Chapter

Updates in Neuroanesthesia

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Abstract

Providing anesthesia care to neurosurgical and neurocritical care patients presents unique challenges to the anesthesiologist. Over the last century, anesthetic care for such patients has become a robustly studied field, with tools and techniques to keep patients safe and comfortable in the perioperative period. A review of the major updates and considerations for perioperative care for awake craniotomies, thrombectomy for stroke, and endoscopic neurosurgery is critical for the anesthesiologist. Additionally, newly developed enhanced recovery after surgery procedures have improved patient experiences and outcomes after both cranial and spinal neurosurgery. Finally, post-operative delirium is a major neurologic complication in elderly patients undergoing all types of procedures which all anesthesiologists should be well versed in. Here, such topics are reviewed with a focus on recent updates to the literature which are important for clinical practice.

Keywords: neuroanesthesia, intraoperative brain mapping, thrombectomy, enhanced recovery after surgery, neurotoxicity, perioperative delirium

1. Introduction

From Henry Cushing in the early 20th century to Jane Matjasko in the 1980s, over the last century anesthesia for neurosurgical patients has advanced enormously through the work of many brilliant physicians. What was once a field that posed enormous difficulty for anesthesiologists and surgeons alike, has become robustly studied and an established subspecialty of anesthesiology. Anesthesiologists now have a range of tools at their disposal to ensure patient safety during cranial or spinal procedures, can develop plans to keep patients awake during intracranial surgery for brain mapping and language center preservation, and can provide enormous benefits in the intensive care unit for the neurosurgical patient. Here, a discussion of some of the more recent advances in neuroanesthesiology is reviewed.

2. Methods

Research presented in this chapter was collected via a relevant literature search and review. Online databases and search engines including Pubmed.gov and GoogleScholar were utilized to search out peer-reviewed articles relating to each of the major topics discussed. Keywords included but were not limited to: “awake craniotomy”, “intraoperative brain mapping", "Anesthesia for Thrombectomy", "ERAS for craniotomy", "ERAS for spinal surgery", and "postoperative delirium". Published articles including original research, case reports, and reviews were all included. Articles with key and up-to-date information were selected and compiled and major take-aways across the articles were synthesized and included in this chapter. The majority of topics were chosen based on the topics of major reviews or landmark studies published between 2019 and 2022.

3. Updates to neuroanesthesia: cranial procedures

3.1 Anesthesia considerations during asleep craniotomy

A craniotomy is an extraordinarily common neurosurgical procedure in which portions of the skull are removed in order to gain access to the intracranial vault [1]. Traditionally, this procedure is performed with the patient asleep under general anesthesia for the duration of the operation. This can be a component of a larger procedure such as tumor resection or can be the primary procedure being performed such as in patients with brain swelling and refractory increased intracranial pressure (ICP). Other indications can include clipping of large ruptured or unruptured aneurysms when endovascular therapy is not indicated, hematoma evacuation, tissue biopsy, and debridement of an abscess [1]. In cases where the bone flap removed is not immediately placed back after the procedure, often in cases of brain swelling after TBI or massive stroke, the procedure is called a craniectomy. Cranioplasty to replace the bone flap can be done once the swelling has subsided.

3.1.1 Preoperative assessment

In the case of craniotomy, in addition to traditional pre-anesthesia work ups, establishing the neurological status of a patient and individualizing their premedication regimen are key pre-operative steps to ascertain. Determining a baseline neurological status for all neurosurgical patients is critical as this helps delineate whether deficits present upon the patient awakening from surgery were present prior to surgery or appeared after [1]. Establishing their Glasgow Coma Scale score, whether they have signs of elevated intracranial pressure, or if they have any focal neurological deficits are all key to establishing prior to surgery so that changes can be detected post-operatively [1]. In terms of premedication, whether the patient takes anticonvulsants and has a history of seizures is important to determine. For most procedures, premedication with daily anti-epileptic drugs (AEDs) is appropriate [2]. If the patient is undergoing resection of epileptic foci, the use of benzodiazepines should be avoided. However, more unclear, and individualized is whether the patient should take their regular anticonvulsants on the morning of epilepsy surgery [2]. Different institutions will have variable procedures regarding AEDs, but consultation with the patient's neurologist, neurosurgeon, and institutional procedures should be done to determine whether the patient takes AEDs prior to epilepsy surgery [2]. If the patient takes regular steroids, stress dose steroids should be administered as well prior to surgery.

3.1.2 Intraoperative considerations

Patients are positioned on the operating table in a variety of ways depending on which region of the skull is being removed. Patients may be prone, supine, lateral, semi-lateral, or even in a sitting position [1]. In most cases, the head is immobilized utilizing head pins attached to a Mayfield apparatus which pierce the skin, galea aponeurosis, and the skull itself and hold the head in a fixed position throughout the procedure [1]. Often a dose of propofol, opioids, or local lidocaine is administered just prior to pinning as this can induce hemodynamic responses including hypertension and tachycardia just as incisions or other painful stimuli do. Additionally, it is important that pressure points throughout the body and regions associated with peripheral nerve compression are padded as many neurosurgical procedures take long periods of time and patients can develop compressive neuropathies and skin pressure injuries [1]. Ocular injury from cleaning solutions and other surgical fluids can be avoided by placing an adhesive over the eyes just after anesthesia is induced.

Monitoring craniotomy patients intraoperatively is a very individualized job and should be planned on a patient-by-patient basis. In most cases, an arterial line is needed. Accurate monitoring of blood pressure is paramount in neurosurgical patients, as blood pressure can be reflective of intracranial pressures and high blood pressure increase the risk of intracranial bleeding after surgery [1]. In patients undergoing craniotomy after traumatic brain injury (TBI) often intracranial pressure (ICP) monitoring may be critical. In those patients, they may have an external ventricular drain (EVD) in place or will have one placed during the procedure which will allow for continuous ICP monitoring [3].

Anesthetics generally do not have a major effect on ICP or will actually promote brain relaxation, with the exception possibly of ketamine [4]. This means most typical choices for induction, such as propofol and opioids work well to induce general anesthesia in most craniotomy patients. Some studies have reported that ketamine induces an increased ICP, while others have shown no changes or even decreases in ICP after its use [5]. While ketamine's use remains controversial in the literature, avoiding its use in most craniotomy patients is advisable. Total IV anesthesia (TIVA) is primarily maintained in craniotomy with propofol (50–100 μg/kg/minute), a short-acting opioids such as remifentanil (0.1–0.2 μg/kg/minute), and dexmedetomidine 90.1–0.3 mcg/kg per hour) [6]. Note that doses of propofol and opioids should be titrated based on the patient's age and other medical conditions that may affect their ability to metabolize the anesthetics.

Somatosensory Evoked Potentials (SSEP) and Motor Evoked Potentials (MEP) are monitoring steps often taken during craniotomies to establish the location of the primary motor and somatosensory cortices [1]. Often these are used when resection will include resection of the brain tissue and function to avoid or minimize damage to brain tissue involved in motor and sensory functions. With SSEP, peripheral nerves, most often the ulnar, median, and tibial nerves, are stimulated and the regions of the brain that become electrically active on EEG as a result help the surgeon determine the boundaries of the primary somatosensory cortices [1, 7]. MEP on the other hand includes electrical or magnetic stimulation of the brain surface and records muscular responses throughout the body so as to delineate the boundaries of the primary motor cortex [1, 8]. If MEP is required, neuromuscular blockers can be used during intubation, but are not used in the maintenance of anesthesia afterward, as MEP monitoring requires muscles to contract in response to cerebral stimulation [1, 8].

3.1.3 Postoperative care

In the postoperative period, a neurologic exam should be performed once the patient is awake enough to follow commands and once the neuromuscular block has been completely reversed [1]. If the patient underwent an infratentorial craniotomy, there is a higher risk of damage to the cranial nerves which innervate the reflexes of the airway, such as the vagus nerve [9]. In such patients, extubation may be delayed until the patient is awake enough for the cough reflex to be tested [9]. The patient will need to undergo serial neurologic exams by the nursing team and the neurointensivist during recovery. While somewhat controversial, most craniotomy patients, even those without complications, should be admitted to the ICU [10]. As such, opioids for pain control should be titrated to maximize pain control but not to depress the patient's ability to cooperate with a neurologic exam. Additionally, blood pressure should be maintained below 160 mmHg systolic as pressures greater than that are associated with a higher risk of postoperative intracranial bleeds [11]. Both beta-blockers such as labetalol and calcium channel blockers like nicardipine can be used if medication is needed to reduce the patient's pressures.

