occurrence. BMJ Case Rep 12 (11): e230650. https://doi.org/10.1136/bcr-2019-230650.

Kamata K, Fukushima R, Nomura M et al. (2017). A case of left frontal high-grade glioma diagnosed during pregnancy. JA Clin Rep 3: 18.

Kapetanakis S, Giovannopoulou E, Blontzos N et al. (2017). Surgical management for lumbar disc herniation in pregnancy. J Gynecol Obstet Hum Reprod 46: 753–759.

Kataoka H, Miyoshi T, Neki R et al. (2013). Subarachnoid hemorrhage from intracranial aneurysms during pregnancy and the puerperium. Neurol Med Chir (Tokyo) 53: 549–554.

Kazemi P, Villar G, Flexman AM (2014). Anesthetic management of neurosurgical procedures during pregnancy: a case series. J Neurosurg Anesthesiol 26: 234–240.

Khurana T, Taneja B, Saxena KN (2014). Anesthetic management of a parturient with glioma brain for cesarean section immediately followed by craniotomy. J Anaesthesiol Clin Pharmacol 30: 397–399.

Kim H, Ryu J, Hwang JW et al. (2013). Anesthetic management for cesarean delivery in a Guillain–Barre syndrome patient—a case report. Korean J Anesthesiol 64: 268–271.

Kim KD, Chang CH, Choi BY et al. (2014). Endovascular treatment of a ruptured posterior inferior cerebellar artery aneurysm during pregnancy. J Korean Neurosurg Soc 55: 273–276.

Kinsella SM, Winton AL, Mushambi MC et al. (2015). Failed tracheal intubation during obstetric general anaesthesia: a literature review. Int J Obstet Anesth 24: 356–374.

Kinsella SM, Carvalho B, Dyer RA et al. (2018). International consensus statement on the management of hypotension with vasopressors during caesarean section under spinal anaesthesia. Anaesthesia 73: 71–92.

Kocabas S, Karaman S, Firat V et al. (2007). Anesthetic management of Guillain–Barre syndrome in pregnancy. J Clin Anesth 19: 299–302.

Koubeissi M (2013). Levetiracetam: more evidence of safety in pregnancy. Epilepsy Curr 13: 279–281.

Kovari VZ, Horvath L (2018). Surgical management of cauda syndrome in third trimester of pregnancy focusing on spinal anesthesia and right lateral positioning during surgery as possible practices. Eur Spine J 27: 483–488.

Kozberg MG, Camargo EC (2019). Management of maternal stroke and mitigating risk. Curr Treat Options Cardiovasc Med 21: 72.

Ladhani NNN, Swartz RH, Foley N et al. (2018). Canadian stroke best practice consensus statement: acute stroke management during pregnancy. Int J Stroke 13: 743–758.

Lars Peter Wang M (2008). Neuroanesthesia for the pregnant woman. Anesth Anal 107: 193–200.

Lavie C, Rollot F, Durand-Dubief F et al. (2019). Neuraxial analgesia is not associated with an increased risk of postpartum relapses in MS. Mult Scler 25: 591–600.

Laviv Y, Bayoumi A, Mahadevan A et al. (2018a). Meningiomas in pregnancy: timing of surgery and clinical outcomes as observed in 104 cases and establishment of a best management strategy. Acta Neurochir 160: 1521–1529.

Laviv Y, Ohla V, Kasper EM (2018b). Unique features of pregnancy-related meningiomas: lessons learned from 148 reported cases and theoretical implications of a prolactin modulated pathogenesis. Neurosurg Rev 41: 95–108.

Leffert LR, Schwamm LH (2013). Neuraxial anesthesia in parturients with intracranial pathology: a comprehensive review and reassessment of risk. Anesthesiology 119: 703–718.

Leffert L, Butwick A, Carvalho B et al. (2018). The society for obstetric anesthesia and perinatology consensus statement on the anesthetic management of pregnant and postpartum women receiving thromboprophylaxis or higher dose anticoagulants. Anesth Analg 126: 928–944.

