Anesthesia for the Parturient with Intracranial and Spinal Surgery

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7.1 Introduction

Neurosurgical disorders requiring neuroanesthesia during pregnancy are not common and still present a significant cause of morbidity and mortality in pregnant women [1, 2]. Decision regarding timing of neurosurgery and delivery is not straightforward and requires multidisciplinary discussion between the neurosurgeon, obstetrician, and anesthetist by assessing fetal maturity and the urgency to perform neurosurgical process. Conduct of anesthesia in a parturient presenting with a neurosurgical disorder is a major challenge. Physiological changes due to pregnancy can cause difficulty in any kind of surgery [3]. Moreover, airway, anesthetic, and hemodynamic management for neuroprotective interventions unique to neuroanesthesia should be used with caution in order to preserve fetal well-being. The literature on the evidence-based neuroanesthetic management of the pregnant patient is limited, and so decision-making should be based on general principles of both neurosurgical and obstetric anesthesia [4]. Maternal well-being without compromising fetal safety should remain a primary concern. The main goal is to provide a balance between some competing and even contradictory interventions unique for neuroanesthesia and obstetric anesthesia [5, 6].

7.2 Indications for Neurosurgery During Pregnancy

Essentially incidence of neurosurgical problems does not appear to be more in pregnant women than nonpregnant women. However, because of physiological and anatomical changes associated with pregnancy, pregnancy itself may promote or

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accelerate some certain neurosurgical diseases. The physiological changes related to pregnancy such as increased estrogen/progesterone levels and cardiac output in addition to edema formation and depressed immunotolerance are suspected to promote tumor growth [2].

Non-obstetric surgery during pregnancy is not uncommon; neurosurgical conditions encountered during pregnancy are cranial pathologies such as intracranial hemorrhage, hydrocephalus, intracranial tumors, spinal pathologies, trauma, and diagnostic and therapeutic interventions [1].

7.2.1 Cranial Pathologies

7.2.1.1 Brain Tumors

In general, a pregnant woman doesn't develop an intracranial tumor more than a nonpregnant woman [1, 3]. Exceptionally, choriocarcinoma is an aggressive gestational tumor, which is specifically associated with pregnancy [3].

The incidence of primary central nervous system tumor is approximately 6 per 100,000 pregnancies [4]. However, some tumors appear to manifest more rapidly because pregnancy seems to aggravate the natural history of tumor or become symptomatic during pregnancy. This exacerbation can be explained by increased blood volume, which increases the volume of vascular tumors; increased salt and water retention, which increases peritumoral edema and hence increases intracranial pressure (ICP); and hormonal influences of pregnancy that are associated with increased growth of meningiomas. Moreover, immunological tolerance, steroid-mediated growth, and hemodynamic changes are other factors contributed to tumors becoming symptomatic in the pregnant state [2].

Presentation, similar to nonpregnant, may include focal neurological defects, seizures, or signs of raised ICP such as headache, vomiting, seizures, and visual impairment. Differential diagnosis of raised ICP can be challenging during pregnancy because symptoms like headache and/or vomiting are common. Nevertheless, any pregnant patient with rapidly progressing headache, vomiting in the second or third trimester accompanied with new onset seizures and visual disturbances, should be evaluated accordingly [5]. Impending or actual cerebral herniation may be exacerbated with pregnancy at all gestations presenting with worsening headache, hypertension, deteriorating Glasgow coma scale, dilating ipsilateral pupil, bradycardia, and respiratory irregularity [3].

Meningiomas are the most common benign tumors, which may express estrogen or progesterone receptors and continue to grow in size during pregnancy [4, 5]. The incidence of meningioma is higher in women than in men. There is considerable relationship among menstrual cycle, pregnancy, and symptomatology of meningioma [1]. Treatment is mainly conservative unless they present with progressive neurological deficits. Pituitary adenomas and cerebellopontine angle tumors are other common types of intracranial tumors, and acute neurological deterioration of both tumors that warrant surgical resection during pregnancy has been reported [4].

Gliomas are the most common malignant tumors, which are rarely seen in pregnancy, but pose a risk for both mother and baby especially aggressive gliomas like glioblastoma multiforme grow rapidly and cause progressive neurological deficit [5]. So, definitive treatment should not be delayed. If the fetus is viable, neurosurgery can be performed after Cesarean section (C/S) or can be done at any time of gestation with adequate fetal monitoring. However, treatment should be individualized and tailored.

Imaging may be required to diagnose a new lesion or worsening of a previously known one. Magnetic resonance imaging (MRI) has been shown to be safe for detailed imaging in pregnancy. However, there are concerns on timing of imaging and contrast administration. In an acute setting, computed tomography (CT) is preferred, despite its risks.