3.1.4 Complications

Craniotomy complications are numerous including seizures, subdural hygroma, and increased intracranial pressure [1]. If a seizure occurs during a craniotomy and the dura is open, the first line treatment is the application of sterile iced saline to the brain surface by the surgeon [12]. If the seizure continues, a dose of midazolam (1 mg or 2 mg IV) or propofol (10 mg or 20 mg IV) can be administered to abort the seizure [1]. Prevention of brain herniation in those who have suffered TBI with rising ICP is critical. If an EVD is in place, the first line treatment for high ICP is CSF drainage from the EVD [13]. Other methods of lowering ICP could include hyperventilating the patient, sedation to reduce cerebral metabolism, elevation of the head of the bed, and in critical situations, IV mannitol or hypertonic saline [13]. Subdural hygroma refers to a collection of cerebral spinal fluid in the subdural space secondary to tears in the arachnoid membrane [13]. Such collections can increase in size and cause mass effects on the brain, causing focal neurologic findings and CSF density fluid on CT or MRI [14]. If symptomatic, treatment could include burr hole drainage, placement of a subdural drain, and in recurrent or severe cases repeat craniotomy and the placement of a subdural-peritoneal shunt [14]. If developing after craniectomy, cranioplasty is the definitive treatment for hygroma [14].

3.2 Anesthesia considerations during awake craniotomy for intraoperative brain mapping

Over the last 40 years, intraoperative cortical and subcortical brain mapping has led to major improvements in both recurrence-free survival and postoperative outcomes in patients undergoing resective brain surgery [15]. The primary goal of mapping is to identify and preserve tissue associated with speech and motor function while also ensuring adequate margins during mass resection [15]. This often includes waking a patient after a successful craniotomy in order to ask the patient a series of questions to test speech and cognitive function while brain regions are stimulated. Such methods have been enhanced and supported by advances in anesthesiology [15]. This poses unique challenges to the anesthesiologist and preparation is paramount. Here, the major considerations for the anesthesiologist caring for a patient undergoing intraoperative brain mapping with awake craniotomy are reviewed through the entire perioperative period.

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3.2.1 Preoperative assessment

A key first step in the preparation for surgery is the pre-operative assessment of each surgical candidate. An awake craniotomy can create enormous anxiety and some patients may be unable to undergo this type of procedure. Additionally, if the patient cannot cooperate with the surgeon's commands due to altered mental status, baseline aphasia, or confusion, an awake craniotomy is contraindicated [15]. Patients who may be more difficult and necessitate consideration of other alternative methods include those patients with uncontrolled seizures, a history of anesthesia emergence delirium, obstructive sleep apnea, patients which may present a challenging airway, and those with GERD [15]. Prior to surgery, the anesthesiologist should discuss with the patient what an awake craniotomy entails. Discussion of possible complications and adverse events should be discussed, as well as the testing that they will undergo while the surgeon operates.

Consideration regarding the type of procedure and why it is performed should also inform the anesthesiologist's premedication of the patient. Patients who are undergoing surgical resection of epileptogenic brain foci should not be premedicated with benzodiazepines as this will hinder the identification of target regions by suppressing epileptiform activity [2]. If the patient takes daily steroids or anti-hypertensives those should also be given on the day of surgery.

3.2.2 Intraoperative anesthesia

Anesthetic strategies for patients undergoing intraoperative mapping can range from the use of an "awake-asleep-awake" strategy to conscious sedation [15]. In the former, patients are placed under general anesthesia for the initial craniotomy, awakened for mapping, and then are placed back under general anesthesia for the resection of the tumor and cranioplasty. In conscious sedation, the patient is sedated but arousable throughout the surgery but the depth of sedation can vary throughout [15]. General anesthesia methods require the establishment of an airway, but in awake craniotomy using an endotracheal tube is difficult, as the patient must be extubated when they are awakened for monitoring [15]. Some anesthesiologists still prefer to use endotracheal intubation, but supraglottic airways and laryngeal mask airways are other viable options during deep sedation [15]. One major benefit of this strategy is that general anesthesia allows for more control of the blood carbon dioxide levels and encourages brain relaxation, which is beneficial during the resection of highly vascular tumors or large deep-seated tumors such as those found in the insula [15].

The major concern of the general anesthesia pathway is the need for airway management which may include inducing coughing, distress, and aspiration while emerging from anesthesia mid-operation. Conscious sedation alleviates this concern as the goal is to avoid the use of airway management by avoiding oversedation [15]. However, oversedation and airway obstruction remain a concern if a fine balance is not found between sedation and airway patency. While these two plans have variable strengths and weaknesses, meta-analyses comparing these two have failed to find major differences in postoperative outcomes, so planning and shared decision-making between the surgeon, the patient, and the nursing team are important, as both methods are appropriate for most patients [15].

In terms of the medications used to induce anesthesia, historically propofol and midazolam have been used in patients who are undergoing awake craniotomy [16]. Propofol is rapid in its onset and offset and can be used to titrate sedation and rapid awakening, Midazolam also has long been used as an anxiolytic during awake sedation

Anesthetic	Dosage regimen	Indications and considerations
Propofol	CS drip: 20–50 μg/kg/minute	For CS regimens, dosages can be titrated so the patient is arousable but drowsy
	GA drip: 50–100 μg/kg/minute	Respiratory depression should be monitored
Remifentanil	CS drip: 0.01–0.06 μg/kg/minute	Respiratory depression should be monitored
	GA drip: 0.1–0.2 μg/kg/minute	While transitioning to awake phase, continued low-dose remifentanil can maintain analgesia
Dexmedetomidine	CS drip: 0.3–0.5 μg/kg/minute	Less respiratory depression than propofol
Midazolam	Pre-op: 1–2 mg IV bolus	Pre-op can be used as an anxiolytic, unless performing epilepsy surgery
Sevoflurane	GA: <0.5 MAC	Rapid onset and rapid clearance allow for rapidly inducing GA and rapidly awakening the patient

CS, conscious sedation, GA, general anesthesia, MAC, minimum alveolar concentration.

Table 1.
Anesthetics typically utilized for awake craniotomy [16].

but cannot be used in patients undergoing epilepsy surgery [16]. Dexmedetomidine is a newer agent recently approved by the FDA for use in awake craniotomy in 2008 [16]. This can be used as an anxiolytic and as a sedative and is associated with fewer respiratory side effects as compared to propofol [15]. The dosages and onset times for key drugs used during awake craniotomy are given in **Table 1**.

For CS regimens, low-dose propofol and remifentanil drips are often given simultaneously, unless respiratory depression necessitates the use of dexmedetomidine [16]. For GA regimens, propofol and remifentanil can also be used, as well as inhaled agents, such as sevoflurane, with IV remifentanil [16].

Key procedures to perform prior to craniotomy include placement of an arterial line, a central venous catheter, and a foley catheter [15]. For intraoperative monitoring, body temperature surveillance is crucial; if the patient begins to shiver, brain mapping will become extremely difficult. The threshold for shivering in most unanesthetized adults is 35.5°C, but this threshold can be lowered by inhaled anesthetics and opioids [17]. Typically, maintaining a patient's core body temperature above this threshold will prevent shivering. The addition of dexmedetomidine or ondansetron to the anesthesia regimen may reduce shivering, but body temperature monitoring remains paramount [17]. Keeping the room warm, warm IV fluids, and utilizing forced air warming blankets are standard methods that are also employed to maintain normal body temperature in surgical patients.

Among those undergoing awake craniotomy, scalp blocks can be particularly helpful in reducing patient discomfort during and after craniotomy [15, 18]. This is especially important in those undergoing awake sedation. These blocks can either be performed by targeting specific nerves innervating the scalp, most often the zygomaticotemporal, supraorbital, auriculotemporal, lesser occipital, and greater occipital nerves [18]. Scalp blocks can also be done by creating a circumferential block around the surgical field subdermally. Neurosurgeons or anesthesiologists can perform this technique by injection of a long-lasting local anesthetic, usually 2 mL of 0.5% bupivacaine, with effects lasting up to 8 hours after injection [18].

In these procedures, the patient will be awakened after the craniotomy is complete and the brain surface is exposed. A grid will be placed on the brain surface to allow the surgeons to keep track of regions of tissue and their effects on the patient's speech and motor capabilities. Before the patient is awakened, MEP and SSEP are typically used to identify the sensory and motor cortices, as this method can be used in anesthetized patients [1]. After being awakened, a bipolar stimulator is then used to stimulate various brain regions with varying amounts of current while the patient is shown a series of cue cards displaying words and imagery [15, 19]. The patient is instructed to read and name the objects on each card out loud. Often the cards will contain widely recognizable objects such as a ball or a tree. The surgeon stimulates various brain regions while listening for changes in the patient's speech patterns as they read each of the cards [15, 19]. Changes include total speech arrest, dysnomia, semantic errors, and phonological paraphasia [1, 15]. Each of these speech errors correlates to the afterdepolarization of a key region of the eloquent brain and by identifying the region responsible for each of these functions, the surgeon can spare this tissue during resection. For example, total speech arrest correlates to the primary speech area in the frontal operculum whereas dysnomia (the inability to name

