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Catastrophic Perioperative Complications and Management

A Comprehensive Textbook

Springer

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ISBN 978-3-319-96124-8 ISBN 978-3-319-96125-5 (eBook)
https://doi.org/10.1007/978-3-319-96125-5

Library of Congress Control Number: 2019930728

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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Sleep Apnea

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_1

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Sleep apnea is a sleep disorder characterized by respiratory pauses or periods of hypopnea (shallow breathing) during sleep. An episode of hypopnea is not considered to be clinically significant unless there is a 30% (or greater) reduction in flow lasting for 10 s or longer and accompanied by a 4% (or greater) desaturation in the person's O_2 levels or if it results in arousal or fragmentation of sleep.

Each respiratory pause can last for a few seconds to a few minutes, and they happen many times a night [1]. In the most common form, this follows loud snoring [2]. There may also be a choking or snorting sound as breathing resumes. As it disrupts normal sleep, those affected may experience sleepiness or feel tired during the day [3]. In children, obstructive sleep apnea (OSA) may cause problems in school or hyperactivity [4].

When considering obstructive sleep apnea, there should first be a clarification of the difference between the terms "sleep apnea" and "apnea." While the term "apnea" refers to the suspension of breathing or absence of spontaneous breathing, and may be performed voluntarily in the awake patient, "sleep apnea" is not associated with a conscious voluntary choice. Certainly, similarities exist, as usually there is often no change or minimal change in the gas volume contained in the lungs in either situation. While movement of the muscles associated with inhalation is usually voluntarily ceased during intentional apnea, during sleep apnea there are frequently continued attempts to breathe, with the associated contraction of these muscles of respiration. During these continued attempts though, no overt gas exchange occurs due to airway obstruction. In sleep apnea, the episodes of apnea may last for 10 s or longer, and there may be as many as 300–500 episodes each night. Sleep apneas can be caused by obstruction of the upper airways, especially the pharynx, or by impaired central nervous system respiratory drive [5]. Depending on the patency of the airways, there may or may not be a flow of gas between the lungs and the environment. Concurrently though, gas exchange within the lungs and cellular respiration is not affected, at least not in the early stages of the episode.

Sleep apnea is probably a more common problem in patients presenting for surgery than is realized. It is estimated that 9% of middle-aged women and 24% of middle-aged men have sleep apnea [6]. It is an established risk factor associated with hypertension. When considering a group of hypertensive patients from the general population, and not just to those presenting for surgery, 3–4% of the women and 7–9% of the men are expected to be diagnosed with moderate-to-severe obstructive sleep apnea. Some estimates state that obstructive sleep apnea has been identified in up to 24% of adult surgical patients and note that obesity is a major risk factor, with up to 71% of morbidly obese suffering from obstructive sleep apnea [7]. Factors that increase vulnerability for the disorder include age, male sex, obesity, family history, menopause, craniofacial abnormalities, and certain health behaviors such as cigarette smoking and alcohol use. The prevalence of snoring and sleep apnea increases with age, with a peak between the ages of 55 and 60 years old; women start to snore later in life than do men, with an increased prevalence following menopause [6].

Often, sleep apnea is undiagnosed, even though chronically present. The only "symptom" patients may even notice is tiredness during the day, morning headaches, difficulty concentrating, and feeling irritable, depressed, or having mood swings or personality changes [4]. This "tiredness" is frequently due to continual disruptions of the normal sleep pattern during the night, as an apneic episode causes transient arousal from the deeper stages of natural sleep. As the breathing patterns become shallow, or even transiently interrupted, a person will often partially arouse from a deep stage of sleep to a lighter stage, until normal breathing resumes. At that point, the patient may again return to a deeper stage of sleep, only to have the process repeat again a short while later. Because this person does not spontaneously arouse to the stage of actual wakefulness, this pattern may not be recognized, and may go on for a prolonged period, with the only noticeable symptom being that of "tiredness" during the day. Beyond just the sensation of tiredness, excessive daytime sleepiness may occur; this may interfere with job responsibilities, making it difficult to pay continual sharp attention to critical tasks such as operating machinery or driving a car [8].

Although obstructive sleep apnea is more common in patients who are overweight, this condition is not restricted to obese or morbidly obese patients. Nighttime snoring suggests at least a partial airway obstruction during sleep. Even small children with enlarged tonsil tissue in the throat may experience obstructive sleep apnea. Any condition that causes partial airway

obstruction, whether from hypertrophied tissue from an infection or just from excessive tissue presence in the pharyngeal and hypopharyngeal area due to any hereditary or acquired condition, can result in obstructive sleep apnea. Sleep apnea does not even have to arise from hypertrophy of tissue in the airway. Central sleep apnea, felt to be due to modification in the way signals to breathe are processed in the brain, may occur along with obstructive airway conditions or have no association with any other airway condition. Sleep apnea can raise a patient's risk for high blood pressure, coronary heart disease with resulting heart attack or heart failure, cardiac arrhythmias, stroke, obesity, diabetes, and death [9].

Three forms of sleep apnea are described: obstructive (OSA), central (CSA), and a combination of the two called mixed. OSA is the most common form [2]. Risk factors for OSA include being overweight, a family history of the condition, allergies, a small airway, and enlarged tonsils [6]. During obstructive sleep apnea, breathing is interrupted by a blockage of airflow, while in central sleep apnea, breathing stops due to a lack of effort to breathe [2]. Opioid administration during surgery or in the perioperative period certainly increases the risk of the latter, especially during the immediate postoperative period in the postanesthesia care unit.

People with sleep apnea may not be aware they have it; in many cases it is first observed by a family member [2]. Sleep apnea is often diagnosed with an overnight sleep study [10]. For a diagnosis of sleep apnea, more than five episodes an hour must occur [11].

Treatment may include lifestyle changes, mouthpieces, breathing devices, and surgery [2]. Lifestyle changes may include avoiding alcohol, losing weight, smoking cessation, and sleeping on one's side. Breathing devices include the use of a CPAP machine to deliver Continuous Positive Airway Pressure.

With no considerations of gender differences, obstructive sleep apnea affects 1–6% of adults and 2% of children [5, 12]. It affects males about twice as often as females [5]. While people at any age can be affected, it occurs most commonly among those 55–60 years old [2, 5]. Central sleep apnea affects less than 1% of people [13]. Without treatment sleep apnea may increase the risk of heart attack, stroke, diabetes, heart failure, irregular heartbeat, obesity, and motor vehicle collisions [2].

A type of central sleep apnea was described in "Ondine," the 1938 play by French dramatist, Jean Giraudoux, based on the story of "Undine" from 1811 by the German romanticist Friedrich de la Motte Fouque (and actually traces back to even earlier European folk tales). This play presented the nymph, Ondine, who tells her future husband Ritter Hans, whom she had just met, that "I shall be the shoes of your feet ... I shall be the breath of your lungs." However, after their honeymoon, Hans is reunited with his first love, Princess Bertha, and Ondine leaves Hans. Ondine's father, the King of the Sea, inflicted a curse on Hans, her unfaithful husband, so that he would have to consciously remember to breathe. Due to this, he was unable to sleep [11]. On meeting Ondine again, on the day of his wedding to Bertha, Hans tells her that "all the things my body once did by itself, it does now only by special order ... a single moment of inattention and I forget to breathe." Apparently, Ondine truly took his breath away, for following her kiss, Hans apparently forgets to take his next breath and dies.

Central hypoventilation syndrome (*CHS*) is a respiratory disorder that may result in respiratory arrest during sleep. Congenital central hypoventilation syndrome (CCHS) and sudden infant death syndrome (SIDS) were long considered rare disorders of respiratory control. The study of genes related to autonomic dysregulation and the embryologic origin of the neural crest led to the discovery of *PHOX2B* as the disease-defining gene for CCHS [13].

Central hypoventilation syndrome can either be congenital or acquired later in life and is fatal if untreated. Symptoms of congenital hypoventilation syndrome usually become apparent shortly after birth [11]. Acquired central hypoventilation syndrome can develop as a result of severe injury or trauma to the brain or brainstem [12]. Congenital cases are very rare and involve a failure of autonomic control of breathing. In 2006, there were only about 200 known cases worldwide, and with further investigations, by 2008, only 1000 total cases were known [11]. Although rare, cases of long-term untreated central hypoventilation syndrome have been reported. It is also known as Ondine's curse.

During sleep, the drive to maintain a patent upper airway is diminished. When this is combined with the susceptibility to collapse, the result is obstruction. There is a decrease in the

responsiveness of the body to maintain wakefulness ventilation, a decrease in diameter of the upper airway causing increased resistance, as well as an increase in the compliance of the pharynx promoting collapse. In anesthesiology, this results in perioperative considerations and complications that may be partially avoided or improved with an understanding of the pathophysiology and risks involved with obstructive sleep apnea.

Sleep-related changes range from healthy individuals who experience a small increase in $PaCO_2$, to those who develop motion of the soft tissue with inspiration leading to turbulent airflow which causes snoring, to complete collapse or obstructive sleep apnea. In anesthesiology, all patients on this spectrum are seen, and it is necessary to manage sleep apnea not only perioperatively but also intraoperatively, particularly in MAC sedation cases where the airway is not protected.