Although evidence-based strategy for the management of intracranial tumors during pregnancy is lacking, management can be summarized depending on the gestation as presented in Table 7.1.

If a brain tumor is diagnosed which is asymptomatic during pregnancy, then waiting and watching the patient is the advised approach [3]. Close observation of the mother and fetus is critical, since possible acute worsening may necessitate hospital admission. There is no evidence that C/S is advantageous over vaginal delivery in protecting from increased ICP in term parturients.

7.2.1.2 Hydrocephalus

In the treatment of hydrocephalus, which may be congenital or acquired, ventriculoperitoneal (VP) shunts are indicated. With advancing medical care in surgical

Table 7.1 Management of intracranial tumors during pregnancy

Preconceptual diagnosis
• Delay pregnancy: Treat as any other nonpregnant woman • Continue pregnancy: Concerns on mother's prognosis and the potential risk of worsening during pregnancy
First and early second trimesters
• Fetus is not viable • Hemodynamic changes of the pregnancy are not remarkable • Stable patient: Permit gestational advancement to early second trimester for neurosurgery or adjuvant radiotherapy • Unstable patient: Urgent neurosurgery
Late second and third trimesters
• At the end of the 2nd trimester due to the high maternal intravascular volume, increased risk of significant hemorrhage may occur during tumour resection • Fetus is very premature • Stable patient: Gestational advancement can be permitted. In a patient with worsening neurology, radiotherapy with appropriate radiation doses may be an option to delaying surgery • Unstable patient: C/S under general anesthesia, followed immediately by surgical decompression
Term
• Stable patient: Vaginal delivery • Unstable patient: C/S under general anesthesia, followed immediately by surgical decompression

technique and shunt technology, more women with shunts may survive to childbearing age. During pregnancy, a woman with an in situ shunt or a woman who acquires the need for a shunt may present. Due to a combination of increased intra-abdominal pressure and anatomical changes, pregnancy is associated with an increased rate of complications such as VP shunt displacement or occlusion [3, 7]. The literature available to guide this group of patients' management is limited to case reports or case series. Management of VP shunt complications may be dependent upon symptoms and gestational age and guided by clinical status and imaging (Table 7.2).

7.2.1.3 Vascular Lesions and Intracranial Hemorrhage

Subarachnoid hemorrhage (SAH) occurs in 10–20:100,000 pregnancies with devastating consequences where maternal mortality rates range between 35 and 83% [8]. Presentation is the same as in the nonpregnant population with sudden onset severe headache. There is a spectrum of subsequent neurological sequel ranging from isolated cranial nerve lesions to a rapid reduction in Glasgow coma scale and unconsciousness. Most SAHs are thought to occur due to intracranial aneurysms. Rupture of intracranial aneurysms is believed to occur with a higher incidence during pregnancy. Additionally, the risk of aneurysmal rupture rises in each trimester, which

Table 7.2 Management of ventriculoperitoneal (VP) shunt complications during pregnancy

Preconceptual diagnosis
• In those considering pregnancy with a shunt already in situ, a CT or MRI of the brain, which acts as a baseline, should be performed • The baby may also have a neural tube defect, if the indication for the shunt was for a neural tube defect. Genetic counseling may be required
During pregnancy
• Attention to developing symptoms and signs of increasing ICP (headache, nausea, vomiting, ataxia, and seizures) • There is significant overlap with the presentation of preeclampsia • Increase in ICP is suspected, a CT or MRI of brain should be undertaken and compared with the baseline – If there is no change from preoperative imaging, the ICP should be measured and cerebrospinal fluid samples are collected for culture. If ICP is normal, and cultures are negative, physiological changes may be responsible. Treatment is bed rest. The shunt may be pumped to aid cerebrospinal fluid flow – If there is an increase in ventricle size or if ICP is raised on shunt puncture, shunt revision is required. In the first and second trimesters, this may be performed as in the nonpregnant. In the third trimester, a VP shunt or third ventriculostomy may be considered as an alternative; however, risks of uterine trauma or induction of labor should be avoided
During labor and delivery
• Prophylactic extended antibiotic regimens • No symptoms of increased ICP: Vaginal delivery is safe and may be the preferred option • A shortened second stage is suggested, as increases in ICP may lead to functional shunt obstruction • If patient becomes symptomatic during labor, C/S under general anesthesia is advised • Epidural anesthesia is contraindicated in case of elevated ICP

reaches its highest in the third trimester. In a pregnancy, SAH is associated with 35% risk of poor feto-maternal outcomes [5].

