

# Neuroanesthesia for the Pregnant Woman

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Neuroanesthesia for the pregnant patient is required infrequently, and evidence-based recommendations for neuroanesthetic management are sparse. We present a framework for a practical approach to anesthesia of the pregnant patient with subarachnoid or intracerebral hemorrhage, intracranial tumor, traumatic brain injury, spinal tumor, or spinal injury. The importance of a team-approach is emphasized. The anesthesiologist may have to anesthetize the pregnant patient for neurosurgery well before delivery, for cesarean delivery at the time of the neurosurgical procedure, or for delivery after neurosurgery. These scenarios are discussed along with fetal safety and anesthetic considerations for interventional neuroradiology.

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**N**euroanesthesia during pregnancy encompasses anesthesia for intracranial and spinal surgery and for diagnostic and therapeutic interventions, but is required infrequently. Indications for neurosurgical interventions or interventional neuroradiology during pregnancy include intracranial vascular lesions (subarachnoid hemorrhage [SAH], intracranial hemorrhage [ICH], arteriovenous malformation [AVM], and sinus thrombosis), ischemic stroke, symptomatic intracranial tumor, cerebral abscess, and spinal cord tumors and lesions. Trauma during pregnancy, including head injury, is a leading cause of incidental maternal death and morbidity, and complicates 6%–7% of all pregnancies.<sup>1,2</sup>

The literature is generally unhelpful with respect to evidence-based neuroanesthetic management for the pregnant patient, and so planning and decision-making must be based largely on general principles of neurosurgical and obstetric anesthesia. Case reports and small studies or case series thus form an important source of knowledge and experience. We present a review of the literature to provide the anesthesiologist with a practical approach to such cases.

## THE REQUIREMENT FOR NEUROSURGERY DURING PREGNANCY

### Brain Tumors

Primary central nervous system tumors occur in approximately 6 in 100,000 females,<sup>3</sup> but are not

more frequent during pregnancy. Symptoms may present or be exacerbated because of increased tumor growth or edema, increased vascularity or pregnancy-related immunotolerance.<sup>4</sup> Meningioma is the most common primary intracranial neoplasm and some of these tumors grow faster during pregnancy because they contain estrogen and progesterone receptors.<sup>5</sup> Acute neurological deterioration of both suprasellar and cerebellopontine angle tumors during pregnancy, mandating resection, has been reported.<sup>3,6,7</sup>

### ICH

ICH is due to SAH from ruptured aneurysms (65%), bleeding from AVMs (35%),<sup>8</sup> and other very rare causes.<sup>9</sup> The incidence of ICH is approximately 10–50 in 100,000 deliveries<sup>10</sup> and ICH accounts for 7% of pregnancy-related maternal mortality.<sup>11</sup> Most cases occur antenatally,<sup>10</sup> and the maternal mortality is approximately 20%. Pregnancy does not confer an increased risk of hemorrhage in women harboring an AVM<sup>8</sup>; however, the risk of rebleeding is 25% during the same pregnancy, compared with a 3%–6% risk during the first year in nonpregnant women. Craniotomy, with removal of hematoma and resection of the AVM, provides the best means of avoiding rebleeding.<sup>8</sup>

SAH is a leading cause of indirect maternal death in triennial mortality reports from both the United Kingdom and Australia.<sup>12,13</sup> During pregnancy, SAH carries a sinister prognosis, with a 35% risk of fatal maternal outcome<sup>10</sup> and a 25% fetal mortality rate.<sup>14</sup> Most cases of SAH are caused by the rupture of an intracranial aneurysm, an event thought to occur more frequently during pregnancy (approximate incidence 20 in 100,000 pregnancies).<sup>8,10</sup> The increased risk of aneurysm rupture during pregnancy has been explained by a pregnancy-induced increase in circulating blood volume and cardiac output, and the hormonal changes to the arterial wall.<sup>15</sup> Others believe that, although there may be