The muscle activity in the upper airway is reduced while asleep. This has little effect on people who are in good health, but in those who are susceptible, this results in narrowing of the upper airway. The tensor palatini muscle relaxes, which results in a tendency toward obstruction of the upper airways and causes a decrease in inspiratory flow upon sleep onset.

Upper airway narrowing results in increased resistance as well as compliance, leaving the airway prone to collapse. This narrowing causes airflow to become turbulent and results in a limitation to the flow. The turbulent flow results in resonant motion of the tissue in the soft palate and soft tissue in the upper airway. This combination of movement of the soft tissue with turbulent flow and limitation to airflow results in what is universally recognized as snoring. Even in healthy patients, noisy breathing can be heard during sleep or sedation secondary to the turbulent airflow.

In patients who do not snore, airflow is not limited, just as it is not limited in the wakeful state. In those who do snore and have airflow limitations, there is a much higher risk of airway collapse. Complete closure may occur in patients with extreme airway narrowing during sleep, which leads to obstructive sleep apnea.

The patency of the upper airway is maintained by the structural foundation of the airway as well as its neuromuscular support. The structure of the upper airway is determined by craniofacial structure, soft tissue, vascular structures, and mucosal factors. Neuromuscular support is derived from motor tone for ventilation and muscle activity in the upper airway itself. Structurally, the upper airway is enclosed not only by the soft tissues but also by the mandible, maxilla, skull base, and cervical spine. Anatomic changes to this craniofacial structure can result in narrowing of the upper airway, leaving one more susceptible to obstruction during sleep. Examples of such a change would include retrognathia or inferior displacement of the hyoid. The soft tissues surrounding the upper airway include skin, adipose, vascular, and lymphatic tissue. An increase in amount of these tissues or increased pressure on the upper airway will subsequently result in narrowing. An increase in pressure exerted by the tissues promotes upper airway collapse and can be secondary to large tongue, size of the pharyngeal walls, adipose tissue, large tonsils, vascular congestion, etc.

In patients with unfavorable anatomy prone to collapse, hypoxia and hypercapnia may cause vascular volume to increase thereby further increasing the soft tissue pressures exerted on the upper airway lumen. This increase in vascular volume may also be caused by other comorbidities such as congestive heart failure, hypertension, and renal disease, for which lying flat may cause a rostral shift in volume. This rostral shift in volume may be seen in various positions required for surgery, including supine and prone position.

In the upper airway, the tensor palatini muscle is responsible for tensing the pharyngeal wall thereby decreasing the degree to which the pharyngeal opening can be compressed. During sleep, this muscle relaxes causing the upper airway to become more susceptible to collapse, and in certain individuals can result in transmural pressures on the pharynx by the soft tissues overcoming the intraluminal pressures which maintain patency of the upper airway. The genioglossus muscle is responsible for dilating the pharynx in preparation for inspiration. Relaxation of this muscle during sleep can result in narrowing of the pharynx and thereby increasing inspiratory resistance.

During sleep, there is also a decrease in the tonic activity of the upper airway muscles that reflexively increase during wakefulness in response to a negative pressure in the upper airway during inspiration. During REM sleep atonia of all muscles involved in pharyngeal patency

and respiration occurs, with the exception of the diaphragm. This can accentuate hypoventilation and hypoxia. Following the induction of general anesthesia, apnea tends to occur more quickly in patients with susceptible airways. Obstructive sleep apnea (OSA) can lead to desaturations more quickly than anticipated, and difficulty reopening the airway with positive pressure may be experienced. Devices and techniques are used fairly often to assist ventilation. Examples of these include oral airways or nasopharyngeal airways (also known as nasal trumpets) which combat the relaxed musculature and excess tissue. Assisted positive pressure ventilation prior to apnea helps stent the airway open and usually prevents complete collapse (similar to the CPAP machine).

To maintain alveolar ventilation when there is an increase in airway resistance, the patient must increase work of respiration. During sleep the body may not recognize this change in resistance readily, and effort of breathing does not increase to compensate. This results in decreased alveolar ventilation and rise in $PaCO_2$. In those without OSA, this increase in $PaCO_2$ would restore their ventilatory drive; however, in those with OSA, it may not, resulting in worsening hypercapnia.

During non-rapid eye movement sleep, intercostal and abdominal muscles (accessory muscles) play a larger role in maintaining tidal volume than during wakefulness. During rapid eye movement sleep, a loss of accessory muscle activity occurs. Therefore, an even greater decrease in ventilation accompanies REM sleep. The natural increase in $PaCO_2$ associated with decrease in ventilation during sleep is termed physiologic hypercapnia, as it is seen even in healthy individuals. The $PaCO_2$ is noted to increase by 4–5 mmHg during sleep in all patients, including those without sleep apnea. In patients with obesity or pulmonary disease such as COPD, the changes that are seen during sleep are exaggerated and can lead to obstruction, hypoxia, and worsening ventilation-perfusion mismatch [6, 14, 15].

When considering risk factors for sleep apnea, the strongest risk factor, obesity, is usually the one that generally is felt to be the most obvious. The risk of OSA in these patients increases proportionally with body mass index (BMI) or more specifically with neck circumference. For men, risk is increased with a neck circumference greater than 17 inches and for women, risk is increased with a neck circumference greater than 15 inches. As the circumference of the neck and the adipose tissue within the pharyngeal wall increases, so do the collapsing pressures on the lumen of the upper airway.

This applies to any cause for redundant tissue in the upper airway, such as for those with large tonsils or adenoids and obesity. Other structural risks include short mandibles, an abnormal maxilla, or a wide craniofacial base. In children, in addition to large tonsils and adenoids, cerebral palsy and other neuromuscular disorders may play a role in obstructive sleep apnea. Nasal passage obstruction via structural abnormalities or congestion are also risk factors for OSA. Smoking has been shown to be a risk factor for OSA in that it potentiates pulmonary disease such as COPD, limiting one's responsiveness to sleep-related increase in $PaCO_2$ and ventilatory motor drive. It also is thought to narrow the airway by increasing inflammation and fluid in the upper airway tissues. Increasing age is a risk factor for OSA, as upper airway tissues become increasingly compliant with normal age-related changes. The male gender is twice as likely to develop OSA although overweight women remain at risk and menopause has been shown to be an independent risk factor for OSA.

Not only can obesity-related factors become a family trait, but heritable craniofacial anomalies also make family history a risk factor for obstructive sleep apnea. Congestive heart failure, end-stage renal disease, and pregnancy can all increase the risk of obstructive sleep apnea as they promote a rostral shift of vascular volume in the recumbent position. Pulmonary diseases such as COPD, asthma, and pulmonary fibrosis also increase risk of OSA secondary to decreased ventilatory motor drive and reflexive ventilation with increased PaCO2 during sleep. Acromegaly is a risk factor as the tongue is large and upper airway tissues are in abundance. Stroke, hypothyroidism, and polycystic ovarian disease are also recognized risk factors for OSA.

During anesthesia preoperative evaluations, there is a recurring need to evaluate patients for risk factors, signs, and symptoms of obstructive sleep apnea. This impacts perioperative management, particularly the pain management strategies and intraoperative induction technique and extubation criteria [14, 16].

Untreated OSA has been linked to the development of coronary artery disease, cardiac arrhythmias, hypertension [17, 18], and even heart failure [19]. Although it is impossible to pinpoint OSA as causative for each of these, it has been shown

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that with treatment of OSA, cardiovascular outcomes have improved [20, 21]. The individual with OSA experiences periods of apnea during sleep, resulting in hypoxia and hypercapnia. This individual is subsequently awakened from sleep, which restores the patency of their upper airway. As the individual returns again to sleep, this cycle repeats itself. These cycles of obstruction, apnea, and arousal from sleep have effects on all bodily systems [15, 22]. The hypoxemia and hypercapnia associated with OSA stimulate chemoreceptors which increase respiratory rate. Additionally, impaired venous return to the heart, changes in cardiac output, and arousal from sleep occur. All of these phenomena are thought to cause a great increase in sympathetic activity during sleep in patients with OSA. This autonomic dysfunction causes an increase in circulating plasma catecholamines and hypertension. Blood pressure does not decrease during sleep in these patients, as it typically does during sleep in healthy individuals. It has been shown that patients who are treated with CPAP have a lower risk of developing hypertension than those who are untreated [23].

Interestingly, it has also been shown that the hypertension associated with OSA seems to be more resistant to antihypertensive medications [24].

In patients with OSA, treatment with CPAP has actually been shown to decrease blood pressure regardless of baseline. A meta-analysis demonstrated that systolic blood pressure was reduced by 2.6 mmHg with CPAP. Although this may seem quite small, a 1–2 mmHg decrease in blood pressure has been shown to significantly reduce the risk of myocardial infarction, stroke, and heart failure. The effects are amplified when combined with an antihypertensive regimen [25].

For patients who have more profound sleep apnea, with greater depths and durations of associated hypoxemia, treatment with CPAP tends to result in more significant reductions in their elevated blood pressure. These effects on blood pressure have not only been shown with the use of CPAP but also for other treatments of OSA such as upper airway surgeries or the use of devices which advance the mandible.

OSA increases the risk of a cardiovascular event by inducing or worsening hypertension and increasing inflammatory mediators such as C-reactive protein, "adhesion molecules," inflammatory and anti-inflammatory cytokines, matrix metalloproteinase-9, and vascular endothelial growth factor. Increased levels of homocysteine and blood glucose along with insulin resistance and decreasing HDL levels have also been noted. Studies have shown elevated troponin-I levels in patients with increasingly severe OSA and hypoxemia suggesting myocardial injury. In patients with preexisting coronary artery disease, it has been shown that those with OSA are at higher risk of developing major cardiac adverse events [25–27].