There are no objective data to say vaginal delivery is associated with an increased incidence of aneurysmal rupture. However, valsalva maneuver might increase the chances of aneurysmal rupture. Hence, labor analgesia with epidural block should be provided to all patients planned for vaginal delivery [9]. Epidural analgesia is considered as safest because there is no dural breach or fall in ICP, unless an accidental dural puncture occurs. General anesthesia is reserved for fetal distress; care should be taken on hemodynamics throughout the surgery. Ruptured aneurysm in pregnant women is treated similar with nonpregnant women, where the patient is taken up for immediate craniotomy or coil embolization under general anesthesia. The safety and efficacy of coil embolization are established, and it is also an effective option in pregnant patients with a ruptured or unruptured aneurysm under sedation and local anesthesia or under general anesthesia [3].

Arteriovenous malformations (AVMs) are not more prevalent during pregnancy. Unlike intracerebral aneurysms, AVMs have the highest associated risk of bleeding in the second trimester because of the maximum changes in cardiovascular status [5]. There is an increased risk of rebleeding (25%) during the same pregnancy. In incidentally diagnosed unruptured or ruptured AVMs without new focal deficits and with stable neurological course, pregnancy can be continued, and definitive neurosurgical intervention is planned in the postpartum period. If a patient with ruptured AVM has progressive neurological dysfunction, an emergency craniotomy or endovascular procedure can be planned depending on the medical condition of the patient. At that point, maternal well-being becomes the primary concern compared to fetal outcomes. If a patient with unruptured AVM is scheduled to undergo C/S, neuraxial analgesia would be safer. However, if the same patient undergoes a sequential craniotomy and C/S, or it is an emergency situation, then general anesthesia is the preferred technique [10, 11].

7.2.2 Spinal Pathology

Low back pain is common during pregnancy, reported in over half of pregnant women [12]. However, symptomatic lumbar disc herniation is extremely rare, with an incidence of around 1:10,000 pregnancies [13]. Hormonal changes including increased concentrations of relaxin and altered body posture are argued to exacerbate previous spinal problems, but there is no increased risk of disc herniation in the pregnant group [14]. Back pain experienced during pregnancy is more severe than nonpregnant women. That disabling symptom attributed to sacroiliac is typically dull and radiates into the buttocks and thighs. Pain associated with lumbar disc herniation differs from backpain of pregnancy because nerve root compression may cause a sharp shooting pain in the dermatomal distribution of the nerve compressed. Therefore, neurological dysfunction of that nerve is evident on examination. Cauda equina syndrome, resulting from lumbar disc herniation and subsequent compression of the cauda equina, is extremely rare in pregnancy but presents a neurosurgical

emergency [3]. Clinical features include lower back pain with or without sciatic nerve compression pain, sphincter disturbance, and numbness in the sacral region, motor weakness, and loss of ankle reflexes.

Diagnosis of lumbar disc herniation is made with a spinal MRI without contrast, and pregnancy does not preclude MRI. Neurosurgical management of these conditions in the pregnant woman is the same with the nonpregnant. Back pain of pregnancy resolves once pregnancy has completed. Therefore, surgery is not indicated. Conservative measures such as physiotherapy, bed rest, etc. along with simple analgesic medication are advised. It is also important to note that in those with symptomatic disc herniation due to nerve root compression, 85% of patients will get better with conservative management within 6 weeks [3]. In contrast, women presenting with worsening neurological deficit may require surgical intervention, and those with a cauda equine syndrome represent a surgical emergency.

In addition to disc herniation, parturients may present for surgery as a result of newly symptomatic spinal tumors or more rare complications such as vertebral canal hematoma (either spontaneous or following neuraxial procedures) and vertebral canal abscess or for vascular malformations. Spinal tumors may become symptomatic with hormonal effects. Bleeding from spinal tumors and spontaneous hematomas needing evacuation has been reported [15, 16].

Case reports have demonstrated that spinal surgery in the pregnant patient is safe [12]. The prone position is the preferred access for spinal surgery. During the first and early second trimester, surgery can be performed in the prone position as there is minimal aortocaval compression by the gravid uterus. Prone position for spinal surgery in pregnancy may cause difficulties with respect to fetal monitoring, emergent Cesarean delivery, and increased epidural venous bleeding. In this position, placental perfusion has been shown to increase in 23 pregnant women [17]. Three patients had successful lumbar spinal surgeries performed in the prone position under epidural anesthesia [12]. Some anesthesiologists do not prefer spinal surgery in the prone position if the spinal procedure follows C/S [18, 19].