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an increased risk of aneurysm rupture around the time of delivery,<sup>16</sup> parity confers a moderate long-term protective effect on the risk of SAH.<sup>17</sup>

### Traumatic Brain Injury

Traumatic brain injury in the pregnant patient may be associated with other trauma and early aggressive maternal resuscitation is the main priority because effective maternal resuscitation also provides fetal resuscitation. If tracheal intubation and positive pressure ventilation are indicated, a rapid sequence induction with thiopental or propofol and succinylcholine should be used. To avoid caval venous compression, after 20 wk gestation, left lateral tilt of the whole body should be applied through "log-rolling," because a wedge under the right hip may result in undesirable vertebral column rotation.

Difficult intubation can be expected in 1 in 300 pregnant patients.<sup>18</sup> Although there is no consensus as to the best method of intubation in patients with cervical-spine injury, fiberoptic techniques may be preferable in a pregnant patient with cervical-spine injury<sup>19</sup> because of the additional difficulty that may come from pregnancy and an unstable neck. Lack of time, equipment, or expertise may necessitate direct laryngoscopy with manual in-line stabilization for intubation.

### Spinal Procedures

Several conditions that may cause cauda equina syndrome or progressive neurologic deficit can necessitate urgent spinal surgery in the pregnant patient. Spinal tumors may become symptomatic under hormonal influence.<sup>4</sup> Bleeding from spinal tumors<sup>20</sup> and spontaneous hematomas needing evacuation have been reported,<sup>21</sup> as have vertebral vascular malformations needing decompression.<sup>22</sup> The rate of symptomatic lumbar disk displacement at the time of delivery is approximately 1 in 10,000. In a small series,<sup>23</sup> three pregnant patients positioned themselves prone for lumbar spinal surgery under epidural anesthesia. The prone position for spinal surgery in pregnancy may cause difficulties with respect to fetal monitoring, emergent cesarean delivery, and increased epidural venous bleeding. However, in this position, the placental perfusion may increase as shown in 23 pregnant women.<sup>24</sup> Some anesthesiologists avoid spinal surgery in the prone position in the pregnant patient.<sup>25</sup> Instead, the spinal procedure follows delivery by cesarean delivery.

### FETAL CONCERNS IN THE PERIPARTUM PERIOD

The fetus may be compromised indirectly by maternal hypotension, uterine artery vasoconstriction, maternal hypoxemia, and acid-base changes, indeed any change in maternal physiology that reduces uteroplacental perfusion or compromises fetal gas exchange.<sup>26</sup> The direct effects on the fetus and neonate of anesthetic and analgesic drugs (for example neonatal respiratory depression after predelivery administration of an opioid) or the adverse fetal effects of drugs,

such as anticonvulsants, during organogenesis (0–8 wk), also need to be considered. Recommendations in relation to radiation exposure of the pregnant patient suggest a maximum acceptable dose of 1 rem (roentgen equivalent man = 10mSivert)<sup>1</sup> and a safe maximum fetal dose of 0.5 rem.<sup>8</sup> Fetal radiation effects are highly gestational age- and dose-dependent and have the potential to cause early fetal loss or congenital abnormalities after exposure during the period of organogenesis. Exposure after organogenesis may cause growth restriction, microcephaly, and childhood cancer.<sup>13,27</sup> A calculated fetal dose of 0.3 rem occurs during the endovascular closure of an intracranial aneurysm<sup>27</sup> and cerebral angiography delivers a dose of 0.1 rem to the fetus if the woman's abdomen is shielded with a lead apron front and back.<sup>8,15</sup>