Limaye K, Van de Walle Jones A, Shaban A et al. (2019). Endovascular management of acute large vessel occlusion stroke in pregnancy is safe and feasible. J Neurointerv Surg. https://doi.org/10.1136/neurintsurg-2019-015578. Epub ahead of print.

Lu E, Zhao Y, Dahlgren L et al. (2013). Obstetrical epidural and spinal anesthesia in multiple sclerosis. J Neurol 260: 2620–2628.

MacDonald SC, Bateman BT, McElrath TF et al. (2015). Mortality and morbidity during delivery hospitalization among pregnant women with epilepsy in the United States. JAMA Neurol 72: 981–988.

Makris A, Piperopoulos A, Karmaniolou I (2014). Multiple sclerosis: basic knowledge and new insights in perioperative management. J Anesth 28: 267–278.

Mankowitz SKW (2018). Consults in obstetric anesthesiology, first edn Springer Science+Business Media, New York, NY.

Martin E, Vickers B, Landau R et al. (2018). ABM clinical protocol #28, peripartum analgesia and anesthesia for the breastfeeding mother. Breastfeed Med 13: 164–171.

Meenakshi-Sundaram S, Swaminathan K, Karthik SN et al. (2014). Relapsing Guillain–Barre syndrome in pregnancy and postpartum. Ann Indian Acad Neurol 17: 352–354.

Meng L, Han SJ, Rollins MD et al. (2016). Awake brain tumor resection during pregnancy: decision making and technical nuances. J Clin Neurosci 24: 160–162.

Miller EC, Leffert L (2019). Stroke in pregnancy: a focused update. Anesth Analg 130: 1085–1096.

Myers TR, McCarthy NL, Panagiotakopoulos L et al. (2019). Estimation of the incidence of Guillain–Barre syndrome during pregnancy in the United States. Open Forum Infect Dis 6: ofz071.

Olsson GL, Hallen B, Hambraeus-Jonzon K (1986). Aspiration during anaesthesia: a computer-aided study of 185,358 anaesthetics. Acta Anaesthesiol Scand 30: 84–92.

Pacheco LD, Saad AF, Hankins GD et al. (2016). Guillain–Barre syndrome in pregnancy. Obstet Gynecol 128: 1105–1110.

Pasto L, Portaccio E, Ghezzi A et al. (2012). Epidural analgesia and cesarean delivery in multiple sclerosis post-partum relapses: the Italian cohort study. BMC Neurol 12: 165.

Po G, Olivieri C, Rose CH et al. (2019). Intraoperative fetal heart monitoring for non-obstetric surgery: a systematic review. Eur J Obstet Gynecol Reprod Biol 238: 12–19.

Rajiv KR, Radhakrishnan A (2019). Status epilepticus in pregnancy—can we frame a uniform treatment protocol? Epilepsy Behav 101 (Pt B): 106376. https://doi.org/10.1016/j.yebeh.2019.06.020.

Reece-Stremtan S, Campos M, Kokajko L et al. (2017). ABM clinical protocol #15: analgesia and anesthesia for the breastfeeding mother, revised 2017. Breastfeed Med 12: 500–506.

Rossignol M (2016). Trauma and pregnancy: what anesthesiologist should know. Anaesth Crit Care Pain Med 35: S27–S34.

Roth J, Deck G (2019). Neurovascular disorders in pregnancy: a review. Obstet Med 12: 164–167.

Sachs A, Guglielminotti J, Miller R et al. (2017). Risk factors and risk stratification for adverse obstetrical outcomes after appendectomy or cholecystectomy during pregnancy. JAMA Surg 152: 436–441.

Sahu S, Lata I, Gupta D (2010). Management of pregnant female with meningioma for craniotomy. J Neurosci Rural Pract 1: 35–37.