7.2.3 Trauma

Maternal mortality due to obstetric causes is gradually decreasing due to better obstetric management however; non-obstetric causes of maternal mortality are increasing worldwide. Trauma is the leading non-obstetric cause of incidental maternal death during pregnancy [20]. Trauma itself complicates 6–7% of pregnancies and may involve cranial or spinal injuries that necessitate surgery [21, 22]. A multi-trauma will present significant clinical challenges in the care of mother and fetus, and early aggressive maternal resuscitation is the main priority. In life-threatening multi-trauma, C/S should be performed to improve maternal hemodynamics. Trauma carries worst outcome in the fetus. Fetal compromise is the result of the systemic effect of trauma on maternal physiology, mainly posttraumatic hypotension and hypoxia, hypovolemia, acidosis, or as a result of drugs used during the resuscitation process [23]. Head injury can increase the overall morbidity and mortality. If tracheal intubation and positive-pressure ventilation are indicated, a rapid sequence induction with thiopental

or propofol and succinylcholine may be used. To avoid caval venous compression after 20 weeks' gestation, left lateral tilt of the whole body should be applied. Difficult intubation can be expected in 1 per 300 pregnant patients. Although there is no consensus on the best method of intubation in patients with cervical-spine injury, fiberoptic techniques may be preferable in a pregnant patient with cervical-spine injury because of the additional difficulty that may come from pregnancy and an unstable neck [24]. Treatment can be conservative or surgical. Progressive worsening of the symptoms is an indication for emergency surgery [5, 25].

7.2.4 Diagnostic and Therapeutic Neuroradiology

Diagnostic and therapeutic neuroradiology during pregnancy should be considered as a major procedure, and the management of anesthesia should be planned accordingly [4]. The interventional neuroradiology suite is a remote environment in where it is difficult to provide obstetric anesthesia. For both diagnostic and therapeutic interventions, concerns are fetal radiation exposure, anesthesia at remote location, anaphylaxis, and renal dysfunction due to contrast agents. Procedures can be done under sedation and local anesthesia at femoral cannulation site or can be done under general anesthesia. Both of the anesthesia techniques have their own advantages and disadvantages. Selected patients will need to be awake at important points of the procedure. Most interventions require invasive blood pressure monitoring. Levels of sedation should be carefully titrated [26]. Before femoral artery cannulation, precautionary steps should be taken, such as administration of aspiration prophylaxis and, for gestations over 20 weeks, uterine displacement [27]. 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, neuroradiologic procedure may have to be stopped until the baby is delivered. In that circumstance, the intracranial catheters should be withdrawn and the femoral artery sheath left in situ, after which heparin can be reversed. Although fetal monitoring has not been shown to reduce fetal mortality or morbidity, Doppler monitoring has been advocated but poses its own practical difficulties in the radiology suite [28]. A small case series of patients treated with coiling after SAH suggests that sequential vaginal delivery is the safest choice [29].

7.3 Anesthesia for Neurosurgery in a Parturient

7.3.1 Timing

Pregnant women presenting for non-obstetric surgery represent a unique surgical and anesthetic challenge where the health of the mother is prioritized but equally careful consideration needs to be given to fetal well-being. If the conditions permit, it is recommended to wait until term. On the other hand, life-threatening, emergency neurosurgical conditions should be treated promptly [3].

Before 24 weeks' gestation, there is no option to deliver the baby, and neurosurgical intervention can proceed while maintaining the fetus in utero. Therefore, both optimizing maternal physiology and consideration for fetal well-being should be aimed and will result in the best outcomes. Subsequent fetal management following surgery can be then based on obstetric principles.

At gestational ages greater than 24 weeks, if the fetus is viable at the time of planned neurosurgery, consideration must be given to whether delivery is appropriate or not. There are three options:

- Neurosurgery during pregnancy: Continuous procedures; C/S proceeded by neurosurgery. Obstetric and neurosurgical anesthesia principles may need to be modified.
- Neurosurgery after delivery: C/S followed by later neurosurgery.
- Maintenance of pregnancy and proceeding with neurosurgery: Pregnancy in a parturient with a history of previous neurosurgical procedures or current neuropathology may have implications on the anesthetic management for later C/S, which is discussed below.

7.3.2 Concerns in Neuroanesthesia

Neuroanesthetic concerns include maintaining stable hemodynamics, hyperventilation, controlled hypotension, and ICP reduction [5]. Meanwhile, obstetric anesthetic concerns may be listed as potentially difficult intubation, rapid sequence induction, aspiration prophylaxis, maintenance of uteroplacental circulation, uteroplacental drug transfer, avoiding aortocaval compression, fetal monitoring, tocolysis, postpartum hemorrhage, dosage modifications, and teratogenicity. In recent years, major concerns on the neurotoxic effects of anesthetics, awareness during general anesthesia, and the airway management of pregnant women have arisen [6, 23].