The decision to use fetal heart rate (FHR) monitoring perioperatively should be individualized and based on consultation with obstetricians. It will only be of clinical utility if the woman is willing to accept intervention in the event of significant and uncorrected fetal compromise, if a person capable of interpreting the findings is present to avoid unnecessary intervention,<sup>28,29</sup> and if immediate delivery is feasible (staff and facilities). Although FHR monitoring is possible after 16 wk gestation, changes in baseline (severe bradycardia and tachycardia) are only predictive of neonatal mortality after 24 wk gestation and baseline rate changes also occur in the healthy fetus, and so unnecessary premature delivery is a significant risk.<sup>30,31</sup> FHR variability is only a useful variable after 26 wk and drug-induced loss of variability is common during anesthesia. Severe fetal bradycardia intraoperatively mandates attempts to improve uteroplacental flow and fetal oxygenation by increasing maternal arterial blood pressure (BP) and ensuring left lateral tilt and normoventilation.

### TIMING AND METHOD OF DELIVERY

If neurosurgical intervention has been performed in early pregnancy (at <24 wk), the decision about subsequent fetal management can be based on obstetric considerations.<sup>32</sup>

If the fetus is viable at the time of planned neurosurgery, a decision must also be made whether delivery is appropriate. The anesthesiologist may face one of three scenarios:

1. Neurosurgery performed with a view to maintaining the fetus *in utero* in early pregnancy. General principles of neurosurgical and obstetric anesthesia apply. Previous neurosurgical procedures and current neuropathology may have implications for anesthetic management for later cesarean delivery.
2. Cesarean delivery before the neurosurgical procedure. Obstetric and neurosurgical anesthesia principles may need to be modified.
3. Cesarean delivery followed by later neurosurgery.

## Basic Anesthetic Considerations During Pregnancy

The anesthesiologist must understand the physiological changes of pregnancy, their implications, and the specific risks of anesthesia during pregnancy,<sup>33,34</sup> so that a plan can be developed. Individual case management has to be tailored to the surgical and neuroanesthetic requirements and to the gestational age. When time permits, a multidisciplinary and cooperative approach involving neurosurgeon, neuroradiologist, anesthesiologist, obstetrician, midwife, and neonatologist is recommended.<sup>13,27</sup>

Anticonvulsant therapy may need to be implemented or continued in the preoperative phase, and pregnancy-induced changes occur in the clearance, unbound fractions and half-lives of some anticonvulsant drugs.<sup>35</sup> Neurological advice should be sought.

Although not supported by good levels of evidence, aspiration prophylaxis is considered to be important before anesthesia during pregnancy, because pregnant women are more likely to experience both symptomatic and silent regurgitation. Inhibitors of gastric acid secretion, such as ranitidine 150–300 mg, may be given orally 1 h before anesthesia or as a 50 mg IV dose once a decision to proceed with operative delivery has been made.<sup>36</sup> Thirty milliliter of 0.3 M sodium citrate is recommended within 30 min of induction of general anesthesia.

During pregnancy, oxygen requirements increase and respiratory mechanics change due to the effects of the gravid uterus and weight gain. The reduction in functional residual capacity may lead to rapid maternal desaturation during hypoventilation or apnea. Because the arterial oxygen tension decreases at twice the nonpregnant rate, thorough administration of oxygen is essential.<sup>37</sup>

Careful airway assessment and management planning is necessary. As a result of fat deposition and upper airway mucosal edema, pregnant women are considered more likely to be difficult to intubate. Smaller than usual oral tracheal tubes are useful; additional equipment to manage a difficult airway should be readily available, and awake fiberoptic intubation should be considered when significant difficulty is anticipated.

A case report described the use of a laryngeal mask airway (LMA) in a case of difficult ventilation and intubation of a pregnant patient.<sup>38</sup> Ventilation became possible with the use of an LMA and a tracheal tube was inserted through the LMA to finally secure the airway during cesarean delivery. Although LMAs have been successfully used for airway management during cesarean delivery in a large series of pregnant women,<sup>39</sup> their use in pregnant neurosurgical patients should not extend beyond emergency use as a rescue device for the unanticipated difficult intubation.<sup>40</sup>