OSA has been described as a modifiable risk factor for atrial fibrillation, both new onset and reoccurrence after cardioversion or ablation. This may be in part caused by OSA-related hypoxemia and hypercapnia, autonomic dysfunction, and exaggerated negative intrathoracic pressures which can be transmitted across the atria during inspiration while obstructed.

During apneic events of sleep, hypoxia can delay depolarization of the heart, causing the patient to become bradycardic. When the sympathetic system is suddenly activated after an apneic period, the patient becomes tachycardic. This bradycardic-tachycardic trend along with respiratory acidosis can cause QT prolongation and can trigger atrial and ventricular arrhythmias. The bradycardia seen during apneic periods can be so severe that asystole results, particularly if the patient has preexisting conduction defects. Sudden cardiac death can occur in some instances, and preexisting ventricular tachycardia or ectopy is a risk factor for such an event in someone with OSA.

Individuals with OSA are at risk of developing pulmonary hypertension, and the development of pulmonary hypertension adversely impacts prognosis. The survival rates in patients who have developed pulmonary hypertension are lower than those who have not. In an observational study, it was determined that the 1-, 4-, and 8-year survival rates with pulmonary hypertension were 93%, 75%, and 43%, whereas survival rates in those without pulmonary hypertension were 100%, 90%, and 76% [28]. CPAP and weight loss surgeries have been shown to reduce pulmonary artery systolic pressure and vascular resistance.

It is thought that secondary to the nocturnal stresses imparted on the body in an individual with OSA, morning coagulation markers are elevated, causing such individuals to be two to three times more likely to develop venous thrombosis [29].

In anesthesiology, care is provided for many patients with untreated OSA. Awareness of the associated cardiovascular complications may help

manage these patients more effectively. In particular, when associated with sleep apnea, awareness of minor EKG changes that may indicate ischemia, QT prolongation, or the beginning of an arrhythmia, along with DVT prophylaxis and hypertension management, potentially improves the overall intraoperative management of the patient. These relatively minor cardiovascular findings, when considered out of context, may not be considered as significant risks.

OSA is known to cause daytime sleepiness, hypersomnolence, and cognitive impairment. These symptoms may be readily identified in patients with Pickwickian syndrome. Pickwickian syndrome, also known as obesity hypoventilation syndrome (OHS), is similar in pathophysiology to OSA; however, OHS occurs during waking hours. Patients with this syndrome experience chronic hypoventilation even while awake, and approximately 90% of patients with OHS have concurrent obstructive sleep apnea [30]. Symptoms of this syndrome include daytime somnolence, headaches, depression, shortness of breath, and acrocyanosis [31]. The name, Pickwickian syndrome, came from Charles Dickens' first novel, *The Posthumous Papers of the Pickwick Club* (more commonly known as *The Pickwick Papers*) in which he described Joe, a character from the book, in ▶ Chap. 4:

» The object that presented itself to the eyes of the astonished clerk, was a boy–a wonderfully fat boy–habited as a serving lad, standing upright on the mat, with his eyes closed as if in sleep. He had never seen such a fat boy, in or out of a travelling caravan; and this, coupled with the calmness and repose of his appearance, … smote him with wonder.

Joe is constantly hungry, very red in the face, and is always falling asleep in the middle of tasks.

» "Sleep!" said the old gentleman, 'he's always asleep. Goes on errands fast asleep, and snores as he waits at table." "How very odd!" said Mr. Pickwick. "Ah! odd indeed," returned the old gentleman; "I'm proud of that boy–wouldn't part with him on any account–he's a natural curiosity!"

The risk of stroke, and therefore neurologic damage, is also increased in obstructive sleep apnea [32, 33]. There is a demonstrated association between OSA and seizure disorder. Treating coexisting OSA enhances treatment of seizures.

The fragmentation of sleep with OSA causing daytime sleepiness and cognitive impairment causes increased risk in daytime activities such as driving or using machinery. Cognitive dysfunction associated with OSA includes diminished reaction time, motor performance, speed of processing information, attention, working memory, executive function, retention of memory, visuospatial learning, and level of alertness. This cognitive dysfunction as a whole is likened to intoxication [34]. In children the cognitive dysfunction mirrors ADHD and includes inability to hold attention, hyperactivity, aggressive behaviors, and impulsivity. Interestingly, despite significant improvements in cognitive dysfunction with treatment of OSA, long-term damage has been found on neuroimaging in the hippocampal, prefrontal, cingulate, and parietal areas suggesting permanent effects of untreated OSA [31, 35]. This knowledge should remind the anesthetist to be hypervigilant with monitoring patients for seizures and for stroke in the perioperative period. It should also remind everyone caring for the patient with OSA to maintain increased awareness of cognitive dysfunction that may have impacts on perioperative functioning.

It has been described that patients with OSA experience prolonged apneic periods for up to 1 week postoperatively. This may influence the decision for the surgical setting and postoperative management, particularly in light of the need for analgesic opioids [36]. In one study, ventilatory dysfunction was noted to be most significant on the second and third postoperative nights, depicting the need for prolonged monitoring during the recovery period in patients with OSA [37]. In the ambulatory setting, even in patients who had been undiagnosed, it was found that patients who are high risk for OSA required an increased level of care in the perioperative setting. These patients were found to be more difficult to intubate, were more likely to require vasopressors intraoperatively, and were more likely to require oxygen in PACU [38].

In several studies, however, patients with OSA who underwent surgery in the ambulatory setting did not tend to require unanticipated hospital admission more frequently than their counterparts. They were also not found to have increased rate of cardiovascular or respiratory complications compared to those patients without OSA [22]. It has been demonstrated that patients with

OSA who have surgery in the hospital setting may have more serious and frequent postoperative complications including arrhythmia, myocardial infarction, respiratory distress, and prolonged ICU stays. It is thought that to reduce the risk of such complications, the patient may be treated with CPAP in the perioperative period, particularly if they are on CPAP at home. The positive effects of perioperative prophylactic CPAP have also been shown in those patients who have been undiagnosed with OSA but who are suspected to be at high risk [27]. In high-risk patients or those with known OSA, it is recommended that in PACU oxygen saturation and hemodynamics be monitored carefully for 2 h postoperatively, with the patient's head elevated 30° and with early implementation of CPAP in the instance of any desaturation.

It is well accepted that opioids should be minimized where possible, as intraoperative use of opioids tends to increase the risk of postoperative respiratory depression [39]. If patient- controlled systemic opioids are used, continuous background infusions should be used with extreme caution or avoided entirely. If the patient is to remain in-hospital postoperatively in addition to PACU monitoring, the patient should be kept on continuous supplemental oxygen administration (unless contraindicated by the surgical procedure); pulse oximetry and CPAP should be implemented, regardless if they had previously been prescribed CPAP or not [39]. In one study, nasal CPAP was implemented in patients having a wide variety of surgeries preoperatively and was continued after extubation for 24–48 h postoperatively. This study concluded that there were no postoperative complications for these patients related to the use of CPAP, and they maintained the ability to have sedatives, analgesics, and anesthetic agents administered as needed without further consideration of the patient's OSA status [40].

1.1 Identifying Patients with OSA

Given the increased perioperative risks for patients with sleep apnea undergoing general anesthesia, ASA guidelines stress the importance of perioperative diagnosis and management of these patients. The Society of Anesthesia and Sleep Medicine (SASM) recently published a guideline on preoperative screening and assessment of adult patients with obstructive sleep apnea [24, 41]. This guideline notes that a reduction in perioperative complications may result from correctly identifying patients at high risk for OSA to focus on perioperative precautions and interventions.

The majority of patients with OSA presenting for surgery are undiagnosed, and it is often impractical, due to time and cost constraints, to undergo formal polysomnography testing (the "gold standard") [42]. Screening tools, including STOP-Bang, P-SAP, Berlin, and ASA checklist, have been formulated and validated for this purpose; however, screening tools vary in accuracy across different populations and may not have the same accuracy when implemented in clinical practice. Questionnaires are used most commonly and have modest accuracy compared to clinical models using simple clinical measurements [24, 41].

The STOP-Bang questionnaire has been found to be the most validated screening tool in surgical patients, sleep clinic patients, and the general population. In a meta-analysis of clinical screening tools for OSA, the STOP-Bang was identified as being easy to use, having a favorable diagnostic odds ratio. A STOP score $\geq$2 with BMI >35 kg/m^2 or male sex is associated with greater risk of OSA [24, 41]. This threshold is a good starting point for many institutions, but may need to be altered to adjust for specific patient populations due to the inverse relationship between sensitivity and specificity in any diagnostic test.

1.1.1 Common Questionnaires

The STOP-Bang questionnaire (Table 1.1) is a patient-completed survey with yes/no questions assessing subjective symptoms and clinical signs: snoring, tiredness, observed apnea, high blood pressure, BMI (>35 kg/m^2), age (>50), neck circumference (>40 cm), and gender (male). High risk is determined by more than five affirmative answers to the questions presented.