One of the challenges is obtaining a balance between adequate cerebral perfusion pressure and uteroplacental perfusion pressure. Factors that precipitate fetal hypoxia and compromise uteroplacental perfusion can adversely affect fetal outcomes with poor Apgar scores. Hypotension and hypovolemia should be strictly avoided for better maternal and neonatal outcomes. In general, hemodynamic fluctuations should be avoided, anxiety and pain should be vigorously treated, and normoxemia, normoglycemia, and normothermia should be maintained to avoid fetal asphyxia at all times.

There is no evidence that premature labor is associated with types of the anesthetic drugs and anesthetic technique. Role of prophylactic use of tocolytics is controversial because of its own side effects. Nevertheless both intraoperative and postoperative tocolysis may be required in cases with high risk of preterm labor.

The use of fetal heart rate monitoring in the emergency setting is debatable. The decision to use fetal heart rate 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, and if immediate delivery is feasible [30, 31]. American Society of Anesthesiologists guideline on fetal monitoring during non-obstetric surgery suggests that surgery should be done at an institution including neonatal and pediatric services and an obstetric provider with C/S privileges and a qualified individual to interpret the fetal heart rate should be readily available during procedures [6]. Although fetal heart rate monitoring is possible after 16 weeks' gestation, changes in baseline are only predictive for neonatal mortality after 24 weeks' gestation, and baseline rate changes also occur in the healthy fetus, and drug-induced loss of variability is common during anesthesia, and so unnecessary premature delivery is a significant risk [32]. In case of intraoperative severe fetal bradycardia, increase maternal arterial blood pressure by ensuring left lateral tilt and normoventilation to improve uteroplacental flow and fetal oxygenation.

Another challenge is the drug dosing due to pregnancy-related pharmacodynamic and pharmacokinetic changes in absorption, distribution, metabolism, and excretion of drugs and teratogenicity. Pregnancy is also associated with lower anesthetic requirements, with the minimum alveolar concentration of inhalational agent being reduced by up to 30%. Intravenous induction agents are also often required in lower doses. It is important to note that the incidence of awareness in the pregnant population is higher. This is in part due to the emergency nature of a large proportion of obstetric surgery, reduced induction to incision times to minimize fetal transfer, and a higher maternal cardiac output resulting in rapid redistribution of induction agents. Special care should be taken to avoid drugs, which cause fetal teratogenicity. Most of the anesthetic agents fall in the category of B and C in the Food and Drug Administration labeling system for drugs in pregnancy, that is, these can be used safely with caution. Controversy exists regarding the use of nitrous oxide and benzodiazepines. Cocaine is the only anesthetic agent known as teratogen, which is not even in use [5].

Furthermore, as there are a number of radiological investigations for imaging in neurosurgical conditions, concerns exist regarding fetal radiation exposure. Recommendations in relation to radiation exposure of the pregnant patient suggest a maximum acceptable dose of 1 rem (roentgen equivalent man = 10 mSivert) and a safe maximum fetal dose of 0.5 rem [4, 21]. Concerns of radiation-induced teratogenicity include microcephaly and childhood cancers. Fetal radiation effects are highly dependent on gestational age and dose that 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. A calculated fetal dose of 0.3 rem occurs during the endovascular closure of an intracranial aneurysm, and cerebral angiography delivers a dose of 0.1 rem to the fetus if the woman's abdomen is shielded with a lead apron [33].

7.3.3 Conduct of Anesthesia

The safe management of the parturient and the preservation of fetal well-being during anesthesia are closely linked to understanding the pregnancy-related

physiological changes [34]. Individual management has to be tailored to the surgical and neuroanesthetic requirements and to the gestational age. The best approach is involvement of a coordinated multidisciplinary team with clear plans regarding timing of surgery, timing of delivery, and maternal and fetal management.

Relevant recommendations on obstetric practice in a non-obstetric surgery during pregnancy can be extracted from the American College of Obstetricians and Gynecologists Committee opinions [35].

Sedative premedication may be needed in an extremely anxious patient; however, the risk of hypoventilation, hypercarbia, and subsequent increases in ICP should be considered. Since pregnant patients are prone to gastric regurgitation and aspiration, medications to decrease gastric acidity and the volume of gastric contents are recommended. 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 operation decision has been made [36]. 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 [37].