Rapid sequence induction is advisable early within the second trimester to reduce the risk of aspiration. Effective pelvic tilt of at least 15 degrees to the left to minimize aortocaval compression is required after 20 wk gestation by means of either a hip wedge or a side-tilting table.<sup>27</sup>

## INTRAOPERATIVE MANAGEMENT OF THE PREGNANT PATIENT DURING NEUROSURGERY

### Hemodynamic Considerations

Intraarterial BP monitoring is recommended before induction of anesthesia, so that hemodynamic changes are quickly observed and treated. To preserve both cerebral and uteroplacental perfusion, maintaining hemodynamic stability is important, which can be achieved through appropriate fluid administration, avoidance of aortocaval compression, the prophylactic or early use of vasopressor drugs, and arterial BP monitoring. Maternal positioning should effectively displace the gravid uterus to the left. If surgically acceptable, the patient should be placed in the lateral position for long intracranial procedures. Neurosurgery may cause substantial bleeding and warrant large bore IV access. Central venous access may be considered for administration of concentrated vasoactive drugs, central venous pressure monitoring, or aspiration of air emboli.

Ephedrine is no longer considered the vasopressor of choice for obstetric anesthesia, because good levels of evidence support advantages such as better maternal cardiovascular stability and improved neonatal acid–base status when an  $\alpha$ -receptor agonist, such as phenylephrine, is administered.<sup>41</sup>

In general, the BP should be regulated within narrow limits, close to baseline values. If the BP is within the range of 140/90 (mild preeclampsia) to 160/110 (severe preeclampsia), it should be reduced or controlled, aiming for a level of approximately 140/90 mm Hg. For an emergency neurosurgical procedure where the intracranial pressure (ICP) is increased, decreasing the BP is less advisable. The ideal BP in the case of an unsecured cerebral aneurysm remains controversial, although a systolic BP of <150 mm Hg has been recommended for the normotensive patient.<sup>42,43</sup>

### Ventilatory Management

As a result of increased ventilation during pregnancy, the normal arterial carbon dioxide tension ( $P_{aCO_2}$ ) at steady-state is 30–32 mm Hg. Controlled hyperventilation to reduce the ICP remains an option in the case of acutely increased ICP. Although the clinical effects on placenta blood flow are arguable, severe hyperventilation ( $P_{aCO_2}$  <25 mm Hg) may cause uterine artery vasoconstriction and leftward shift of the maternal oxyhemoglobin dissociation curve.<sup>44</sup> Indeed, prophylactic hyperventilation of head-injured patients to  $P_{CO_2}$  values <25 mm Hg has a negative impact on patient outcome.<sup>45</sup> We therefore suggest that maternal  $P_{aCO_2}$  be kept in the range of 25–30 mm Hg.

### Depth of Anesthesia Monitoring

Providing an adequate depth of anesthesia will reduce the risk of awareness.<sup>46</sup> However, it is also desired to avoid the hemodynamic effects of excessively deep anesthesia and achieve rapid recovery. Bispectral index or an alternative monitor of conscious

state may be useful if electrode placement does not interfere with surgical access.<sup>46</sup>

### Temperature Regulation

Although induced hypothermia is no longer recommended as a means of neuronal preservation, it is worth remembering that fetal temperature parallels maternal temperature and that both maternal hyperthermia and hypothermia may be associated with increased morbidity in the presence of increased ICP.<sup>47,48</sup> Preservation of normal body temperature of the pregnant patient undergoing neurosurgery may be achieved with a forced air warmer and the body temperature monitored with a urinary bladder or esophageal temperature probe.