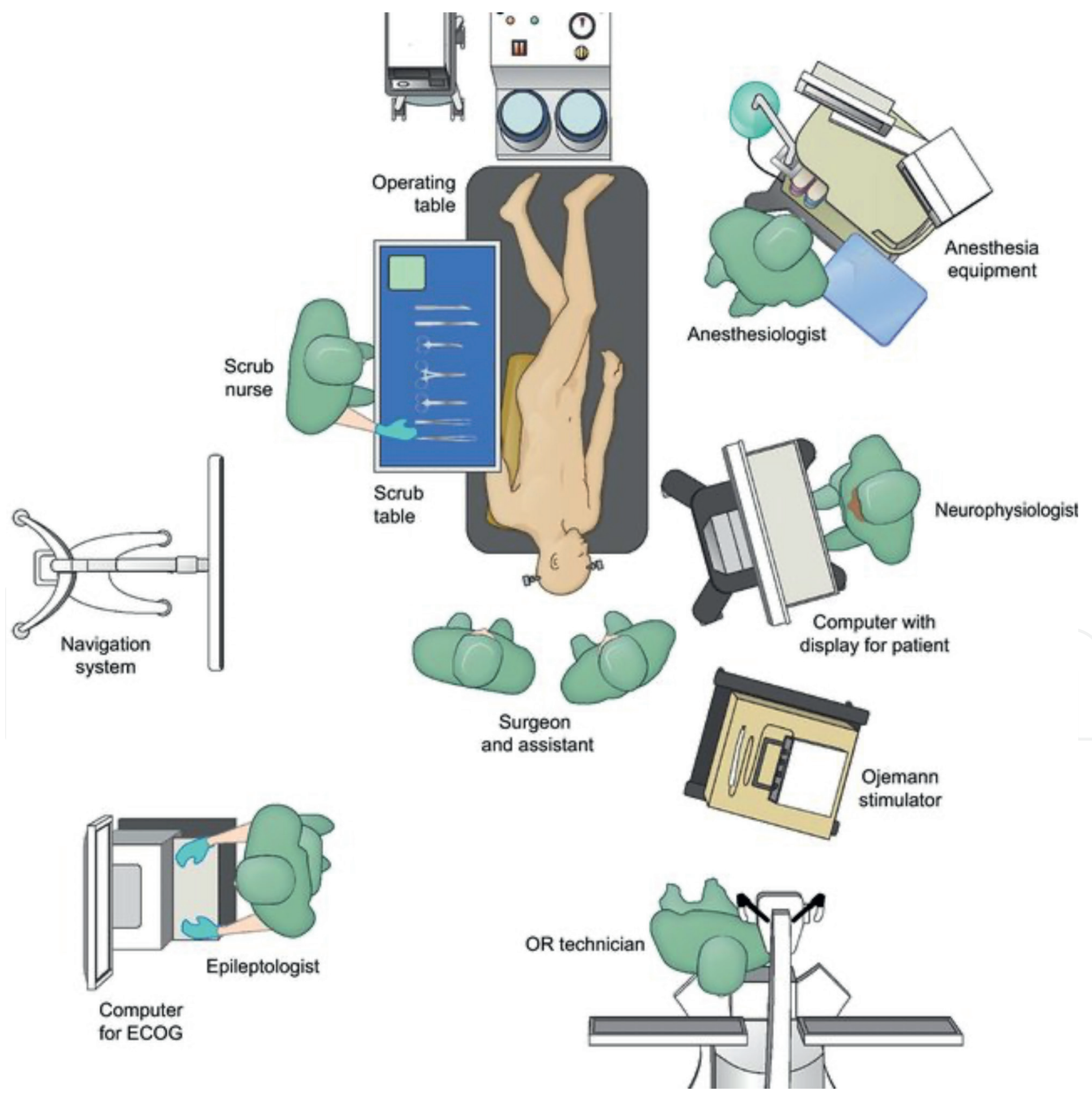

Figure 1.
Room set up and patient positioning for awake craniotomy. Note the display within the patient's field of view and the surgical team at the head of the bed. Typically, anesthesiology will be at the head of the patient's bed, but in the case of a craniotomy, the neurosurgeon must be at the patient's head [19].

objects) typically is associated with the posterior, inferior frontal gyrus, and inferior parietal and temporal regions [1]. **Figure 1** shows a schematic of what an awake craniotomy may look like in terms of room set up and patient positioning.

3.2.3 Post-operative care

Post-op care for patients after awake procedures is fairly standard. In fact, patients who underwent awake craniotomy for resections had better outcomes than those who underwent general anesthesia for the duration of their resection [20]. Nursing should perform neurological exams on the patient every 1 to 2 hours while the patient is inpatient post-operatively. Neurologic exams in these patients should always include pupillary light reflex exam, cranial nerve assessment, testing of the extremity muscles for new focal or global weakness, and cognitive status [15]. There are currently no major differences between postoperative care in patients who had "asleep-awake-asleep" or who had conscious sedation [15]. Key considerations are maintaining a target blood pressure of 150–160 for most patients, as uncontrolled hypertension is associated with longer hospital stays and a higher risk of intracranial bleeds [21]. Special care should be taken to monitor for surgical site infections, brain herniation, intracranial bleeds, hydrocephalus, and seizure, as these are common complications post-craniotomy. Like asleep craniotomy, awake craniotomy patients should be admitted to the ICU post-operatively.

While most craniotomies come with numerous risks and complications, awake craniotomy in particular comes with some specific concerns. Seizure for example is a risk of all craniotomies, but in particular risk of seizure is particularly high during stimulation for brain mapping purposes [22]. Most are focal and brief and do not pose a major risk to the patient [22]. In the case of patients who are undergoing monitored anesthesia care and are not intubated, risks for airway complications including hypoventilation leading to hypercarbia are of particular concern [15]. Hypercarbia can contribute to brain swelling as well. If the patient is to deeply be sedated and not respirating well on their own, medications should be backed off and the patient should be aroused and asked to breathe deeply until blood gases normalize [15].

3.3 Cerebral aneurysm procedures

While the treatment of unruptured cerebral aneurysms is controversial, neurosurgeons still intervene on those aneurysms whose risk of rupture is high. Generally, aneurysms between 7 mm and 10 mm are considered high risk, but a multitude of factors including morphology and regional anatomy are considered [1]. While in some cases open craniotomy and aneurysmal clipping cannot be avoided, endovascular interventions became another standard therapy for aneurysms in the 1990s [1]. This includes access to the cerebral vasculature via the advancement of a catheter that entered the vascular system at another site (femoral artery or radial artery) [1]. Once the aneurysm is reached, titanium coils are inserted into the aneurysm lumen where a thrombus forms around the coils, filling the space within the outpouching [23]. Advances in this technique have included the use of balloons and stents to aid in coil insertion and more recently the use of flow diverters. Flow diverters are mesh-like stents that are placed into the parent vessel to redirect blood flow along the original path of the parent artery while stagnating flow into the aneurysm itself [23]. This causes shrinkage and thrombosis of the aneurysm and remodeling of the artery [23].

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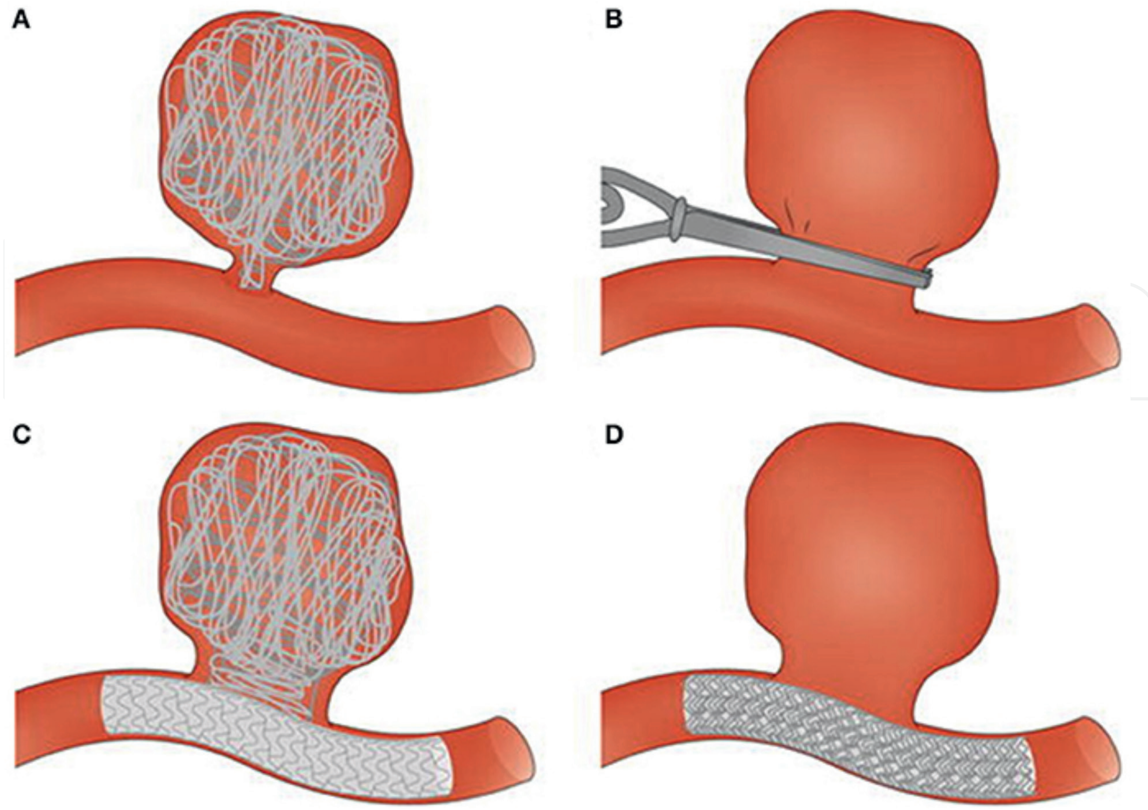

Figure 2.
Treatment strategies for unruptured intracranial aneurysms. (A) Depicts endovascular coiling embolization alone, (B) depicts aneurysmal clipping, (C) depicts stent placement and coil embolization combined, and (D) depicts the use of a flow diverter alone [24].