Pregnancy is associated with increased oxygen requirements and change in respiratory mechanics due to the effects of the gravid uterus and weight gain. Administration of oxygen is essential, as the reduction in functional residual capacity may lead to rapid maternal desaturation during hypoventilation or apnea. Pregnant women are considered more likely to be difficult to intubate, so careful airway planning for assessment and management is necessary. Intubation with smaller than usual tracheal tubes are better, additional equipment to manage a difficult airway should be readily available, and awake fiberoptic intubation should be considered when significant difficulty is anticipated. Although LMA has been successfully used for airway management during elective C/S in a large series of healthy parturients, its use in pregnant neurosurgical patients should not extend beyond emergency use as a rescue device for the unanticipated difficult intubation [38, 39].

The majority of neurosurgical procedures require general anesthesia, and rapid sequence induction is advisable early within the second trimester to reduce the risk of aspiration. 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 C/S 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 [40, 41].

Succinylcholine administration (1–1.5 mg/kg) may cause a transient increase in ICP. The choice of a non-depolarizing neuromuscular blocking drug for tracheal intubation is controversial because of increased risk in difficult intubation. Avoidance of responses to laryngoscopy is vital especially for SAH. Induction of anesthesia includes use of short-acting opioids. Magnesium sulfate can be used to blunt the response to laryngoscopy. Actually, it is the drug of choice in eclamptic and preeclamptic patients. The literature also describes the use of lignocaine (1 mg/kg) and

short-acting beta-blockers such as esmolol (0.5–1 mg/kg). Lignocaine is found less effective than remifentanil, and beta-blockers have been associated with fetal bradycardia. Actually, in high doses ketamine increases uterine tone.

Volatile anesthetics suitable for anesthesia during pregnancy include isoflurane and sevoflurane, which are also favored in neuroanesthesia because they reduce cerebral metabolic rate, have the least effect on ICP, preserve cerebral autoregulation, and provide a level of cerebral protection in animal studies [42], and a degree of uterine relaxation because of their tocolytic effect. The MAC of volatile anesthetics is reduced by 25–30% during pregnancy. Nitrous oxide should be avoided in neuroanesthesia, since 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 safe use of synthetic oxytocin has been described in patients with intracranial tumors [43]. It should be noted that oxytocin causes transient hypotension and a significant increase in heart rate and cardiac output for several minutes [44]. Ergometrine is a potent venoconstrictor, producing a hypertensive response that may further elevate ICP in the presence of a disrupted blood-brain barrier and loss of autoregulation. The use of ergometrine in the presence of intracranial disease in pregnancy should be discussed with the neurosurgical team.

Maternal $PaCO_2$ implicates oxygen delivery to the fetus both in terms of uterine perfusion and the maternal oxygen-hemoglobin dissociation curve. Hyperventilation to manipulate maternal ICP remains an option although normocarbia is recommended [3].

Maintaining hemodynamic stability and avoiding fluctuation in blood pressure during the perioperative period are beneficial for maternal, fetal, and neurosurgical reasons. Therefore, it is advised to site invasive arterial pressure monitoring prior to induction. Hypertension related to laryngoscopy can be prevented by short-acting opioids. Magnesium sulfate given at induction is also effective, especially in preeclamptic states. Maternal positioning to avoid aortocaval compression is essential. Effective pelvic tilt of at least 15° to the left to minimize aortocaval compression is required after 20 weeks' gestation by means of either placing a hip wedge or a side-tilting table. Large-bore intravenous access is required, and central venous access should be sited if vasoactive substances or central venous pressure monitoring is required. Blood pressure should be maintained within normal limits. Ephedrine is no longer recommended for the vasopressor choice in the parturient [4]. Phenylephrine, a selective alpha agonist, is associated with better maternal cardiovascular stability and improved fetal acid-base status [45, 46]. Intravenous fluid therapy during cerebral and spinal neurosurgery should include isonatremic, isotonic, and glucose-free solutions to reduce the risk of cerebral edema and hyperglycemia [4].

A variety of measures to control ICP consists of slight head-up position, low tidal volumes during intermittent positive-pressure ventilation, and avoidance of vomiting. Mannitol and furosemide should be used cautiously. The administration of steroids to reduce peritumoral edema appears safe, as it accelerates fetal lung maturity at the same time [4].

It is worth remembering that fetal temperature is consistent with its mother's temperature and both maternal hyperthermia and hypothermia may be associated with increased morbidity in the presence of increased ICP [47]. Monitoring body temperature and preserving normal body temperature of the pregnant patient undergoing neurosurgery is beneficial [4].