The Perioperative Sleep Apnea Prediction (P-SAP; see Table 1.2) score validates six of the eight elements of STOP-Bang, but it also uses the presence of diabetes and the upper airway physical exam findings of Mallampati score and thyromental distance. It also uses yes/no questions. A P-SAP score >4 out of 9 is indicative of sleep apnea.

Table 1.1 STOP-Bang questionnaire

	Yes/No
*S*noring (Do you snore loudly?)	☐ ☐
*T*iredness (Do you often feel tired, fatigued, or sleepy during daytime?)	☐ ☐
*O*bserved apnea (Has anyone observed that you stop breathing or choke or gasp during your sleep?)	☐ ☐
High blood *p*ressure (Do you have or are you being treated for high blood pressure?)	☐ ☐
*B*MI (Is your body mass index >35 kg/m^2?)	☐ ☐
*A*ge (Are you older than 50 years?)	☐ ☐
*N*eck circumference (Is your neck circumference greater than 40 cm [15.75 inches]?)	☐ ☐
*G*ender (Are you male?)	☐ ☐

Score 1 point for each positive response
Scoring interpretation: 0–2 = low risk; 3–4 = intermediate risk; ≥5 = high risk

Table 1.2 P-SAP questionnaire

	Yes/No
Male gender	☐ ☐
History of snoring	☐ ☐
"Thick" neck	☐ ☐
Mallampati 3 or 4	☐ ☐
Hypertension (treated or untreated)	☐ ☐
Type II diabetes (treated or untreated)	☐ ☐
BMI ≥ 30	☐ ☐
Age ≥ 43	☐ ☐
Thyromental distance < 4 cm	☐ ☐

Score ≥ 4 is indicative of sleep apnea

The ASA checklist (▶ Box 1.1) is divided into three categories – predisposing physical characteristics, history of airway obstruction during sleep, and somnolence. Two out of three positive categories are indicative of OSA.

In addition to these questionnaires, the Berlin Questionnaire coupled with sleep testing is used to establish the diagnosis of sleep apnea. Patients with sleep apnea may present for surgery without receiving a prior diagnosis. The diagnosis of sleep apnea may be difficult to distinguish from normal

Box 1.1 ASA Checklist

Category 1: Predisposing physical characteristics
A. BMI ≥ 35
B. Neck circumference >43 cm (17 in) men and >40 cm (16 in) women
C. Craniofacial abnormalities affecting the airway
D. Anatomical nasal obstruction
E. Tonsils touching or nearly touching the midline

Category 2: History of apparent airway obstruction during sleep
A. Snoring
B. Frequent snoring
C. Observed pauses in breathing during sleep
D. Awakens from sleep with choking sensation
E. Frequent arousals from sleep

Category 3: Somnolence
A. Frequent somnolence or fatigue despite adequate "sleep."
B. Falls asleep easily in a non-stimulating environment.
C. [Parent or teacher comments that the child appears sleepy during the day.]
D. [Child is often difficult to arouse at typical waking time.]

If two or more responses in the first category are positive, then category 1 is positive.
If two or more responses in the second category are positive, then category 2 is positive.
If one or more responses in the third category are positive, then category 3 is positive.
High risk for OSA: At least two categories are positive. Low risk: zero or one category positive.
*Responses in brackets apply ONLY to pediatric patients

variations in sleep behavior [43]. The Berlin Questionnaire, developed in 1996, screens for sleep apnea based on ten questions across three categories. Each category contains between two and five questions [44].

Category 1 presents four questions which deal with snoring and also asks if there was awareness that anyone had witnessed pauses in the patient's breathing during sleep. Positive responses in this category include presence of snoring, snoring that occurs at least three times a week or more, snoring that is louder than talking, snoring that can be heard in adjacent rooms, snoring that is loud enough to bother other people, or any witnessed apnea episodes more than three times a week during sleep.

Category 2 questions the presence of tiredness or fatigue that is noticed following sleep, or the sensation of feeling tired or fatigued during normal waking hours. A response of at least three or four times per week to either question constitutes a positive response. This category then questions whether "nodding off" or falling asleep has occurred while driving a vehicle and, if so, how often this is noted to occur (if occurring more than three or four times a week, this also constitutes a positive response in this category of questions).

Category 3 questions if the individual has a diagnosis of high blood pressure and asks for the calculated body mass index. Scoring of each category of questions is done separately; a positive response to at least two questions in either the first or second category is a positive response to that section. The third section is scored as a positive response if the patient has a BMI greater than 30 or has hypertension. If two or more categories demonstrate a positive score, the patient is considered to have a high likelihood of sleep apnea. An alternate approach to scoring considers more than five positive responses from all categories to be indicative of obstructive sleep apnea. This survey has a disadvantage of being lengthy with similar sensitivity and specificity to the other three tests.

1.1.2 Anesthetic Management

Patients with sleep apnea are at increased risk of complications postoperatively including adverse respiratory events, arrhythmias, hypertension, and myocardial infarction. Patients scheduled for elective surgery who are at higher risk for OSA may be referred for preoperative polysomnography.

The diagnosis and severity of sleep apnea should be confirmed both with obtaining the patient's history and physical and reviewing sleep study results. A commonly used severity index is AHI – the number of complete breathing cessations (apnea) and partial obstructions (hypopnea) per hour of sleep. To be considered as an apnea episode, the pauses in breathing must last for at least 10 s and be associated with a decrease in blood oxygenation. The AHI score is calculated as the average number of apnea events per hour of sleep. The diagnosis of OSA is based on AHI $\geq$ 5 and either excessive daytime sleepiness or two other symptoms of OSA (choking/gasping during sleep, recurrent nighttime awakenings, unrefreshing sleep, daytime fatigue, or impaired concentration).

1.1.3 The American Academy of Sleep Medicine Defines Mild OSA as AHI 5–15, Moderate OSA as AHI 15–30, and Severe OSA as AHI >30

It may be necessary to refer some patients to sleep medicine for reassessment, especially those patients who are non-compliant with CPAP, those with recent OSA exacerbations, and those who have recently undergone OSA-related airway surgery.

1.1.4 Patients with Moderate-to-Severe OSA on CPAP Therapy Should Continue CPAP in the Preoperative Period

Preoperative considerations should include anticipation of a difficult airway, the use of short-active anesthetic agents (e.g., propofol, remifentanil, desflurane), careful management of opioid administration, verification of full reversal of neuromuscular blockade prior to extubation, and extubation in a non-supine position [45].

Current guidelines encourage anesthesiologists and surgeons to evaluate for OSA well before surgery. The evaluation should be initiated in a pre-anesthesia clinic or via direct consultation

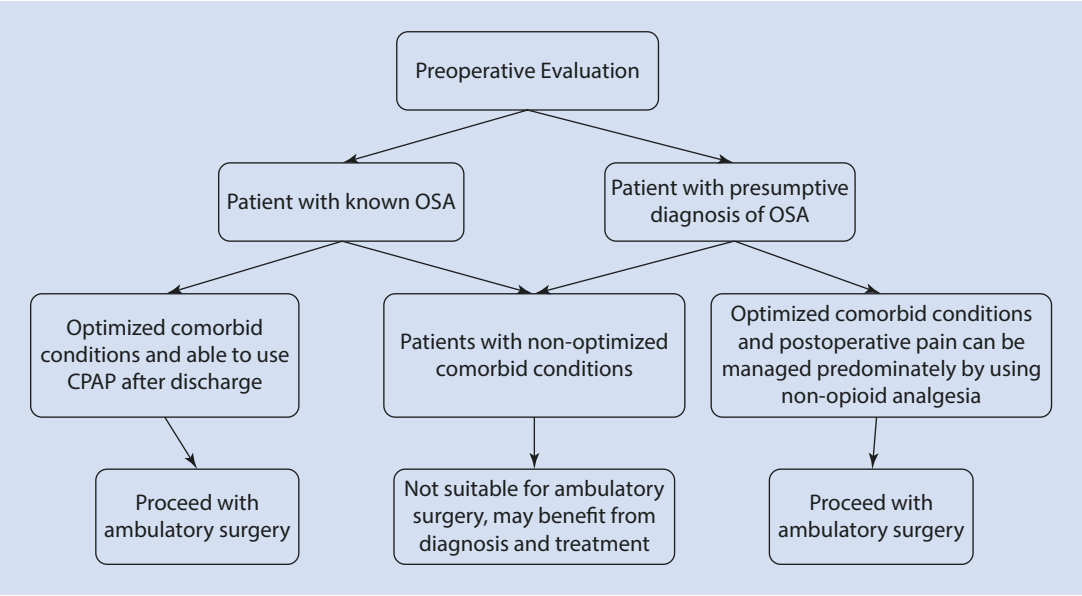

Fig. 1.1 Preoperative evaluation. (Adapted from Joshi et al. [46])

from the surgeon. A preoperative interview allows practitioners to gather a thorough patient history and physical, including data concerning the patient's sleep habits and OSA screening. This might include an appropriate survey or diagnostic measure or information from a formal sleep study. The evaluation should include all past medical history with records if available, an inquiry into past airway or anesthetic complications, documentation of the presence of hypertension and cardiovascular problems, and any other congenital or acquired medical comorbidities. Performing an OSA survey and gathering pertinent physical findings (airway classification, nasopharyngeal characteristics, neck circumference, tongue and tonsil size) are encouraged. The decision must be made between the anesthesiologist and the surgeon whether to manage the patient based on clinical criteria alone or whether to pursue further diagnostic studies and initiate specific OSA treatment prior to the procedure. Literature is insufficient as to which patients with OSA can be managed on an inpatient vs outpatient basis (Fig. 1.1) [39].