As compared to traditional coiling techniques, flow diversion is associated with lower rates of aneurysm recurrence and higher rates of successful occlusion [23]. While these diverters have become a widely accepted method of endovascular treatment for aneurysms very recently, their role in the treatment of ruptured aneurysms or aneurysms which would typically be treated by craniotomy and clipping is yet to be determined. **Figure 2** shows an image of some of the key treatment strategies for intracranial aneurysms.

While every aneurysm warrants individual assessment, some factors can delineate whether a ruptured aneurysm is an ideal candidate for endovascular treatment or for open craniotomy. Emergent craniotomy for rupture aneurysms used to be the standard of care, but recently endovascular treatment has become more utilized in emergent cases as well [25]. Ideal candidates for endovascular treatment after rupture include elderly patients, with aneurysms smaller than 15 mm, those with aneurysmal necks less than 4 mm wide, those found in the posterior circulation and those with major medical comorbidities [25]. Those which may be more ideal for open surgery include aneurysms in younger patients, diameters greater than 15 mm or very small aneurysms, those arising from the middle cerebral artery, those with complex aneurysmal neck anatomy or fusiform shape, fear that the patient cannot cooperate with diligent follow up [25]. It is also worth noting that studies have found higher rates of recurrence in ruptured aneurysms which undergo endovascular coiling as compared to those which underwent surgical repair [25]. As such, follow-up is critical, particularly in the 6 months after an endovascular repair of a ruptured aneurysm [25].

3.3.1 Preoperative assessment

Like most intracranial surgeries, neurological assessment should be performed prior to anesthesia induction for endovascular coiling procedures. This should include a neurologic exam including assessing whether the patient is alert and oriented, the function of the cranial nerves, and sensation and motor function of all the extremities. This allows for tracking of neurologic status post-operatively and better identification of postoperative complications. Baseline blood pressure should be determined for the patient and determination if pre-medication for blood pressure management will be needed [24]. In a more emergent situation, such as endovascular treatment of a ruptured aneurysm, these are the two most important steps to take in the pre-operative assessment. More careful examination can be performed for the treatment of unruptured aneurysms.

3.3.2 Intraoperative considerations

Endovascular therapy is generally performed under general anesthesia and includes catheter access to the cerebral vasculature from another access site. During these procedures prevention of hypertensive responses to components of the procedure such as foley catheter insertion, intubation, or incision should be avoided [24]. High blood pressures increase the risk of aneurysmal rupture intraoperatively, so small doses of opioids (for example fentanyl 3 μg/kg) are given just prior to intubation and incision to prevent hemodynamic responses. An arterial line should be placed for blood pressure monitoring and typically systolic blood pressure should not rise above 120 mmHg [24]. If the patient has hypertension or pressures are running higher than intended, using a beta-blocker or calcium-channel-blocker like nicardipine may help manage blood pressure.

3.3.3 Complications of endovascular coiling and post-operative care

In the event that the patient's aneurysm has ruptured and subarachnoid hemorrhage has developed, it is key to maintain higher pressures than in unruptured patients to ensure cerebral perfusion is maintained in the face of vasospasm, but not to exceed pressures of 160 mmHg so as to protect the patient from re-bleeding [26]. Vasospasm is a major complication after intracranial hemorrhage and can result in ischemia to affected brain regions. Treatment with nimodipine (often 60 mg every 4 hours) is standard of care in such patients with subarachnoid hemorrhage [27]. Nimodipine is a calcium channel blocker that induces vasodilation in the cerebral blood vessels [27]. Heparin is also usually dosed before the procedure and hourly throughout, but it is important to be prepared to rapidly reverse heparin if an intracranial bleed should occur so having protamine (50 mg) available to rapidly administer is wise. Protamine is the reversal agent for Heparin and can be used in the case of a bleed to rapidly reverse Heparin's effects. To assess for complications, post-operatively, serial neurological exams should be performed by the nursing team and the neurointensivist. Again, opioid pain control should be titrated so as to ensure full neurologic exams can still be performed as needed.

3.4 Endoscopic neurosurgery

Another recent and major advancement in cranial neurosurgery is the use of endoscopic navigation, which allows the surgeon to reach and operate in deep-seated regions of the brain without extensive dissection [28]. Such techniques allow for advanced skull base tumor resections, ventriculostomy, intraventricular tumor resections, and sellar tumor resections using only burr hole-sized craniotomies [28]. The ability for extensive tumor resection with minimal manipulation of healthy brain tissues thereby reducing post-operative complications [28]. The angled optics that endoscopy allows also offers particular advantages to the neurosurgeon. Accessing some sites in the intracranial vault to perform microscopic neurosurgery is difficult and requires a large craniotomy, such as the cerebellopontine angle [28]. However,

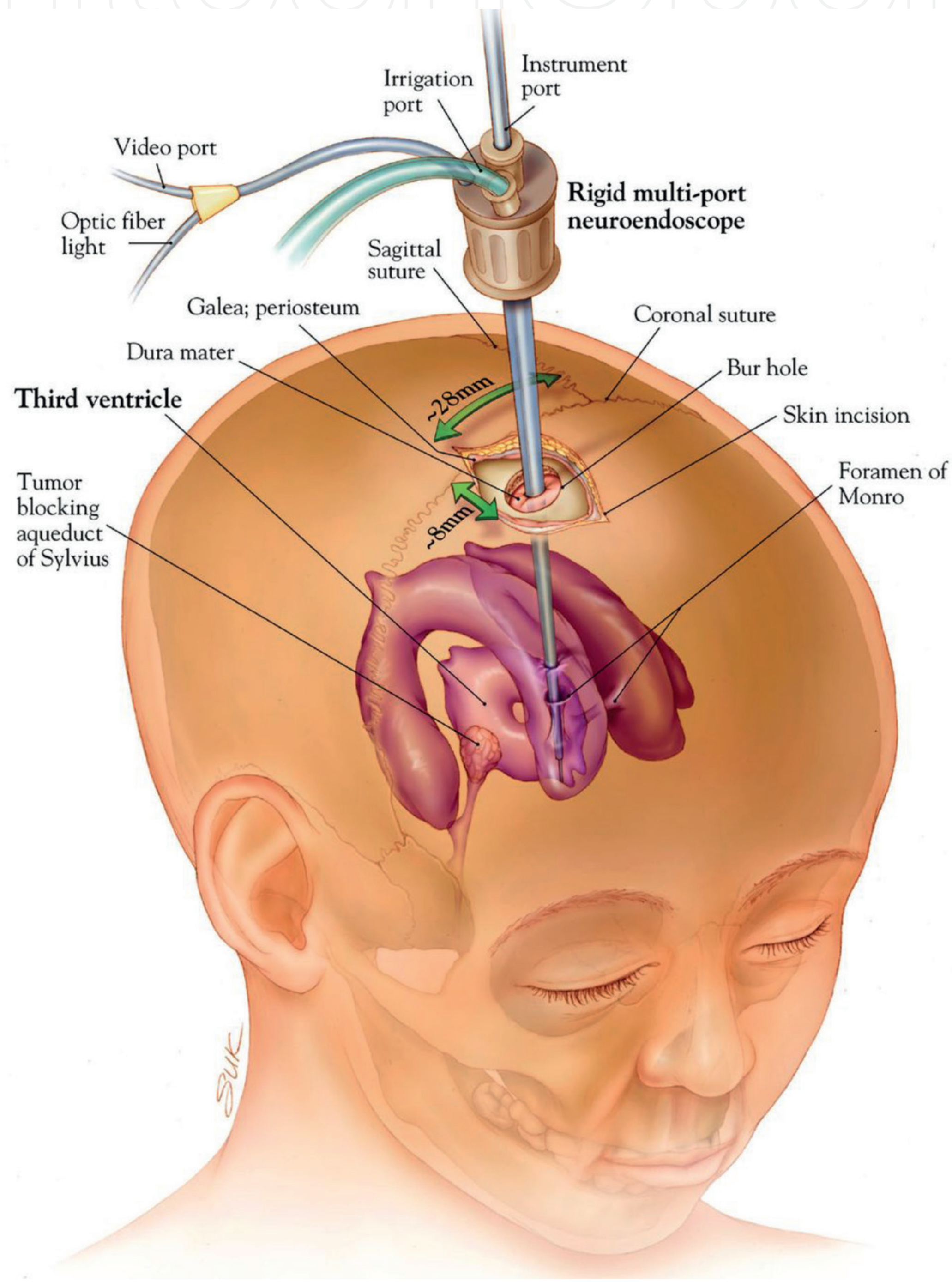

Figure 3.
Endoscopic neurosurgery for ventricular tumor resection schematic. Shown here is an example of an endoscopic cranial procedure. A key-hole-sized craniotomy is made in the skull and an endoscope is advanced into the ventricles so that microscopic resection can be done [28].

with angled optics offered by the endoscope, such tumors in precarious positions can be reached without aggressive dissection [28]. However, it is important to note that the use of minimally invasive neurosurgery is elective in nature and the surgeon's comfort in removing a particular tumor or cyst via this method will determine if a patient is eligible for a minimally invasive approach. Such methods are still being studied for a variety of new procedures and are likely to become more widely used in the future. **Figure 3** shows an example schematic of an endoscopic neurosurgical procedure.