### Mannitol and IV Fluid Therapy

A variety of measures to control ICP, such as slight head-up position, low tidal volumes during intermittent positive pressure ventilation, and avoidance of vomiting are applicable. Mannitol given to the pregnant woman slowly accumulates in the fetus, and fetal hyperosmolality leads to physiological changes such as reduced fetal lung fluid production, reduced urinary blood flow, and increased plasma sodium concentration.<sup>49,50</sup> In animal models, a net transfer of water from the fetus to the mother occurs over time, raising concern about the effect of fetal dehydration.<sup>51</sup> However, in individual case reports, mannitol in doses of 0.25–0.5 mg/kg has been used and appears safe.<sup>52,53</sup> Furosemide is an alternative but should also be used cautiously. Hourly urine output should be monitored. It is well established that IV fluid therapy during cerebral and spinal neurosurgery should consist of isonatremic, isotonic, and glucose-free solutions to reduce the risk of cerebral edema and hyperglycemia.

### Steroid Treatment

A single dose of dexamethasone is not teratogenic or carcinogenic in animals and appears safe, having been used in limited numbers of pregnant women without evidence of harm. The administration of steroids to reduce peritumor edema (e.g., dexamethasone 4 mg IM or IV injection four times a day) also acts to accelerate fetal lung maturity by increasing surfactant production, although betamethasone is the preferred steroid for this purpose based on better neonatal outcome.<sup>54</sup>

### Antiemetic Treatment

Most antiemetic drugs appear to be safe to use during pregnancy, with the best risk categorizations and widest clinical experience supporting drugs such as metoclopramide, antihistamines, and droperidol.<sup>55</sup> The serotonin<sub>3</sub> receptor (5-HT<sub>3</sub>) antagonists also appear safe based on animal studies and limited clinical experience and are widely used during pregnancy.<sup>56,57</sup>

To reduce fluctuations in ICP and cerebral blood flow secondary to the intubation-induced hypertensive response or anesthesia-induced hypotension, a smooth rapid sequence induction with pharmacological ablation of the response to laryngoscopy is required. Thiopental is still most frequently used as the IV induction drug for general anesthesia during pregnancy because in several countries propofol is stated by the manufacturer to be contraindicated during pregnancy. In clinical practice, however, propofol appears acceptable.<sup>58–61</sup> Both thiopental and propofol reduce the hypertensive response, ICP, and cerebral metabolism, maintaining cerebral autoregulation and permitting rapid awakening, although propofol may better attenuate the hemodynamic response to laryngoscopy and intubation.<sup>61</sup> Two cases of prolonged IV anesthesia with propofol for neurosurgery during pregnancy (14–18 h) resulted in mild metabolic acidosis after 11 and 10 h, respectively.<sup>62</sup> The reported changes suggest that propofol should not be used for very long procedures.

Volatile anesthetics suitable for anesthesia during pregnancy include isoflurane and sevoflurane. These are also favored in neuroanesthesia because they reduce cerebral metabolic rate, have the least effect on ICP, and provide a level of cerebral protection in animals.<sup>63</sup> The MAC of most volatile anesthetics is reduced by approximately 25% during pregnancy, and so initial end-tidal isoflurane or sevoflurane concentrations of 1.0% and 1.5%, respectively, are appropriate. These maintain a suitable depth of anesthesia, a degree of uterine relaxation because of their tocolytic effect and preserve cerebral autoregulation. Postoperative prophylactic tocolysis with drugs such as nifedipine and nonsteroidal antiinflammatory drugs is generally only used to prevent premature labor if the risk of fetal loss is high. The onset of labor postoperatively should be suspected if abdominal pain occurs, and some authors recommend tocodynamometric monitoring during the postoperative period.<sup>64</sup>

## ANESTHESIA FOR COMBINED CESAREAN DELIVERY AND EMERGENCY NEUROSURGERY

Few neurosurgical procedures are indicated urgently during pregnancy, but a ruptured intracranial aneurysm or a patient with cauda equina syndrome<sup>25</sup> may need acute treatment. General anesthesia will almost always be indicated. For third trimester gestations, the patient may be suitable for initial cesarean delivery, followed by the neurosurgical procedure, using an appropriately modified anesthetic technique.<sup>8,65</sup> Postpartum hemorrhage from uterine atony remains a risk during the subsequent neurosurgery. Despite infusion of an oxytocic drug, some authors suggest a change from a volatile-based anesthetic for cesarean delivery to an IV technique for the intracranial procedure to further reduce uterine blood loss.<sup>66</sup> Others have uneventfully used a volatile anesthetic for both procedures.<sup>25</sup>