1.1.4.1 Preoperative Considerations

Preoperative preparation is aimed at optimizing the patient's physical status. Initiating continuous positive airway pressure (CPAP) should be considered, particularly in patients with severe obstructive sleep apnea, as it has been shown to lower the risk of postoperative complication [39]; however, data on other techniques including noninvasive positive pressure ventilation (NIPPV), mandibular advancement and oral appliances, and preoperative weight loss are not sufficient to promote their use. NIPPV can be considered if patients do not respond to CPAP [39].

1.1.4.2 Intraoperative Considerations

Difficult tracheal intubation occurs eight times more frequently in OSA patients than non-OSA patients. In general, all patients should be adequately preoxygenated before induction of anesthesia, but this becomes even more important in the patient with a known history of obstructive sleep apnea. Adequate preoxygenation simply allows a few more minutes to accomplish airway instrumentation prior to oxygen desaturation. Sometimes, these few extra minutes are critical and potentially lifesaving. To improve the direct laryngoscopic view, the practitioner may build a progressively elevated ramp under the patient from the scapula to the head, aligning the tragus with the sternal notch in a line parallel to the floor. Commercial devices are available for this, but this can also be accomplished by blankets which are stacked progressively higher as they approach the patient's head. Airway adjuncts must be readied in advance such as video

laryngoscopy, flexible fiber-optic bronchoscopy, or even laryngeal masks. It must be kept in mind however that flexible fiber-optic bronchoscopy requires patient and equipment preparation, so it is very difficult to use this as an emergency "rescue technique" for an intubation failure following anesthesia induction. OSA patients are sensitive to respiratory depressant effects of anesthetic agents due to redundant tissue and airway collapse and blunting of the physiologic response to hypoxia and hypercarbia. All central depressant drugs diminish the action of the pharyngeal dilator muscles thereby promoting pharyngeal collapse in OSA patients. For this reason, short-acting anesthetic agents are preferred over longer-acting agents. Extubation should be performed only after the patient is fully conscious with a patent airway and full reversal of neuromuscular blockade. When extubating, an oropharyngeal or nasopharyngeal airway should be in place, and additional trained personnel should be readily available for management of two-person mask ventilation [45].

The literature cannot definitively endorse exact anesthetic techniques as they apply specifically to OSA patients. Nonetheless, the potential for post-extubation airway compromise must be considered in selecting intraoperative medications. When possible and practical, consideration should be given to management of superficial procedures with local or regional nerve blocks with or without moderate sedation. Preop techniques (e.g., CPAP, oral appliances) should be continued during the procedure. Spinal/epidural anesthesia is also recommended over general anesthesia whenever applicable [39]. Finally, general anesthesia with a secure airway is recommended over deep sedation without a secure airway, and awake extubation is preferable to deep extubation. Extubation and recovery should be attempted in positions other than supine – either lateral or semi-upright. In any case, careful titration of respiratory depressants and sedatives, especially opioids, is crucial in managing postoperative airway compromise [39].

1.1.4.3 Postoperative Considerations

Patients with obstructive sleep apnea are at increased susceptibility to respiratory depression based on severity of OSA, perioperative administration of sedatives and opioids, and the invasiveness of the operative procedure. It is during the recovery period of an OSA patient when most airway emergencies occur. Routine post-op monitoring of blood pressure, heart rate, respiratory rate, and oxygen saturation should be employed. Maintaining semi-upright or sitting positioning and continuing preop airway techniques (CPAP, NIPPV) are recommended [39]. OSA patients who receive opioids are 12–14 more times as likely to experience oxygen desaturations than those patients who receive exclusively non-opioid analgesics. To avoid the over-administration of systemic opioids, regional/neuraxial analgesia, or patient-controlled analgesia (PCA) *without a basal rate* can be considered. Neuraxial analgesia (spinal or epidural anesthesia) must be used with caution, keeping in mind rostral spread of local anesthetics can contribute to either immediate or delayed respiratory depression. Supplemental oxygen should be administered continuously until the patient can maintain baseline oxygen saturation on room air. Patients with OSA should not be discharged to an unmonitored setting until they are no longer at risk for respiratory depression [39]. To determine this, the patient's respiratory function should be observed while in an unstimulating environment, preferably while asleep, and monitoring for the risk of respiratory depression should be maintained until the patient is no longer at risk for postoperative respiratory depression [39].

1.2 Consequences of Untreated OSA (Renal)

The prevalence of chronic kidney disease (CKD) and OSA has increased over the last two decades, associated with an aging population and an increased prevalence of obesity. OSA-related hypertension and cardiovascular disease may have detrimental effects on renal function. The renal system is vulnerable to hypoxia, and recurrent nocturnal hypoxemia may contribute to kidney disease through a multitude of effects on:

- Sympathetic nervous system activation
- Hypertension
- Low-grade systemic inflammation
- Oxidative stress
- Accelerated atherosclerosis
- Endothelial dysfunction
- Activation of the renal renin-angiotensin system

Hypoxia is considered an initiator of events leading to renal failure, causing inflammatory, apoptotic, and fibrotic responses [47]. This increases interstitial injury and promotes loss of peritubular capillaries, which furthers hypoxia and leads into a vicious cycle. Hypoxia and frequency of arousals during sleep are significantly associated with CKD, indicating that changes following arousal may be deleterious with prolonged blood gas disturbances and breathing instability [47, 48].

1.3 Consequences of Untreated OSA (Endocrine)

Obstructive sleep apnea is independently associated with metabolic syndrome; 74–85% of patients with OSA also have metabolic syndrome [49]. OSA itself may be a newly realized component of metabolic syndrome. It has been observed that patients with moderate-to-severe OSA who are then treated with CPAP show a lowering blood pressure and a partial reversal of metabolic abnormalities associated with the metabolic syndrome. OSA is associated with abnormal lipid profiles including low HLD, high LDL, and high triglycerides. Treatment with CPAP results in the improvement of dyslipidemia, glucose metabolism, and insulin resistance. There is evidence that hypoxia due to OSA is independently associated with dyslipidemia through the generation of stearoyl-coenzyme A desaturase-1 and reactive oxygen species, resulting in the peroxidation of lipids and sympathetic system dysfunction [50]. Systemic inflammatory markers are higher in OSA patients than in controls. LDL metabolism may be altered by cytokines (e.g., IL-1), resulting in alteration of endothelial cell cholesterol metabolism, thereby promoting atherosclerosis [50].

In the United States, 40% of people with OSA will develop diabetes. This association is independent of other comorbidities such as age, sex, and obesity. Treatment with CPAP can improve glucose tolerance in people with sleep apnea. Intermittent hypoxia has been shown in animal studies to play a key role in metabolic dysfunction associated with sleep apnea. Human data show acute (30 min) and prolonged (up to 180 min) increases in plasma glucose levels during acute exposure to intermittent hypoxia. OSA has been identified as an independent risk factor for the development of insulin resistance, glucose intolerance, and type II diabetes. Disorders of glucose homeostasis in these patients are probably mediated by chronic intermittent hypoxia through the activation of the sympathetic nervous system, hypothalamic-pituitary-adrenal axis, pro-inflammatory paths, and oxidative stress [51, 52].

While all of this appears to present a somewhat bleak picture for the patient with sleep apnea, especially when coming for a surgical procedure, there may be hope demonstrated by research from Brigham and Women's Hospital in Boston, MA. The HeartBEAT Study, published in the June 12, 2014, issue of the *New England Journal of Medicine*, compared treatments for sleep apnea in 318 patients, ages 45–75 years old, with moderately severe obstructive sleep apnea, to see whether the risk of heart disease could be lowered by CPAP or nocturnal supplemental oxygen, in comparison with sleep hygiene and healthy lifestyle education of the patient. The results of this research, which was funded by the American Recovery and Reinvestment Act of 2009, found the use of continuous positive airway pressure, CPAP, was superior to just providing supplemental oxygen, and resulted in significantly lower blood pressure compared to either nocturnal supplemental oxygen or an educational control treatment [10]. They noted that previous studies had already documented that treatment of sleep apnea with CPAP had been shown to reduce blood pressure in patients with previously untreated hypertension and in those with treatment-resistant hypertension. For those patients with sleep apnea, the use of CPAP, both at home and during hospitalization, currently appears to be the best approach to minimizing risks and complications. Future research may provide even better approaches to minimize problems for these patients.

1.4 Review Questions

1. How common is sleep apnea in middle-aged patients presenting for surgery?
   A. 3–4% of all middle-aged patients
   B. 9% of middle-aged women and 24% of middle-aged men
   C. 3% of women and 7% of men
   D. Greater than 40%

1

2. No gas exchange with ambient air occurs during sleep apnea because sleep apnea results in closure of the opening to the trachea and lungs.
   A. True
   B. False

3. Obstructive sleep apnea is expected to be found only in obese or morbidly obese patients who are middle aged or older.
   A. True
   B. False

4. In which patient might postoperative CPAP in PACU be beneficial?
   A. A patient with OSA who uses CPAP at home
   B. A patient who is morbidly obese and has hypertension
   C. A patient who snores loudly while sleeping
   D. All of the above

5. Which of the following makes smoking a risk factor for OSA?
   A. Smoking increases the amount of redundant tissue in the upper airway.
   B. Preexisting pulmonary disease.
   C. Inflammation of the upper airway.
   D. B and C.