3.4.1 Preoperative assessment

Pre-operative assessment for endoscopic neurosurgery is very similar to assessments for other cranial procedures. Always perform a pre-operative neurological assessment, assess the patient's baseline intracranial pressure, and get accurate baseline blood pressure. This allows for adequate intraoperative and postoperative monitoring for complications. The neurologic status of these patients will vary greatly. Some may have neurologic symptoms due to hydrocephalus if an intraventricular tumor is obstructing cerebrospinal fluid flow or is asymptomatic with normal neurologic status.

3.4.2 Intraoperative considerations and complications

General anesthesia remains the method of choice for patients undergoing endoscopic cranial procedures. Unlike most procedures, the unique challenge to the anesthesiologist of endoscopic procedures is the need for accurate and constant monitoring of intracranial pressures [28]. Due to working in the still enclosed space of the cranium with endoscopy, fluid irrigation used throughout the procedure, especially in the ventricular system, can contribute to rapid increases in intracranial pressure [28]. Rapid changes in ICP may not induce the traditional changes associated with the Cushing triad, so monitoring ICP directly and continuously during such procedures is critical [28]. Such monitoring can be done by insertion of a Codman Microsensor through the working channel of an endoscope and allows for continuous ICP monitoring throughout the procedure and while irrigating in the ventricular system [29]. Arterial lines should always be placed in these patients as well to allow for blood pressure monitoring and rapid identification of cerebral ischemia.

3.5 Anesthesia for thrombectomy in acute ischemic stroke

Although stroke mortality has declined over the last decade, ischemic stroke remains one of the top 20 leading causes of death and long-term disability in the United States [30]. Prior to 2015, the only reperfusion therapy with proven efficacy in these patients was thrombolysis with intravenous alteplase (tPA). As a result of a number of successful randomized-controlled trials, the AHA/ASA Stroke guidelines were updated in 2015 to reflect the addition of endovascular thrombectomy (EVT) to the standard of care for acute ischemic stroke due to large vessel occlusion [31]. This revolutionary approach dramatically improved neurological recovery and functional outcomes in these patients. Despite the success and impact of EVT in this setting, the optimal anesthetic strategy for this procedure remains controversial. In this section, preoperative considerations, anesthetic strategy recommendations, and possible complications of EVT will be discussed.

3.5.1 Preoperative planning

Both tPA administration and endovascular thrombectomy are time-limited interventions; the patient must have a last known normal of less than 4.5 and 6 hrs, respectively. Due to the time restrictions, rapid identification and emergent management of acute ischemic stroke are critical and around-the-clock intervention must be available, including the ability to transfer to a facility with appropriate staffing and equipment. As a result, most hospitals have instituted Stroke Alert Protocols to expedite the assessment of hospitalized patients with changes in neurological status [32].

Stroke alerts immediately notify appropriate providers, including neurology, interventionalists, and nursing. Initial management is with emergency non-contrast CT imaging of the brain to assess for hemorrhage prior to tPA administration. Once the patient is determined to be eligible, tPA should be administered even if endovascular treatment is being considered. EVT is indicated when the cause of stroke is deemed to be the occlusion of a large cerebral artery in the anterior circulation and the procedure can be initiated within the 6-hour window of symptom onset. For stroke patients entering the emergency room, the goal for "door-to-needle time" is less than <60 min. In practice, less than one-third of the patients meet this goal [33].

As soon as the need for thrombectomy is confirmed, goals for the procedure need to be addressed between the surgeon and anesthesiology team regarding hemodynamic monitoring and anesthetic approach. In terms of monitoring, blood pressure, heart rate, electrocardiogram, oxygen saturation, and end-tidal carbon dioxide concentration should be continuously monitored throughout the procedure. Invasive arterial blood pressure or blood pressure cycling as frequently or more frequently than every 3 minutes should be employed. Intraoperatively, systolic blood pressure should be maintained between 140- and 180-mm Hg with diastolic blood pressures <105 mm Hg [34]. In the following section, anesthetic strategies for EVT are explored.

3.5.2 Anesthetic strategies

The anesthetic strategies used in EVT include general anesthesia, conscious sedation, and local anesthesia. General anesthesia involves full airway control and the option for neuromuscular blockade; in this state, patients are unconscious, unarousable, and paralyzed. Conscious sedation results in a depressed level of consciousness but allows the patient to protect their own airway, and in certain settings, respond to commands. Local anesthesia is done at the arterial access site and has no effect on the patient's level of consciousness. There are a number of presumed advantages and disadvantages to each strategy when it comes to acute ischemic stroke (**Table 2**) [35].

One of the proposed advantages of general anesthesia is the ability to achieve full paralysis. In theory, this would be expected to increase the chances of successful recanalization and reduce the risk of distal embolization and vessel injury. Additionally, the added airway protection would be beneficial in cases where the patient begins to deteriorate. Possible disadvantages include the significant hemodynamic changes that occur with intubation and induction, and the added time and personnel required to accomplish general anesthesia.

Compared to general anesthesia, conscious sedation is theoretically more cost-effective, as less medication is required, and critical care time can be minimized by avoiding intubation. More importantly, this strategy offers the ability to perform neurologic assessments intraoperatively. The main disadvantage is the potential for airway compromise, and especially in stroke patients, an elevated risk for aspiration.

	General anesthesia	Conscious sedation	Local anesthesia
Advantages	Use of paralytic = little to no patient movement Avoid potential urgent/emergent intubation Airway protection Pain control	Enables intraprocedural neurologic assessment Lower cost (less staffing, equipment, and monitoring) Decreased critical care time	Enables intraprocedural neurologic assessment Lower cost (less staffing, equipment, and monitoring) Decreased critical care time
Disadvantages	Hemodynamic changes w/ induction and intubation Potential for delayed time to recanalization Additional staff required (nursing, anesthetics, ICU)	Lack of airway protection, increased risk of aspiration	Lack of airway protection Aspiration is possible, but mental status is less impacted compared to conscious sedation

Table 2.
Proposed advantages and disadvantages of anesthetic strategies in acute ischemic stroke [35].

The advantages and disadvantages of conscious sedation mirror those of local anesthesia. The main difference is that local anesthesia should pose a lower risk of aspiration since it does not alter the patient's level of consciousness. While these are some of the proposed theories used to argue which strategy is optimal, the answer continues to remain unclear.

A number of large observational retrospective studies have been conducted over the past decade to assess the differences in clinical outcomes between these anesthetic strategies in acute ischemic stroke. Initial nonrandomized studies were in favor of conscious sedation and local anesthesia, suggesting increased adverse outcomes associated with general anesthesia. In more recent years, the data has continued to reveal mixed results. A major multicenter retrospective study in 2021 showed improved functional outcomes and reduced complications and mortality with conscious sedation compared with general anesthesia [33]. Other studies conducted around the same time period showed no difference in outcomes or mortality between these strategies [34]. When comparing local anesthesia to CS and GA, some studies report improved functional outcomes, while others reveal worsened outcomes or no difference at all [36].

To date, five single-center randomized clinical trials have been published comparing the use of general anesthesia to conscious sedation during endovascular thrombectomy. The first was the SIESTA (Sedation versus Intubation for Endovascular Stroke Treatment) trial which found no difference between strategies in the change in NIHSS at 24 hours, but patients managed with GA were significantly more likely to achieve functional independence at 3 months [37]. The ANSTROKE (Anesthesia During Stroke Trial) found no significant difference in neurologic outcomes at 3 months [38]. The GOLIATH trial (General Or Local anesthesia in Intra Arterial Therapy) revealed final infarct volume was significantly lower in the GA, inferring the possibility of higher rates of successful recanalization with GA. Additionally, the GA group had better functional outcomes at 3 months [39]. In Beijing, an RCT called the CANVAS (Choice of ANesthesia for EndoVAScular Treatment of Acute Ischemic Stroke) trial was conducted and found functional outcomes at 3 months were similar between groups and the difference in mortality (GA 5%, CS 30%) was insignificant.

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Most recently, Ren et al. found no significant difference in functional outcomes or mortality at discharge or 3 months post-stroke in AIS patients [40]. Secondary outcome analysis revealed significantly more stable hemodynamics and a lower incidence of pneumonia in the CS group.

Thus far, no RCTs exist that include local anesthesia as a comparator arm and meta-analyses of observational studies have failed to show differences in functional outcomes with LA compared to CS and GA. Some of these studies show evidence of shorter door-to-needle time in patients and less intraprocedural hypotension, which are important considerations for functional outcomes [41].