## GENERAL ANESTHESIA

For general anesthesia, either total IV anesthesia with propofol or balanced IV and volatile anesthesia are reasonable choices. The use of propofol for induction and maintenance of anesthesia for cesarean delivery<sup>59</sup> is controversial because total IV anesthesia is associated with reduced neonatal neurobehavioral performance compared with thiopental and volatile maintenance. These effects, however, are of arguable clinical significance.<sup>59,60</sup>

When adequate doses of thiopental (4–5 mg/kg) or propofol (2–2.5 mg/kg) are followed by succinylcholine (1–1.5 mg/kg), there may be a transient, but clinically unimportant, increase in ICP. The choice of a nondepolarizing neuromuscular blocking drug for tracheal intubation is controversial because of difficult intubation. However, for a pregnant patient with SAH, the main priority is the avoidance of further neurological damage and protection of cerebral function. Therefore, induction of anesthesia may include a moderate dose of fentanyl (2–5  $\mu$ g/kg) and an intermediate-acting neuromuscular blocking drug to achieve stable hemodynamic variables.<sup>66</sup> A number of other approaches have been used to prevent hypertensive surges during laryngoscopy and intubation. A short-acting opioid, for example, a bolus of remifentanyl 1  $\mu$ g/kg over 60 s immediately before induction, is very effective<sup>67</sup> and remifentanyl and target-controlled propofol infusions have been used in a small case series of pregnant women.<sup>59</sup> Case reports of neonatal chest wall rigidity and apnea mandate the presence of personnel skilled in neonatal resuscitation. Other predelivery opioids such as alfentanil are also suitable, provided the person responsible for neonatal care or resuscitation is aware that neonatal naloxone may be required.

IV magnesium sulfate 30–60 mg/kg given as a bolus immediately after induction is effective and a good choice for patients with eclampsia or SAH.<sup>68</sup> Esmolol 0.5–1 mg/kg may cause fetal bradycardia<sup>69</sup> and lidocaine 1 mg/kg is less effective than remifentanyl.<sup>70</sup> Nitrous oxide should be avoided in neuroanesthesia, because it increases ICP, increases cerebral blood flow and cerebral oxygen metabolic rate, impairs autoregulation, expands air bubbles, and may contribute to postoperative nausea and vomiting.

The effect of oxytocic drugs on ICP and cerebral blood flow has not been well studied, but the use of synthetic oxytocin without adverse effect has been described in patients with intracranial tumors.<sup>3</sup> It should be appreciated that oxytocin causes transient hypotension and a significant increase in heart rate and cardiac output for several minutes.<sup>71</sup> Ergometrine is a potent vasoconstrictor, producing a hypertensive response that may further elevate increased ICP in the presence of a disrupted blood–brain barrier and loss of autoregulation. However, such drugs have been used as part of the “Lund Approach” for treatment of intracranial hypertension

because they also produce cerebral venous constriction reducing intracranial blood volume.<sup>72</sup> The use of ergometrine in the presence of intracranial disease in pregnancy should be discussed with the neurosurgical team.

## ANESTHESIA FOR INTERVENTIONAL NEURORADIOLOGY

The diagnostic and treatment principles of SAH in pregnancy are the same as in nonpregnancy. An increasing number of patients may be suitable for treatment by interventional neuroradiology rather than open craniotomy and surgical clipping. The main indications are endovascular coiling of cerebral aneurysms or preoperative embolization of AVMs.