6. Which of the following is not a consequence of untreated OSA?
   A. Increased risk for thrombosis and stroke
   B. Hypertension that is more resistant to antihypertensive regimens
   C. Hyperthyroidism and multinodular goiter
   D. Speed of information processing and memory formation

7. The apnea-hypopnea index determines the severity of sleep apnea. How many episodes or apnea per hour of sleep is considered to represent severe sleep apnea?
   A. 5
   B. 10
   C. 20
   D. 30

8. Which preop preparation for a patient with obstructive sleep apnea has been shown to lower risk?
   A. Initiate (or continue) CPAP.
   B. Initiate noninvasive positive pressure ventilation (NIPPV).
   C. Institute use of mandibular advancement appliances.
   D. Weight loss.

1.5 Answers

1. B
2. B
3. B
4. D
5. D
6. C
7. D
8. A

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Postoperative Visual Loss: Anatomy, Pathogenesis, and Anesthesia Considerations

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_2

2

Key Points

- Several different ophthalmologic injuries can cause postoperative visual loss, with anterior and posterior ischemic neuropathy being the most common.
- Cardiac surgery and prone spinal surgery are associated with higher rates of postoperative visual loss than other procedures; however, the complication is still relatively uncommon.
- Treatment options for postoperative visual loss are limited, with many patients experiencing irreversible blindness.
- Prevention is paramount; avoiding direct pressures on the globe, positioning the head above the level of the heart, and avoiding hypovolemia can help reduce the risk of postoperative visual loss.
- Postoperative visual loss is a well-documented source of medical malpractice claims, and clinicians should discuss the potential complication with patients.

Case

A 66-year-old female with a past medical history including heart failure with a reduced ejection fraction, type 2 diabetes mellitus, peripheral vascular disease, anemia of chronic disease, osteoporosis, and multilevel vertebral collapse is scheduled for posterior multilevel lumbar and thoracic fusion. The patient's preoperative exam is notable for back tenderness to palpation, peripheral edema, weak peripheral pulses, and an audible S3. Her preoperative labs show H/H 7.5/22.5. The surgery is performed in the prone position. The procedure lasts over 7 h and is complicated by substantial blood loss nearing 4 L, and the patient requires intraoperative transfusion. Despite resuscitation the patient experiences intraoperative hypotension. Following the procedure, the patient is transported to the PACU. There, the patient notifies her nurse that she cannot see out of her right eye. Ophthalmology is consulted, and examination reveals optic disc swelling. Unfortunately, a year following the surgery, the patient's vision remains impaired.

2.1 Introduction and History of Postsurgical Vision Loss

Visual loss is an uncommon but potentially devastating postsurgical complication. Since the first case report was published in the late 1940s, there have been numerous studies on the topic. The effects range from permanent visual loss to complete resolution of impairment [1–3]. The pathophysiology of the damage is incompletely understood, but several types of ophthalmologic injuries have been recognized, suggesting there may be multiple etiologies [4]. The relative rarity of perioperative visual loss has made research somewhat challenging. Most publications are case reports, case series, and case-control studies. To facilitate further exploration of the subject, the ASA Committee on Professional Liability established the ASA Postoperative Visual Loss (POVL) Registry in 1999 – a database that includes detailed patient and surgical information on related cases. With the publication of additional findings, an ASA Task Force on Perioperative Visual Loss was established, which has provided practice advisories for clinicians [5].

2.2 Anatomy of the Eye

2.2.1 Basic Structures

Familiarity with some pertinent anatomy of the eye and visual pathways allows a better understanding of the injuries seen in postoperative visual loss. The human eye is made up of three layers (Fig. 2.1). The outer layer includes the cornea, sclera, and limbus. The middle layer includes the iris, ciliary body, and choroid. The retina, the sensory part of the eye, is the inner third layer. Visual processing begins with the passage of light through the cornea and then through the anterior chamber, which lies between the cornea and iris. It then tracks through the opening in the iris known as the pupillary aperture. Subsequently, light travels through the lens

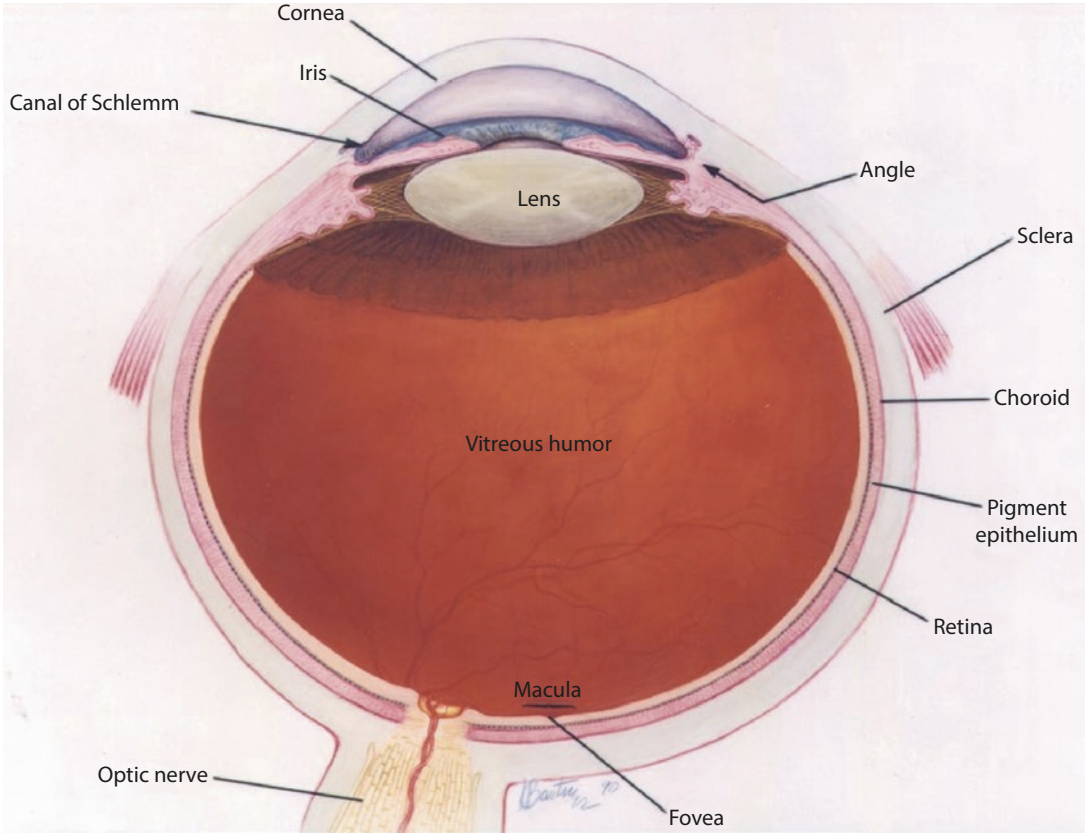

Fig. 2.1 Anatomy of the human eye. (Drawing of the Eye. National Eye Institute, National Institutes of Health)

and vitreous humor to reach the retina. The optic nerve, which can be subdivided into the anterior and posterior optic nerves, transmits the signal from the retina to the brain where neurological pathways lead to the occipital lobe, as well as other structures involved in the processing of vision [6].

2.2.2 Vascular Supply

The vasculature supplying the retina arises from the ophthalmic artery. The central retinal artery enters the posterior optic nerve and travels anteriorly to the optic disc. The central retinal artery then branches into arteriolar and capillary beds supplying the retina. A second retinal vascular supply originates with the long and short posterior ciliary arteries, which divide to form a capillary bed within the choroid. Both vascular sources are required for normal vision [4].

Perfusion of the anterior optic nerve comes largely from the posterior ciliary arteries. The long posterior arteries lack anastomoses, leaving the anterior optic nerve vulnerable to ischemia in the setting of arterial hypotension. The posterior optic nerve has less blood flow than its anterior counterpart. Pial branches derived from the ophthalmic artery provide its supply [4].

2.3 Ophthalmologic Injuries

2.3.1 Anterior and Posterior Ischemic Optic Neuropathy

The most common cause of postoperative vision loss is anterior and posterior ischemic optic neuropathy in non-ophthalmic procedures. This type of ocular injury is more common in high-risk cardiac and spine fusion surgeries. It has also been seen with increasing prevalence in patients having orthopedic procedures for lower extremity joint replacements [7]. Shen et al.'s 10-year study revealed increased incidence of ischemic optic neuropathy in patients with risk factors including male gender, anemia, and age greater than 50 [7].

In the general population, ischemic optic neuropathy can be divided into two types: arteritis and nonarteritis. The arteritic type is almost always from giant cell arteritis, which is not seen after a surgical procedure and is associated with systemic inflammatory vasculitis of unknown etiology occurring in older people. The non-arteritic form is most common and is the type seen after surgical procedures. Ischemic optic neuropathy is further classified as anterior ischemic optic neuropathy or posterior ischemic optic neuropathy [8].