By and large, the optimal anesthetic approach for patients undergoing EVT in acute ischemic stroke therapy remains unclear. Large, multicenter RCTs are warranted comparing LA, CS, and GS with strict blood pressure targets and use of the standardized anesthetic agents to minimize confounding variables. Due to the lack of consensus and the existence of widely contradictory evidence, interventionalists should be advised to choose their anesthetic approach based on their professional experience pending the publication of more conclusive evidence [41]. Regardless of the approach, keeping open communication between the interventionalist and the anesthesiologist is key. Coordinating patient plans and ensuring timely and efficient line placement requires that channels of communication remain open.

3.5.3 Potential complications of EVT

With the success of EVT and its integration into the standard of care for AIS, there are still a number of potential complications that exist intra- and postoperatively. Awareness of these complications is crucial for quick recognition and management when one arises and additionally allows for preventative measures to be taken. Hemorrhagic complications including symptomatic intracranial hemorrhage (sICH), subarachnoid hemorrhage (SAH), and vessel perforation are some of the more serious problems that can occur [34]. sICH is typically a result of hemorrhagic transformation within infarcted brain parenchyma while SAH can be a direct result of traction created by the device used for clot retrieval. Arterial perforation is a rare, but grave complication, leading to poor functional outcomes in up to 75% of cases and a mortality rate greater than 50% [34]. Reported in less than 5% of patients undergoing EVT in large, randomized trials, most perforations occur when crossing the occlusion site or with deployment or retrieval of the stent retriever device. Coiling, balloon devices, or more invasive neurosurgical techniques can be used, but the main supportive measure that can be taken from a Neuroanesthesia standpoint is the temporary reduction of blood pressure until the bleeding is controlled [34].

Another possible complication of EVT is vasospasm. Vasospasm can be induced as a result of mechanical irritation of the vessel wall during catheter or guidewire manipulation [34]. Due to impacts on cerebral blood flow, vasospasm can result in unrecognized residual thrombus and vessel wall irregularities after thrombectomy. These are predictors of early reocclusion and associated with unfavorable outcomes [34]. If recognized intraoperatively, a calcium blocker such as nimodipine can be administered (0.5–1 mg/500 mL infusion), either as a bolus or continuously through the flushing line of the guiding catheter. It is important to note that the administration of nimodipine can result in systemic hypotension, which should be avoided in AIS patients during EVT. Close monitoring of the blood pressure and correction to systolic pressures between 140 and 180 mmHg should be prioritized.

The last major potential complication is embolization, either distal to the initial infarct or to new vascular territories [34]. This typically occurs iatrogenically, with the fragmentation of the original clot during retrieval. Incidence is reported to be around 5%. If new clinical deficits would be reasonably expected as a result, management is with further EVT of the new lesion. The potential of the clinical benefit must outweigh the risk of prolonging the procedure. If EVT is not possible or contraindicated, intra-arterial thrombolysis could be considered.

4. Updates to neuroanesthesia: spinal procedures

Spinal Neurosurgery makes up the majority of the procedures performed by most neurosurgeons. Improving technologies have allowed for more precise surgeries with improving patient outcomes. CT navigation, for example, has become a broadly used technology to allow for more precise placement of screws during spinal fusion surgery. Placement of spinal pedicle screws is done in a broad range of procedures and previously surgeons had to insert these screws using only C-arm fluoroscopy assistance. However, due to the close proximity to the dura, spinal cord, nerve roots, and blood vessels, screw misplacement can cause a multitude of complications that remain relatively common [42]. CT navigated tools, however, use CT scans of the patient's spine to build a three-dimensional map of vertebrae and can display the trajectory of a screw in 3-D space [42]. This method has been shown to be accurate and has low rates of screw misplacement. Other methods to increase screw placement accuracy have also included robot-assisted procedures and even augmented reality-guided screw placement.

While deep brain stimulators for various neurologic disorders including Parkinson's disease, essential tremor, and dystonias, have been used for some time, spinal stimulators have also recently become an option available for patients with a myriad of spinal diseases including sciatica, neuropathy, radiculopathy, complex regional pain syndrome, phantom limb pain, and even complications of multiple sclerosis [43]. The stimulator's electrodes are placed epidurally and, by inducing electrical stimulation of the spinal cord, actually modulate the neural activity being relayed to the brain, masking pain transmission [43]. Patients first undergo a trial period for about a week where a temporary stimulator device is inserted in the outpatient office to see how well the stimulator reduces the patient's pain. If the patient reports a greater than 50% reduction in pain, permanent stimulator placement is indicated. For permanent stimulator implantation, patients must undergo surgery wherein the stimulator and battery are placed under the skin of the upper buttock and using fluoroscopic guidance, each electrode is inserted into the epidural space. Typically, this is performed with conscious sedation with titrated propofol or dexmedetomidine and local anesthesia at sites of incision, but general anesthesia may also be appropriate for some patients.

Minimally invasive spine surgery is also rapidly advancing. Microdiscectomy for example is an option for those with herniated intervertebral discs which require surgical intervention. Previously, discectomies required large incisions with major disruptions of the paraspinal muscles in order to access the spinal canal and included removal of the entire disc. With microdiscectomy, smaller incisions are used to gain a window into the spinal canal and then remove only the portions of the disc that are herniated and causing nerve compression [44]. Multiple methods have been developed to accomplish microdiscectomy including midline discectomy, tubular microdiscectomy, and even endoscopic microdiscectomy. With endoscopic approaches, a small endoscope is advanced through a very small incision into the spinal canal and along with CT-guidance techniques, the endoscope is used to direct the operation with minimal disruption of paraspinal muscles, minimal dural dissection, minimal facet dissection, and minimal blood loss [44]. Such minimally invasive procedures also mean discectomy no longer necessitates general anesthesia. Rather, local anesthesia and conscious sedation is now an option for these procedures. Minimally invasive and endoscopic spine surgery is associated with shorter hospitalizations, faster recovery, and less postoperative pain during recovery [44].

5. Enhanced recovery after surgery protocols in neurosurgery

A relatively new concept in anesthesiology, Enhanced Recovery After Surgery (ERAS) Protocols first emerged in the 1990s for colonic and rectal resections [45]. Some of the earliest studies of ERAS protocols for craniotomy and spinal fusion would come out in the early 2000s and slowly evidence has been built for the dramatic outcomes that ERAS protocols can provide [46]. As consensus is reached on the benefits of ERAS protocols, it is key that anesthesia and neurosurgical departments everywhere begin adopting practices that are well-established in the literature. ERAS protocol development for cranial neurosurgery has lagged behind spinal neurosurgery significantly. While there are few published full ERAS protocols for craniotomy, many studies have been published in the last decade with similar core elements with significant improvement in patient satisfaction and clinical outcomes. ERAS protocols for spinal neurosurgery have been well established and have excellent data supporting the utilization of key practices in the perioperative period to optimize patient satisfaction and clinical outcomes. **Table 3** summarizes some key evidenced based practices which are supported across studies for both cranial and spinal neurosurgery.

Some notable elements specific to craniotomy include the utilization of local anesthetics to perform scalp blocks and minimization of the surgeon's manipulation of brain tissue. A 2019 randomized control trial by Yang et al. of patients undergoing

Pre-operative interventions	Intraoperative interventions	Postoperative interventions
Identification of the right patients for fast-track and minimally invasive surgery Patient education about the perioperative experience, what symptoms and side effects to expect Preoperative carbohydrate loading and nutritional assessment Smoking and alcohol abstinence Mechanical thromboembolism prophylaxis In patients with a seizure history, seizure prophylaxis	Regional or scalp blocks Hypothermia avoidance Minimization of patient or time Avoidance of tissue drains Use of absorbable sutures Minimization of brain tissue manipulation Antibiotic prophylaxis (Cefazolin 1 hour before incision) Post-operative nausea and vomiting assessment and management	Avoidance of ICU admission Early extubation prior to PACU Early mobilization Early fluid de-escalation Resume solid food intake early Early removal of urinary catheters Early removal of arterial lines Post-operative nausea and vomiting assessment and management Post-operative brain imaging within the first 24 hours to rule out bleeding and edema Standardized discharge instructions

Table 3.
Summary of some major ERAS practices for craniotomy and spinal surgery that are supported in the literature.

craniotomy for aneurysm repair compared effects of scalp block with injection of ropivacaine versus standard IV analgesia [47]. They found reductions in postoperative scalp inflammation, blood loss during scalp incision, and better control of postoperative pain as compared to a control group [45]. Minimally invasive techniques for neurosurgical diseases are few and far between, but some patients can be treated through keyhole incisions for some cysts and tumors. A retrospective study of patients elected for minimally invasive surgery found that, unlike typical craniotomy, the vast majority of the complications occurred within hours of the procedure, not days [48]. They suggested that rapid discharge within a day of minimally invasive procedures with minimal manipulation of the brain tissue is appropriate due to the low risk of postoperative complications [49].