Interventional neuroradiology for the pregnant patient should be considered a major procedure and the anesthetic planned accordingly. Most interventions require general anesthesia and invasive BP monitoring whereas diagnostic procedures are typically done with or without minimal sedation. Selected patients will need to be awake at important points of the procedure, e.g., during temporary test occlusion of an intracranial artery. The varying levels of sedation required will need to be carefully titrated.<sup>73,74</sup>

The interventional neuroradiology suite is a difficult or “remote” environment in which to provide obstetric anesthesia, but a small case series of delivery in the radiology suite for pregnant women with a high risk of major postpartum hemorrhage has been reported.<sup>75</sup> Arterial cannulation and endovascular closure of the uterine artery were planned in the case of uncontrollable bleeding.

Before femoral artery cannulation, precautionary steps should be taken, such as administration aspiration prophylaxis and, for gestations over 20 wk, uterine displacement.<sup>15</sup> Heparin is administered for interventional neuroradiology and may need reversal in the presence of emergency cesarean delivery or obstetric hemorrhage. If fetal compromise is detected, the neuroradiologic procedure may have to be halted until the baby is delivered.<sup>15</sup> In this circumstance, the intracranial catheter(s) are withdrawn and the femoral artery sheath(s) left *in situ*, after which heparin can be reversed (personal communication, C Phatouros, Department of Interventional Neuroradiology, Royal Perth Hospital). Although fetal monitoring has not been shown to reduce fetal mortality or morbidity, Doppler monitoring has been advocated<sup>52</sup> but poses its own practical difficulties in the radiology suite. A small case series of patients treated with coiling after SAH suggests that later vaginal delivery is the safest choice.<sup>76</sup>

## ANESTHESIA FOR CESAREAN DELIVERY AFTER RECENT NEUROSURGERY

In the late second and third trimesters, if neurosurgery is undertaken and the fetus remains well, the

pregnancy can be allowed to continue. There are several considerations if subsequent cesarean delivery is planned.

## ICP AND REGIONAL ANESTHESIA

Regional anesthesia may be appropriate to use when cesarean delivery is performed subsequent to recent successful and uncomplicated neurosurgery. The woman should be alert, cooperative, and preferably have normal ICP. This approach allows the woman to see her baby at birth and reduces the risk of life-threatening anesthesia-induced morbidity and mortality. The potential for a serious cerebral complication after dural puncture is of major concern if the ICP is high, because a rapid decrease in spinal cerebrospinal fluid (CSF) pressure may cause herniation or intracranial hemorrhage.<sup>77</sup> Intracranial subdural hematoma formation after epidural anesthesia and SAH after spinal anesthesia have been reported several times in the literature<sup>78</sup> and are thought to result from acute CSF pressure changes. On the other hand, in some patients, the ICP may be reduced by CSF loss during surgery or by CSF rhinorrhea after transnasal pituitary surgery or facial trauma. It is the authors' clinical experience that intentional lumbar dural puncture may be difficult to confirm under these circumstances and, if epidural techniques are used, care must be exercised to ensure true extradural placement of an epidural catheter. Epidural injection can cause an increase in ICP by compression of the dural sac.<sup>79</sup> The clinical significance of this increase has been questioned, but slow injection of incremental volumes of local anesthetic has been recommended.<sup>80</sup> Epidural infection is also a concern after previous spinal surgery, especially with instrumentation, or in the presence of a ventriculoperitoneal shunt.<sup>81</sup>

Regional anesthesia (spinal or combined spinal-epidural) has been successfully used for cesarean delivery in patients with paraplegia,<sup>82</sup> autonomic hyperreflexia,<sup>83</sup> cervical AVM,<sup>84</sup> and ventriculoperitoneal shunt.<sup>81</sup> Epidural anesthesia has been used for cesarean delivery in patients with pseudotumor cerebri and a lumbar-peritoneal shunt *in situ*.<sup>85</sup>