Postoperative anterior ischemic optic neuropathy (AION) is a painless loss of vision after surgery related to insufficient blood supply to the optic nerve and optic disc. The incidence of AION compiled from large studies is 42/172,569 (0.024%) after cardiac procedures and 1/126,666 (0.00079%) after spinal cases [9]. AION is most common in patients with risk factors of cardiovascular disease and in high-risk cardiac or spine surgery requiring prone positioning. The exact etiology and risk factors of this type of injury remain unclear. Other risk factors are thought to include prolonged surgery, sleep apnea, anemia, and arterial hypotension requiring vasopressors [10]. Anatomic abnormalities of circulatory supply of the optic nerve and a small optic cup to disc ratio may also contribute to the development of AION after surgery [11]. Although risk factors are not certain, it appears that patients with a predisposition for risk factors linked to ischemia seem to be the most likely mediators for postoperative AION [10].

Diagnosis of anterior ischemic optic neuropathy must be differentiated from its posterior counterpart, as well as other ocular pathologies. Vision loss in AION is usually seen immediately after the procedure, but it is not uncommon for a patient to start having symptoms an entire day after the procedure. When this occurs, it is normally sudden and progresses over the course of the next few days [12]. The diagnosis of AION is clinical and based off of history, physical exam, and ophthalmologic exam. Important aspects of the patient's history are age, cardiovascular risk factors, timing of visual loss, and recent history of procedure or surgery [12]. Physical exam findings include afferent pupillary light reflex deficit; visual field defects, including scotoma or even complete vision loss; and a dilated fundoscopic exam demonstrating optic disc swelling and splinter hemorrhages [10, 13]. An MRI is unremarkable in AION but should be ordered to rule out other pathologies which can cause postoperative vision loss [14].

No treatments have been proven to help reverse the vision loss associated with anterior ischemic optic neuropathy. An ophthalmology consult is necessary at the onset of symptoms. High-dose oral steroids and oxygen therapy have been utilized but have not proven to be beneficial. Surgical intervention has not been proven to be helpful. The visual loss is normally permanent although in rare cases, some patients have regained some vision loss [15].

Posterior ischemic optic neuropathy (PION) is painless vision loss related to a vulnerable vascular area or infarction at optic nerve posterior to the lamina cribrosa. The vision loss is normally noticed upon awaking from a procedure and is most commonly total bilateral blindness [10]. The overall incidence of PION after surgery from large compiled studies is 7/140,768 (0.005%) in spine cases, 10/164,282 (0.0061%) in cardiac cases, and 4/126,666 (0.0032%) in all other cases [9]. Many different risk factors are associated with PION but like its counterpart AION, the exact risk factors are unclear. Perioperative anemia and hypotension are thought to lead to PION. It is commonly believed that a decrease in blood pressure and oxygen-carrying capacity limits oxygen supply to the posterior optic nerve [9]. Prone spinal procedures and surgeries in the Trendelenburg positon can lead to PION by increasing venous pressure to the orbits [9, 16]. Excessive blood loss and massive fluid replacement in cases requiring prone positioning have also been noted as likely risk factors for developing posterior ischemic optic neuropathy [17].

Posterior ischemic optic neuropathy is typically seen upon awakening from a surgical procedure in the operating room or after extubation in intensive care unit. Diagnosis should be made after complete history and physical exam. The patient's history should include either complete vision loss or, less commonly, partial visual field deficit after surgical procedure. Other risk factors should be noted such as type of surgery, amount of blood loss, fluid resuscitation during surgery, and cardiovascular risk factors. Physical exam findings in PION are similar to that of AION demonstrating visual field deficits and afferent pupillary light deficit. A main difference between PION and its anterior counterpart

is a normal optic disc and fundoscopic exam in PION, whereas AION shows optic disc swelling and hemorrhaging [17, 18]. Treatment for PION starts with an immediate ophthalmology consultation, which should be sought for all cases and causes of postoperative blindness. An urgent MRI with gadolinium should be ordered to rule out other causes of visual loss such as pituitary apoplexy. Additional recommended management is to monitor and to treat any aberrant vital signs, hemoglobin levels, and/or inadequate oxygenation. These recommended treatments for posterior ischemic optic neuropathy are not proven as compared with AION. Visual loss is normally lifelong with little to no vision gained throughout a patient's lifetime after the initial insult [19, 20].

2.3.2 Central Retinal Artery Occlusion/Retinal Vascular Occlusion

As previously described, the central retinal artery arises from the ophthalmic artery and supplies blood to the optic disc and the retina. Conceptually, central retinal artery occlusion (CRAO) is like an ocular stroke (Fig. 2.2). When occluded by embolus or when faced with inadequate circulation, ischemic damage to the optic disc and retina ensues.

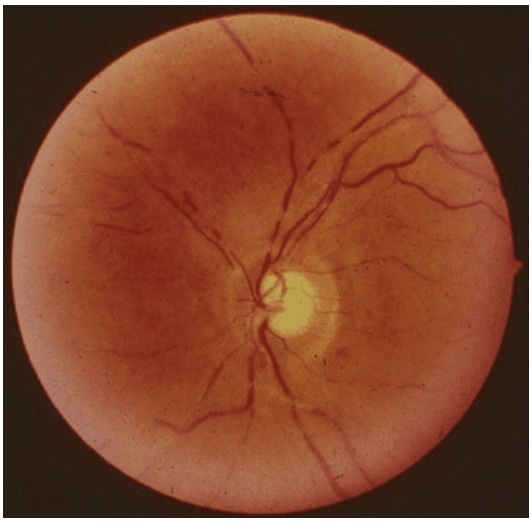

Fig. 2.2 Central retinal artery occlusion. (David G. Cogan Ophthalmic Pathology Collection – Selected Cases. (n.d.). Retrieved 15 June 2017, from ► https://cogancollection.nei.nih.gov/dctcCoganDetails.xhtml (Cogan Collection, NEI/NIH))

While ischemic optic neuropathy is currently the most common underlying injury leading to postoperative visual loss, previous reports of vision loss were attributed to retinal ischemia. Hypotension and ocular compression were identified as suspected etiologies [1–3]. An early publication described a series of eight neurosurgical patients suffering unilateral postoperative vision loss. These surgeries were performed in sitting or prone position using a horseshoe headrest, which was believed to place direct pressure on the patients' eyes, contributing to retinal ischemia. In support of this hypothesis, the authors demonstrated that ocular compression and hypotension cause retinal ischemia in monkeys [3]. This work leads to the term "headrest syndrome" for central retinal artery occlusion in patients undergoing surgery with a horseshoe headrest. These early reports raised awareness among anesthesiologists, leading some to modify their equipment and patient positioning to avoid the complication [3].

Despite new precautions, CRAO continues to be a concern. A large population-based study published in 2009 identified a retinal vascular occlusion rate of 1.54 per 10,000 discharges following spinal, orthopedic, cardiac, and general surgery over a 10-year period. Older age, male gender, and blood transfusion were associated with higher prevalence. Of the types of surgeries analyzed, cardiac surgery had the highest incidence of retinal vascular occlusion at 6.67 per 10,000 cases [7]. A separate retrospective study covering a 10-year period specifically examined retinal artery occlusion following cardiac surgery. The results, published in 2016, revealed an incidence of 7.77 per 10,000 cases [21].

CRAO normally presents with painless monocular vision loss. If the central retinal artery is occluded but a cilioretinal artery is present – an anatomical variation reported in close to 50% of patients – central vision might be spared [22]. The diagnosis is suspected when patients awaken from anesthesia and complain of unilateral visual deficits. Periorbital and eyelid edema, proptosis, ecchymosis, and corneal abrasion have been reported in patients with postoperative CRAO and can be additional clues to suggest excessive ocular compression or trauma [2, 3, 23]. A history of carotid disease, or blindness following a procedure with higher risk of embolization, could

place embolic CRAO higher on the differential diagnosis. Once the diagnosis is suspected, immediate ophthalmologic evaluation is indicated [5]. Ophthalmoscopic examination may show arteriolar narrowing, retinal pallor or opacities in the posterior pole, optic disc edema, and a cherry-red spot at the macula [4, 22, 24]. Intra-arterial emboli can additionally be seen, suggesting the diagnosis [4].

Management of postoperative visual loss can begin even before differentiating between which ophthalmologic injury has taken place. Inspired oxygen can be increased and blood pressure optimized, though it is unclear what ultimate benefit these interventions offer [4]. For CRAO specifically, mannitol, IV acetazolamide, and 5% CO2 in oxygen have been used to decrease intraocular pressure and increase oxygen delivery [4, 22, 23]; however, outcomes following these interventions seem comparable to untreated patients. Ocular massage has also been suggested, with the potential to lower intraocular pressure or dislodge emboli. A Cochrane Review article published in 2009 evaluated two randomized controlled trials for CRAO treatment. Enhanced external counterpulsation (EECP) versus placebo and oral pentoxifylline versus placebo were studied. Oral pentoxifylline resulted in improved retinal artery flow, and EECP improved retinal perfusion in the hours following its use; however neither treatment documented improved visual acuity in these small trials [25, 26, 27]. Additionally, the patients examined in these randomized controlled trials were not postoperative patients, potentially limiting the applicability of the results. In another randomized controlled trial, local intra-arterial fibrinolysis for the treatment or CRAO was compared to placebo. This study conducted by the European Assessment Group for Lysis in the Eye (EAGLE) was terminated early as the two treatment approaches were similarly effective, with a significantly higher rate of adverse reactions in the fibrinolysis arm [28]. Given that there is poor efficacy of treatments for CRAO, prevention of this devastating complication is paramount.