Sanders DB, Wolfe GI, Benatar M et al. (2016). International consensus guidance for management of myasthenia gravis: executive summary. Neurology 87: 419–425.

Sharp LM, Levy DM (2009). Rapid sequence induction in obstetrics revisited. Curr Opin Anaesthesiol 22: 357–361.

Stephen LJ, Harden C, Tomson T et al. (2019). Management of epilepsy in women. Lancet Neurol 18: 481–491.

Stoelting RK, Hines RL, Marschall KE (2008). Stoelting's anesthesia and co-existing disease, fifth edn Churchill Livingstone/Elsevier, Philadelphia.

Swartz RH, Cayley ML, Foley N et al. (2017). The incidence of pregnancy-related stroke: a systematic review and meta-analysis. Int J Stroke 12: 687–697.

Szuchy Kristiansen E, Holm Vestergaard H, Modrau B et al. (2019). Acute ischemic stroke in late pregnancy treated with intravenous thrombolysis and endovascular therapy. Case Rep Neurol 11: 41–46.

Tanoubi I, Drolet P, Donati F (2009). Optimizing preoxygenation in adults. Can J Anaesth 56: 449–466.

Tarnaris A, Haliasos N, Watkins LD (2012). Endovascular treatment of ruptured intracranial aneurysms during pregnancy: is this the best way forward? Case report and review of the literature. Clin Neurol Neurosurg 114: 703–706.

Teoh W, Yeoh S, Ithnin F et al. (2012). Incidence of difficult & failed intubations during obstetric general anaesthesia in a tertiary referral center. Br J Anaesth 108: ii212.

Teoh WH, Yeoh SB, Tan HK (2013). Airway management of an expanding soft palate haematoma in a parturient. Anaesth Intensive Care 41: 680–681.

Tiel Groenestege AT, Rinkel GJ, van der Bom JG et al. (2009). The risk of aneurysmal subarachnoid hemorrhage during pregnancy, delivery, and the puerperium in the Utrecht population: case-crossover study and standardized incidence ratio estimation. Stroke 40: 1148–1151.

Tomimatsu T, Sugihara M, Nagai T et al. (2016). Guillain–Barre syndrome after trivalent influenza vaccination during pregnancy. Eur J Obstet Gynecol Reprod Biol 201: 225–226.

Too G, Wen T, Boehme AK et al. (2018). Timing and risk factors of postpartum stroke. Obstet Gynecol 131: 70–78.

Toscano M, Thornburg LL (2019). Neurologic diseases in pregnancy. Curr Opin Obstet Gynecol 31: 97–109.

Varner M (2013). Myasthenia gravis and pregnancy. Clin Obstet Gynecol 56: 372–381.

Verheecke M, Halaska MJ, Lok CA et al. (2014). Primary brain tumours, meningiomas and brain metastases in pregnancy: report on 27 cases and review of literature. Eur J Cancer 50: 1462–1471.

Volquind D, Fellini RT, Rose GL et al. (2013). Anesthesia for cesarean section in a patient with Guillain–Barre syndrome: case report. Braz J Anesthesiol 63: 369–371.

Wang LP, Paech MJ (2008). Neuroanesthesia for the pregnant woman. Anesth Analg 107: 193–200.

Watanabe TT, Ichijo M, Kamata T (2019). Uneventful pregnancy and delivery after thrombolysis plus thrombectomy for acute ischemic stroke: case study and literature review. J Stroke Cerebrovasc Dis 28: 70–75.

Wiącek M, Kaczorowski R, Oboz-Adaś A et al. (2019). Acute ischemic stroke in a third trimester of pregnancy—cesarean section followed by mechanical thrombectomy. Int J Neurosci 1–4. https://doi.org/10.1080/00207454.2019.1702539. Epub ahead of print.

Wiertlewski S, Magot A, Drapier S et al. (2004). Worsening of neurologic symptoms after epidural anesthesia for labor in a Guillain–Barre patient. Anesth Analg 98: 825–827. table of contents.