## POSTOPERATIVE MANAGEMENT

### Pain Management

After intracranial procedures, the pregnant patient should be admitted to an intensive care unit for observation and further management. Although generally less painful than extracranial surgery, craniotomy pain is moderate to severe in 50% of patients.<sup>86</sup> Good postoperative analgesia should be provided for maternal comfort and mobility and to reduce undesirable hemodynamic disturbances. Analgesia is best obtained using a multimodal approach combining local anesthetic infiltration or scalp blocks, opioids, and paracetamol. A recent comparison of morphine,

codeine, and tramadol for postcraniotomy pain concluded that morphine provided the best pain relief after craniotomy and fewer side effects.<sup>87</sup> Tramadol has very limited use in neurosurgical settings because, although it does not cause respiratory depression, it lowers the seizure threshold. Patient-controlled IV opioid (fentanyl or morphine) can be considered if the maternal mental state is satisfactory and is most appropriate after extracranial surgery. Neuraxial opioids and epidural analgesia are both very effective after spinal surgery, although regional techniques with local anesthetic may delay initial neurological assessment.<sup>86</sup>

The cyclooxygenase<sub>1</sub> and cyclooxygenase<sub>2</sub> inhibitor nonsteroidal antiinflammatory drugs are generally avoided because of their effects on platelet function and potential bleeding after intracranial surgery,<sup>88</sup> or because of their potential fetal complications (renal failure, necrotizing enterocolitis, and persistent fetal circulation after birth) when used for gestations of fetal viability, especially after 32 wk.<sup>89</sup> The cyclooxygenase<sub>2</sub> inhibitors such as celecoxib, parecoxib, and valdecoxib have no platelet effects but have not been evaluated during pregnancy. The safe use of drugs during lactation must also be considered, but is outside the scope of this review.

### Deep Vein Thrombosis Prophylaxis

Pregnancy is a hypercoagulable state and confers a substantially increased risk of thromboembolism after surgery, and so nonpharmacological prophylaxis (antithrombotic [TED] stockings, calf stimulation, calf compressors, or pedal pumps) should be used perioperatively. The risk of hemorrhagic complications after neurosurgery means that the risk-benefit of pharmacological thromboprophylaxis with heparins should be discussed with the neurosurgeon.

### Cerebral Vasospasm

Cerebral vasospasm may complicate SAH 3–6 days after the initial bleeding. Although “Triple H-therapy” (hypertensive and hypervolemic hemodilution) is not based on high levels of evidence, it is applied in many centers. The pregnant woman has an increased plasma volume and to a lesser extent red cell mass, so is relatively hypervolemic and hemodiluted compared with the nonpregnant state. In theory, these changes should be beneficial in the prevention of cerebral vasospasm after SAH. In the presence of preeclampsia, it may be unwise to increase the mean BP given the risk of eclampsia and other cerebral complications. Magnesium sulfate has been shown to reduce the severity of vasospasm after SAH<sup>90</sup> and is the prophylaxis and treatment of choice in eclampsia, a condition associated with periods of cerebral vasoconstriction.<sup>90</sup> If vasospasm is diagnosed from clinical signs or trans-cranial flow velocity changes,

some centers advocate superselective intraarterial papaverine or verapamil injection under general anesthesia. This strategy is controversial in the pregnant woman because of the accumulated fetal radiation dose. Furthermore, the treatment is not strongly evidence-based and the long-term effect on outcome is unproven. Nimodipine, which is commonly used to reduce the incidence of intracranial vasospasm, is potentially teratogenic and embryotoxic in animals,<sup>27</sup> but it has been used without apparent adverse fetal or neonatal effect in the management of preeclampsia. It may cause maternal hypotension<sup>27</sup> and treatment of pregnant patients with SAH-induced vasospasm with nimodipine and "Triple-H" has not been reported.<sup>8</sup>

## SUMMARY

Neurosurgery is infrequently required during pregnancy, but mandates a multidisciplinary approach and careful consideration of the timing of both surgery and delivery. Modification of neuroanesthetic and obstetric practices to accommodate the safety requirements of the mother and fetus may be required.

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