Patient positioning is a particular problem for spinal surgery. Normally spinal surgery is carried out in the prone position. While prone position provides good uteroplacental perfusion, the mechanics are challenging in the pregnant population. There are a few case reports of spinal surgery carried out under regional anesthesia, where the women positioned themselves prone prior to surgery [12].

If the patient is going to be extubated following neurosurgery, similar with induction, care is required to prevent reflux and aspiration of gastric contents. Patients should be fully awake with intact airway reflexes. If abdominal pain occurs following surgery, onset of labor should be suspected, and tocodynamometric monitoring during the postoperative period is recommended [4]. Postoperative prophylactic pharmacologic tocolysis is only indicated to prevent premature labor if the risk of fetal loss is high.

After intracranial procedures, it is better to discharge the pregnant to an intensive care unit for close evaluation and further management. Good postoperative analgesia should be provided by a multimodal approach. Pregnancy is a hypercoagulable state and associated with increased risk of thromboembolism after surgery, so non-pharmacological prophylaxis (antithromboembolic stockings, calf stimulation, calf compressors, or pedal pumps) should be used perioperatively [4].

7.3.4 Anesthesia for Cesarean Delivery with Intracranial Pathology

Parturients with intracranial pathology are thought to have increased ICP, and so the risk of herniation due to an inadvertent dural puncture is cited as a contraindication for neuraxial anesthesia. Following key points may be helpful [1]:

- If the patient has new neurologic symptoms such as worsening headache, visual changes, seizure, and decreased level of consciousness, and there is imaging evidence of significant mass effect with midline shift, then the patient is likely at high risk of herniation.
- If the patient does not have neurologic symptoms but has imaging evidence of significant mass effect with midline shift, then the patient is likely at high risk of herniation.
- If the patient does not have neurologic symptoms but has imaging evidence of minimal mass effect, then do not proceed without neurological consultation; the patient is likely at mild-moderate risk.
- If the patient does not have neurologic symptoms and imaging evidence of mass effect, then search for an imaging evidence of hydrocephalus. If there is an

obstruction at or above the foramen magnum, then do not proceed without neurological consultation; the patient is likely at mild-moderate risk.
- If patient has none of the findings described above and also does not have any clinical or imaging findings suggesting increased ICP, it may be reasonable to proceed with neuraxial anesthesia. Patient is likely at minimal or no risk of herniation.

7.3.5 Anesthesia for Cesarean Delivery After Recent Neurosurgery

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. 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 [48]. Intracranial subdural hematoma formation after epidural anesthesia and SAH after spinal anesthesia have been reported several times in the literature and are thought to result from acute CSF pressure changes [49]. Wang and colleagues [4] suggest that intentional lumbar dural puncture may be difficult to confirm under these circumstances. If epidural techniques are used, care must be given to ensure the placement of an epidural catheter, and slow injection of incremental volumes of local anesthetic is also recommended [50]. Epidural infection is also a concern after previous spinal surgery, especially with instrumentation, or in the presence of a ventriculoperitoneal shunt.

7.4 Maternal and Fetal Implications of Neuroanesthesia

Standard neuroanesthesia practices, including hyperventilation, intravenous fluid management, and administration of mannitol and steroid, can challenge the general obstetric principles of managing a parturient. Parturient may benefit from some neuroprotective measures and interventions unique to neuroanesthesia, whereas fetus may get harm. Avoiding maternal hypoxia, hypocarbia, and hypotension remains as the primary goal to prioritize both maternal and fetal safety and avoid preterm labor.

7.4.1 Induced Hypocapnia

As hyperventilation results in a fall in arterial carbon dioxide pressure ($PaCO_2$), thus in cerebral vasoconstriction, induced hypocarbia is, therefore, one method used to reduce ICP. In pregnancy, there is a progressive increase in minute ventilation lowering $PaCO_2$, and the set point for the cerebrovascular response to hyperventilation

is, thereby, reduced [1]. Attempts to lower ICP necessitate lowering the $PaCO_2$ to as low as 25 mmHg or less. However, this degree of hypokalemia may cause fetal hypoxia and acidosis by decreasing uterine blood flow and reducing release of oxygen secondary to left shift of the hemoglobin-oxygen dissociation curve [4]. For these reasons, maternal $PaCO_2$ should be maintained at around 30 mmHg.

7.4.2 Induced Hypotension

Induced hypotension is used to facilitate aneurysm clipping. Moreover, hypotension is a common side effect of certain neurosurgical practices, such as nimodipine and mannitol [3]. However, uterine blood flow is exquisitely sensitive to maternal systemic blood pressure. In the pregnant patient, maternal hypotension, and subsequent fetal hypoxia, should be avoided. Instead of inducing hypotension, temporary clipping of a vessel may be used to reduce intra-aneurysmal pressure [33].