Additionally, the use of seizure prophylaxis in neurosurgical patients is somewhat controversial, with some critics citing the low doses of anti-seizure medications often used for prophylaxis as not enough to significantly reduce the seizure threshold. Recent systematic reviews of studies exploring the use of antiepileptic drugs to prevent craniotomy-associated seizures have all found minimal evidence to support this practice and agree that a large, randomized trial would be needed to better establish evidence-based guidelines for seizure prophylaxis [49].

Open spinal fusion and removal of spinal tumors are typically perceived by patients as large open procedures with a long recovery and rehabilitation timelines. ERAS protocols, however, have reduced the psychologic, physical, and economic impacts of such life-changing procedures. A consensus statement in ERAS protocols for open spinal surgery was recently published in 2021 by the ERAS Society which outlines the evidence for each practice and their recommendations for perioperative medicine [50]. Taken together, an amalgam of these practices can be applied on an institution-by-institution basis.

More spine-specific interventions could include the use of liposomal bupivacaine or other regional blocks specifically for the treatment of postoperative pain in spinal surgery. Liposomal bupivacaine is included as a strong recommendation by the ERAS Society, but it should be noted that the data supporting its use is relatively weak. A number of studies have attempted to show its effectiveness on postoperative opioid utilization, reduction of adverse reactions, and infection rates [51, 52]. Consistently, these studies have failed to show significant evidence that its use reduces any of these outcomes. As such, further studies into other methods of local analgesia should be performed. Institutions should examine the most up-to-date studies to decide whether to implement regional analgesia in their ERAS protocols.

6. Postoperative delirium

Delirium is defined as an acute deterioration of cerebral function that clinically presents as changes in mental status [53]. In the perioperative setting, delirium presents significant clinical and economic challenges. Patients may experience extended hospital stays and mortality rates of up to 10%, especially within the geriatric population [54]. The occurrence of perioperative delirium also yields a remarkable financial burden. One prospective cohort study analyzed perioperative data from patients undergoing major surgery at Harvard-affiliated hospitals. Their work revealed 25% of 497 eligible patients in the study experienced delirium with an average unadjusted healthcare cost of $146,358 while the cost of care for those without delirium was $94,609 [55]. The economic and clinical burdens of perioperative delirium exemplify the necessity for implementing preventative measures along with risk stratification. Here the diagnosis, risk factors, and management of perioperative delirium will be discussed while also addressing the most current methods of clinical management and risk reduction.

6.1 Epidemiology

The incidence of delirium has long been associated with the geriatric patient population. Recent literature suggests the rate of postoperative delirium among those aged 60–70 is roughly 10–20% [56]. Emergency surgery is associated with a significantly higher risk of postoperative delirium (20–45%) when compared to elective (2.5–3%) and truncal surgery (10–20%) [50]. In addition, hospital stays on average are prolonged by 2–3 days [55].

6.2 Diagnosis

The current gold standard for the diagnosis of delirium technically requires the presence of a psychiatrist to use the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5). Patients can present with an array of symptoms including alterations in their awareness, disturbances in their ability to maintain and shift attention, disorientation, difficulty with speech, misidentification of people and objects, and pathognomonically fluctuations in the severity of these cognitive symptoms over time. Diagnosis is tricky, as this presents typically in elderly patients who may have underlying cognitive impairment at baseline. In the postoperative period, emergence delirium is a common phenomenon that presents as agitation or excessive somnolence as the patient awakens from general anesthesia and is temporary and rapidly resolves as they awaken. If it persists after the patient is awakened and is taken to the PACU, diagnosis at this stage becomes key.

To effectively diagnose delirium, a patient's mental status/arousal must be determined. The Richmond Agitation Sedation Scale (RASS) and the Sedation Agitation Scale (SAS) are commonly used scoring systems [53]. However, recent work suggests that the Confusion Assessment Method (CAM) is the most effective tool for delirium evaluation without the need for a psychiatrist present at the bedside. The CAM evaluates various traits of delirium including altered mental status requiring monitoring, acute onset, fluctuations in behavior, and disorganized thinking [56]. In 2014, the CAM-S was developed as an addition to the original CAM scoring tool with the primary goal of determining delirium severity in a quantitative approach [57]. It is not a diagnostic tool but can be used in conjunction with CAM for a complete assessment. **Figure 4** shows the CAM tool that may be used in a PACU setting to assess a patient's mental status. Versions of this tool have also been developed for the ICU or to be done rapidly in a setting like PACU, such as the 3-D CAM which is a 3-minute version of the tool. Preoperative screening for neurocognitive disorders is not typical in most centers and often pre-existing cognitive disorders can be missed by the surgical and anesthesia teams. However, such practices like obtaining a baseline cognitive exam or CAM could result in the more effective diagnostic value of these tools.

6.3 Risk factors

There is a myriad of factors involved in the development of delirium. Recent literature suggests categorizing risk factors as those preceding or directly causing the onset

Feature	Severity Score		
Scoring the CAM-S: Rate each symptom of delirium listed in the CAM as absent (0), mild (1), marked (2). Acute onset or fluctuation is rated as absent (0) or present (1). Add these scores into a composite. Higher scores indicate more severe delirium.			
	Not Present	**Present (mild)**	**Present (marked)**
1. ACUTE ONSET & FLUCTUATING COURSE	0	1	
2. INATTENTION	0	1	2
3. DISORGANIZED THINKING	0	1	2
4. ALTERED LEVEL OFCONSCIOUSNESS	0	*vigilant/lethargic:* 1	*stupor or coma:* 2
5. DISORIENTATION	0	1	2
6. MEMORY IMPAIRMENT	0	1	2
7. PERCEPTUAL DISTURBANCES	0	1	2
8. PSYCHOMOTOR AGITATION	0	1	2
9. PSYCHOMOTOR RETARDATION	0	1	2
10. ALTERED SLEEP-WAKE CYCLE	0	1	2
Short Form SEVERITY SCORE:	Add the scores in rows 1-4. Range is 0-7.		
Long Form SEVERITY SCORE:	Add the scores in rows 1-10. Range is 0-19.		

Figure 4.
Confusion assessment method [58].

of delirium. Older age, male sex, low pre-operative hematocrit, diabetes, preexisting cognitive impairment, and previous history of delirium are all factors that increase the risk of developing delirium [59]. Substances such as alcohol, recreational drugs, and steroids can lead to altered mental status and eventually delirium. Preventing delirium in the intraoperative setting provides a unique challenge to anesthesiologists, as patients may experience acute changes in hemodynamics due to the pharmacologic properties of volatile anesthetics and narcotics administered. Specifically, one clinical trial assessed postoperative delirium in patients receiving light versus heavy anesthesia. The depth of anesthesia was determined using the bispectral index (BIS). For reference, the BIS ranges from 0 (flatline EEG) to 100 (response to normal voice). Patients undergoing anesthesia with a BIS 35 had a 28% incidence of postoperative delirium compared to 19% of patients with a BIS of 50 [60]. This study suggests patients under deeper anesthesia tend to suffer a higher incidence of postoperative delirium. The necessity for maintaining an appropriate dose of anesthetics has been outlined by the American Society of Anesthesiology Brain Health Initiative, providing evidence-based guidelines for anesthesia providers to follow as reference. These guidelines will be succinctly described in the following section.

6.4 Management and risk reduction

Current literature suggests risk scales or scores are not well-studied or effective tools for guiding providers to appropriate management of postoperative delirium. Rather, success in treatment has been found with the mitigation of underlying precipitating risk factors. Managing postoperative pain, for instance, with epidural analgesia has been associated with a lower risk of delirium [51]. The departure from narcotic pain management in the postoperative setting may prove efficacious in preventing delirium in the future, especially with the increasing popularity of regional anesthesia implementation. Recently dexmedetomidine has revealed promising results with regard to preventing the onset of delirium postoperatively. In one 2019 study, dexmedetomidine treatment in the postoperative setting reduced levels of the inflammatory cytokine interleukin-6, improved MMSE scores, and decreased the development of delirium. It is important to mention that dexmedetomidine is not currently recommended for critically ill patients as advised by the Society of Critical Care Medicine as it has provided little benefit in this demographic [56].

Outside of dexmedetomidine use, the American Society of Anesthesiologists (ASA) Perioperative Brain Health Initiative reviewed the literature on perioperative delirium management released from 2010 to 2019. After considerable filtering, six management options were chosen as recommendations for use among anesthesiologists and their care teams. For patients at risk for developing delirium, the ASA recommends providing baseline cognitive screening, education for providers on delirium, adequate pain control, avoiding the use of antipsychotics and benzodiazepines, and screening in the perioperative setting for noticeable symptoms. In addition, non-pharmacologic methods are encouraged including patient mobilization, communication, and orientation, similar to the current methods used for preventing delirium in the inpatient setting [58].

Following pre-procedure consent, a preoperative cognitive assessment is recommended for developing an understanding of the relative risk of developing delirium for any given patient. A variety of mental status exams such as the MMSE and MoCA are recommended by literature supporting the Brain Health Initiative, specifically. Though, CAM and 3-D CAM have also been used in studies for pre-operative assessment. If patients are determined to have a moderate-high risk of developing delirium, anesthesiologists may take a different approach to perioperative management. For example, providers can consider avoiding medications such as benzodiazepines or reduce doses of narcotics used for pain control and sedation [61].