7.4.3 Mannitol

Maternal administration of mannitol results in significant increases in maternal osmolality; as it crosses the placenta, it may accumulate in the fetus, leading to subsequent changes in fetal osmolality, fetal dehydration, and volume and the concentrations of various electrolytes [1, 3]. However, in dosages used in some case reports (0.25–0.5 mg/kg), mannitol is unlikely to cause severe fluid or electrolyte abnormalities in the fetus [28, 51]. If required to treat severe or life-threatening intracranial hypertension, moderate doses are recommended with judicious monitoring of blood pressure and treatment of any ensuing hypotension [4]. In human studies the effects on fetal outcome are unknown. Furosemide is an alternative but should also be used cautiously. Monitoring urine output is advised [4].

7.4.4 Steroids

Steroids decrease the vasogenic edema associated with tumor growth and improve the patient's symptoms [5]. It is safe to use steroids during pregnancy and have an additional advantage of promoting fetal lung maturity by increasing the fetal surfactant formation. However, maternal steroid administration may contribute to fetal adrenal hypoplasia [3]. Betamethasone has better neonatal outcomes than dexamethasone [52].

7.4.5 Antiepileptics

Antiepileptic drugs are used both for treatment and prophylaxis of seizures. Some of the antiepileptic drugs are teratogenic (e.g., phenytoin) [5, 53]. Therefore, their use in the first trimester requires careful consideration. Phenytoin is one of the most

commonly used antiepileptic drugs in neurosurgical patients, which is poorly absorbed from the gastrointestinal tract and undergoes increased plasma clearance. So, appropriate dosing in pregnant women and monitoring plasma levels to achieve therapeutic plasma concentrations needs particular consideration [53].

7.4.6 Calcium Channel Blockers

There is limited evidence for the use of specific calcium channel blockers in pregnancy. Animal studies suggest that nimodipine may increase the risk of intrauterine growth retardation and congenital abnormalities but no comparative studies in humans are available. However, the known benefits of nimodipine in preventing spasm are likely to outweigh any potential risk to the fetus and should be administered as clinically indicated [4].

7.4.7 Chemotherapy, Radiotherapy, and Gamma Knife

Generalized chemotherapy is not an option in pregnancy; so localized chemotherapy with carmustine-impregnated wafers can be used [54]. Carmustine is an alkylating chemotherapeutic agent, which exerts its effects by alkylating the RNA and DNA. Systemic administration of carmustine is associated with systemic side effects and reduced efficacy; to overcome these problems, a localized delivery of the chemotherapeutic agent is desirable [55].

Radiotherapy is associated with teratogenicity and childhood cancers but still may be safely used if care is taken to decrease the dose of radiation and to provide adequate fetal shielding [56].

Gamma knife procedures during awake craniotomy provide local radiation and can be performed safely [57, 58].

Conclusion

Consequently compared to nonpregnant women, those who are pregnant are no more susceptible to neurosurgical interventions, nor routine neurosurgery is common during pregnancy. However, due to physiological changes of pregnancy, certain neuropathologies may be exacerbated, and standard neuroanesthesia practices may pose too many challenges. Care of the pregnant neurosurgical patient essentially follows the general principles of anesthesia for obstetrics and neurosurgery. On the other hand, anesthesiologists should be aware of various concerns from both neurosurgical and obstetric point of view discussed above. Most importantly, teamwork between the neurosurgeon, neuroanesthetist, obstetrician, and patient is crucial. The nature of neurosurgical conditions during pregnancy requires departments to be familiar with the management of pregnant patients. Protocols should be developed for such cases with close communication and referral between specialties, and thus, a decision will need to be made where the patient will be best cared for, in the neurosurgical or obstetric unit.

Key Learning Points

- Pregnant women presenting for non-obstetric surgery represent a unique surgical and anesthetic challenge where the health of the mother is prioritized but equally careful consideration needs to be given to fetal well-being.
- Even though neuroanesthesia is infrequently required during pregnancy, neurosurgical conditions encompasses anesthesia include cranial pathologies, intracranial hemorrhage, spinal pathologies, trauma, and diagnostic and therapeutic radiologic interventions.
- A multidisciplinary approach and careful consideration of the timing of both surgery and delivery are mandatory based on maternal outcome, assessment of fetal maturity and the urgency to perform neurosurgical process.
- The main goal is to provide a balance between some competing and even contradictory interventions unique for neuroanesthesia and obstetric anesthesia to accommodate the safety requirements of both the mother and the fetus.

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