Providing informed consent to patients about delirium also provides an essential commodity—time. Following an operative procedure, some patients that develop delirium may experience cognitive changes for days, weeks, or even months. The ability of these patients to perform cognitively demanding tasks such as balancing a checkbook and paying bills may be hindered. Therefore, providing timely consent grants patients time to prepare for rehabilitation and support with their family and loved ones in the instance they develop postoperative delirium, improving their long-term clinical outcomes. Anesthesiologists are presented with a unique challenge when following this tenant of care, however. Most patients meet their anesthesiologists and are given consent on the day of their procedure [61]. It may be beneficial for anesthesia providers to meet with patients and families in the postoperative setting to assure adequate resources are in place in the setting of suspected delirium.

Provider education on delirium should include not just the physicians, but also nurse anesthetists, respiratory therapists, and nursing staff who may be caring for the patient in the OR or the PACU. They should also be prepared to recognize signs of cognitive disturbance and relay their concerns to the anesthesiologist or surgeon so that prompt assessment and management can occur.

As the patient is wheeled into the operating room and placed on the table, the anesthesiologist obtains access to a myriad of drugs. Unfortunately, many pharmacological interventions can potentiate the risk of developing delirium in the post-operative setting including benzodiazepines, first-generation antihistamines,

Medication or Class of Medication	Examples	Rationale for Avoiding
First-generation antihistamines	Diphenhydramine	Central anticholinergic effects
Phenothiazine-type antiemetics	Prochlorperazine, promethazine	Central anticholinergic effects
Antispasmodics/anticholinergics	Atropine, scopolamine	Central anticholinergic effects
Antipsychotics (first and second generation)	Haloperidol	Risk of cognitive impairment, delirium, neuroleptic malignant syndrome, tardive dyskinesia
Benzodiazepines	Midazolam, diazepam	Risk of cognitive impairment, delirium
Corticosteroids	Hydrocortisone, methylprednisolone	Risk of cognitive impairment, delirium, psychosis
H_2-receptor antagonists	Ranitidine	Risk of cognitive impairment, delirium
Metoclopramide		Extrapyramidal effects
Meperidine		Neurotoxic effects
Skeletal muscle relaxants	Cyclobenzaprine	Anticholinergic effects

Abbreviation: H_2, histamine 2 receptor.

Figure 5.
Medications that increase the risk of postoperative delirium [61].

corticosteroids, and several others illustrated in **Figure 5** [61]. Avoiding these medications can help to reduce the risk of postoperative delirium. It is also recommended to utilize age-adjusted minimum alveolar concentration (MAC) fractions when providing anesthetic management to geriatric patients. For reference, the MAC is the volume of inhaled anesthetic required to prevent motor response in 50% of patients undergoing surgical stimuli. The MAC tends to decrease in patients with age as much as 6% per decade following the age of 30. It is also essential to recall the most commonly used volatile anesthetics have particularly narrow therapeutic indexes [61]. These factors exemplify the necessity for careful maintenance of anesthetic agents during the management of geriatric patients due to the high risk of overdose and potential postoperative delirium.

Finally, screening during the recovery period by members of the team should be implemented as a routine part of the post-operative process. Assessing pain levels, assessing orientation, and reorienting the patient, if need be, and mobilizing the patient early should all be a part of the recovery protocol for high-risk patients to both monitor and prevent postoperative delirium from occurring. Re-orienting the patient regularly is a key treatment in the inpatient setting and could be implemented as a regular part of PACU care for elderly patients.

7. Discussion

As neurosurgery advances, so does the practice of the anesthesiologists who work alongside them. To best serve neurosurgical patients, anesthesiologists must stay abreast of the options available to their patients. Additionally, anesthesiologists often may be the only physician to see the patient before their procedure on the day of surgery, and being able to answer their questions about the procedure and what their experience will be like in the OR is key. Therefore, updates in surgical techniques and the technologies utilized in the OR are important to understand. The advances discussed thus far are reshaping neurosurgery toward an ever more precise and ever-safer process for patients. On the horizon are newer tools for the anesthesiologist and new procedures that may even expand the gamut of diagnoses treated by the neurosurgeon. Here are reviewed some of those tools and procedures which the anesthesiologist should watch for in the literature.

There has been a resurgence of the study of surgery in the treatment of psychiatric disorders. Deep brain stimulation has become a widely used method of treating tremors from Parkinson's disease and essential tremors which are refractory to medical therapy. While not yet common practice, research into the expansion of the use of

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deep brain stimulators and neuromodulators to treat medication-refractory depression, anxiety, schizophrenia, and obsessive-compulsive disorder is showing great promise [62]. Deep brain stimulation (DBS) utilizes electrodes that when implanted in regions of the brain can stimulate those regions and functionally and reversibly ablate them [62]. Advances in functional neuroimaging such as functional MRI and PET have helped identify dysfunctional brain regions common among those with similar diagnoses and given evidentiary basis for ablative neurosurgery to treat these disorders. Examples of major brain targets supported across studies include the genu of the corpus callosum in major depressive disorder and schizophrenia and the medial cingulate cortex [62].

Currently, clinical trials are ongoing surrounding the use of neuromodulation for each of these disorders with preliminary results being largely promising. Treatment of some disorders is still very early and is not yet beyond the case report level of evidence. Case reports have reported a small number of patients with opioid use disorder who have not had relapses after DBS implants into the nucleus accumbens [63]. However, much more extensive work must be published before this becomes a realistic option for substance use disorders. For the anesthesiologist, relying on the knowledge and experience gained since DBS has been done for other disorders t0 ensure patients remain safe and comfortable while undergoing these new treatments. Such procedures are performed under either monitored anesthesia care or under general anesthesia or at some intuitions deep brain electrodes are placed under MAC and pulse generators are implanted under general anesthesia [64]. Similar protocols would be applied to these treatment options. However, since they are so new, anesthesia protocols specific for the placement of these stimulators have yet to be developed and published. However, as studies are published and this topic is explored further, the anesthesiologist should stay abreast of the advances and be ready to alter practice as we learn more about these procedures and how to best serve these patients.

Advances in therapy for spinal injury may also begin the change the way neurosurgeons and intensivists address traumatic spinal injury and how anesthesiologists care for such patients intraoperatively. Acutely, hypothermia induced either by cold IV saline or local cooling during spinal decompression has been shown to improve functional outcomes in animal models in preliminary studies in the late 60s but little traction was gained in the clinical world after these studies were published. However, following the successful treatment of NFL player Kevin Everett with cooling therapy in the field after a devastating C4 spinal cord injury leaving him paralyzed from the neck down, the clinical literature has begun to examine the possibility of utilizing systemic cooling or localized cooling intraoperatively to improve patient outcomes [65]. While the majority of the research currently is pre-clinical, some small cohort studies have also been published on the topic and so far, the data has largely been supportive of some degree of clinically significant improvement [65]. However randomized clinical trials with large sample sizes are still required before this becomes a regular part of clinical practice.

Finally, emerging tools in monitoring may also lead to new methods for monitoring cerebral blood flow both in the operating room and the intensive care unit utilizing Near-Infrared Spectroscopy (NIRS). NIRS uses changes in photon phases as they pass through tissues and reflect moving blood cells to construct temporal measurements of the amount of red blood cell movement through vasculature [66]. This method can actually detect changes far below the skin surface and could allow for non-invasive bedside monitoring of cerebral blood flow intraoperatively or in the ICU [66]. Interestingly, early studies also have used this method for measuring intracranial pressure and hemoglobin concentrations in non-human subjects [66]. Early studies have supported proof of concept for using these monitors for noninvasive ICP and CBF monitoring but clinical studies have yet to be undertaken to support the clinical efficacy of this method in practice. However, if implemented, neurointensive monitoring of cerebral blood flow and intracranial pressure would become far easier and allow for quicker clinical decision-making in patients with rising ICP or experiencing cerebral ischemia.

8. Conclusions

The anesthesiologist is faced with many challenges in caring for patients undergoing brain or spinal surgery. Facing these challenges with the most up-to-date evidence is critical for excellent clinical practice. Newly developed ERAS protocols and image-guided, minimally invasive cranial and spinal procedures have minimized postoperative pain and shortened hospital stays. New flow diversion stent technology for the endovascular treatment of cerebral aneurysms is improving our control of unruptured aneurysms and in the future may impact our treatment of ruptured cerebral aneurysms as well. The use of spinal stimulators is expanding to include relief of radicular and neuropathic pain.

Many uncertainties still abound in neuroanesthesia, despite the recent advances in the literature. At these unsure junctures, shared decision-making with the patient and the rest of the care team becomes key. In the future, much work will need to be done to delineate which anesthetic techniques most benefit patients for procedures like awake craniotomy and embolectomy. We also expect future work to shine more light on the management of perioperative delirium and the steps that can be taken to prevent it. On the horizon are new treatments for psychiatric disorders, acute treatment of spinal trauma, and noninvasive methods of cerebral blood flow monitoring are on the horizon. Such tools will expand the purview of the neurosurgeon and neuroanesthesiologist into the treatment of psychiatric disorders and will offer new tools to better treat the patients they typically serve in the OR and beyond.

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