2.3.3 Cortical Blindness

While not as common as ischemic optic neuropathy and central retinal artery occlusion, cortical blindness still remains one of the most documented causes of perioperative visual loss (POVL) [7]. Most notably associated with cardiac and spinal procedures, cortical blindness is primarily caused by a disruption of blood flow to the parieto-occipital region of the brain via one of two possible mechanisms: embolism or watershed infarct.

A study by Shen et al. revealed the overall incidence of POVL secondary to cortical blindness to be 0.38 per 10,000 discharges [7]. The retrospective study used data from nearly six million patients from the Nationwide Inpatient Sample (NIS) who underwent knee arthroplasty, cholecystectomy, hip/femur surgical treatment, spinal fusion, appendectomy, colorectal resection, laminectomy without fusion, coronary artery bypass grafting, or cardiac valve procedures. Age less than 18 was found to be a major risk factor for the development of cortical blindness, with an incidence of 4.3 per 10,000 cases. As compared to those >18 years of age, patients <18 were 64 times more likely to develop visual disturbances from cortical blindness. Other risk factors include the type of surgical procedure performed. Spinal fusions were shown to have an incidence of 1.50 per 10,000 cases with an increased risk of 19.1 fold as compared to abdominal surgeries. Similarly, cardiac and non-fusion orthopedic procedures were found to have an increased risk of POVL of 12.7 times and 5.42 times, respectively, as compared to abdominal procedures.

Additionally, a higher score in the Charlson risk index (Table 2.1), a measure of one's comorbidities, is associated with higher rates of

Table 2.1 Charlson risk index

Condition	Weight
Myocardial infarct, heart failure, peripheral vascular disease, cerebrovascular disease, dementia, chronic pulmonary disease, connective tissue disease, ulcer disease, mild liver disease, or diabetes	1
Hemiplegia, moderate/severe renal disease, diabetes with end organ damage, any tumor, leukemia, or lymphoma	2
Moderate or severe liver disease	3
AIDS	6

cortical blindness. A score of 1 is associated with a 2.18-fold increase, while a score of ≥2 increases the risk visual disturbance by over 5 times.

As noted, vision is generated via transduction of light by photoreceptors in the retina to electrical signals, which are subsequently transmitted through the optic nerves. After traveling through the optic canal, the nerve fibers meet in the optic chiasm where decussation, or crossing over of the fibers, occurs, before a majority of the fibers travel via the optic tract to the lateral geniculate nucleus of the thalamus. From the LGN, the visual signal is carried via optic radiations to the primary visual cortex located in the occipital lobe. Any vascular insult to this region, most commonly via embolization of the posterior cerebral arteries, or via hypotension and subsequent watershed infarcts of the parieto-occipital regions, can result in cortical visual loss.

A unilateral insult to the occipital lobe, typically secondary to an embolic event, results in contralateral homonymous hemianopia or loss of the contralateral visual field [9]. Bilateral infarcts, usually as a result from profound perioperative hypotension, can have a wide spectrum of symptomatology, ranging from difficulty in visual judgment of size, movement, and distance to optic ataxia to complete vision loss although this is noted to be a rare occurrence [29]. Because damage is occurring in the cerebrum and not the optic nerve, physical exam will show normal pupillary light reflexes, as well as a normal funduscopic exam. Imaging of the head, either via computed tomography (CT) or magnetic resonance imaging (MRI), will be consistent with infarction of the occipital cortex in the result of emboli or with an infarction in the watershed regions of the parieto-occipital lobes if associated with profound hypotension.

The prognosis of cortical blindness ranges from short episodes of transient ischemic-like attacks with return of function to complete and permanent blindness [9]. Given the nature of the insult, visual loss that has not demonstrated return of function after a few months is typically permanent [30].

Management of cortical blindness depends on the etiology with only a few ideal treatment options, regardless of the nature of the insult. Multiple case reports suggest that timely administration of intra-arterial tPA following acute perioperative ischemic stroke may be efficacious and safe [31, 32]. Neurologic improvement was seen in 5 of 13 patients (38%), while another report showed a risk for surgical site bleeding of only 25%. The use of mechanical thrombectomy or embolectomy has been proposed, particularly in cases when the administration of intra-arterial tPA is contraindicated, but there are few studies available to evaluate the proposed efficacy [33]. The narrow window for treatment highlights the importance of rapid identification of those suffering from cortical blindness and the importance for prevention via risk factor identification and maintenance of intraoperative hemodynamic stability.

2.4 Prevention of Postoperative Blindness

Prevention of postoperative blindness is the key to limiting its occurrence, because in most cases of postoperative vision loss, there are no effective treatments. The American Society of Anesthesiologists created a Perioperative Visual Loss Task Force in 2005 to create a practice advisory to prevent postoperative vision loss, especially from anterior and posterior ischemic optic neuropathy [5]. Practice advisories, such as this task force, are not supported by scientific literature, unlike practice standards and guidelines. This task force focused on advisories for prone spinal procedures because of the high-risk nature of these surgeries. The task force articulated that there are no identifiable high-risk patient characteristics. The task force noted that patients are deemed high risk when having spinal surgeries, when it is anticipated the surgery will be longer than normal or the surgery is anticipated to have a large amount of blood loss. The task force agreed that neurology or ophthalmology consultation prior to surgery for these patients would not be beneficial. Physicians should inform high-risk patients undergoing prolonged cases with an anticipated large volume of blood loss that there is a small risk of permanent vision loss after the procedure. If a high-risk patient is undergoing a prone spinal surgery, the advisory suggests that the head of the patient be kept in a neutral position without flexion or extension at the neck. Additionally, it is suggested to keep the patient's head at or above the level of the heart. The task force suggests checking serial hemoglobin and

hematocrit values in patients that have significant blood loss, although they agree that no specific value is associated with postoperative vision loss. Both colloids and crystalloids are appropriate to maintain euvolemia when patients have significant blood loss. Central venous pressure monitoring should be used in high-risk patients to monitor volume status [5, 20]. The task force suggests avoiding direct pressure on the globe, as increased pressure on the eye has proven to increase the risk of central retinal artery occlusion [5]. Corneal abrasions can be prevented by taping the patient's eyes closed immediately after induction of anesthesia. Ensuring that the eyes of patients are closed should prevent foreign bodies from potentially damaging the eyes. Although some physicians put lubrication ointment on patients' eyes before taping them closed, studies have not found this to be significantly beneficial [34]. Future studies potentially will lead us to more preventative measures to reduce the risk of postoperative vision loss.

2.5 Medicolegal Issues: Historic Considerations and Concerns

Postoperative vision loss (POVL) after a non-ophthalmologic procedure is relatively rare, although POVL can be devastating with effects varying from permanent disability to full recovery. POVL has often been a source of malpractice claims, making it difficult to study as most claims are kept closed [35]. The American Society of Anesthesiology established the POVL Closed Claims Project registry in 1999 to help facilitate the reporting and studying of POVL. The registry consisted of volunteer ASA Anesthesiologists reviewers who worked with malpractice insurance organizations to examine and report malpractice claims involving POVL [36]. Reviews of claims took place on a 1–3 year cycle with anonymity and confidentially respected. Of the data collected on POVL, ischemic optic neuropathy was a common diagnosis resulting in litigation. Ischemic optic neuropathy often does not resolve or improve with time [37]. True cause is yet to be identified, but it is postulated that factors that could contribute include pre-existing conditions such as diabetes mellitus, male gender, obesity, atherosclerosis, hypertension, positioning which elevates blood pressure to the head such as prone positioning or head down positioning, surgeries that involve large volume blood loss with large amounts of fluid administration, hypotension, and anemia [35]. While not all variables are controllable, the clinician should try to optimize pre-existing conditions prior to elective surgeries, avoid hypotension, and ensure anemia (prior to surgery or surgically induced) is treated appropriately.

Using data collected from the Closed Claims Project, intraoperative hypotension and anemia were examined using a sample of 100 patients who did not experience POVL [38]. Selected patients had undergone spinal fusion operations from several academic centers and were matched for year of surgery. Analysis using clinic blood pressure prior to procedure as baseline revealed that over half of the subjects had the lowest MAP greater than or equal to 30% below baseline and 38% had systolic BP <90 for a minimum of 15 nonconsecutive minutes. Patients were also found to have a mean preoperative hematocrit of 39.8+/− 5% with intraoperative being 30.7+/− 5.9% [38]. Blood pressure and hematocrit level have both been tied to ischemic optic neuropathy, but the role they play remains unclear, and no strict cutoffs have been identified as causal. Additional data must be collected to have a better understanding of how each factors into the mediation or modulation of vision loss. Blood pressure and hematocrit can be optimized both in the operating room and prior to surgery. The clinician should maintain strict parameters throughout the procedure and ensure proper documentation of interventions taken to protect the patient from harm.

In 2013, Lee et al. used the Closed Claims Project database to investigate trends in the severity of injuries to the visual pathway to determine whether complications arising from changes in surgical practice were reflected in medicolegal claims against anesthesiologists [39]. They compared claims from 1980 to 1994 to similar claims between 1995 and 2011. In each timeframe, postoperative vision loss represented 4% of claims reported to the Project. They found that higher severity of injury to the visual pathway correlated with a more than threefold increase in the median payments made to the plaintiff [39]. The increased incidence of reported POVL strongly correlates to the increased frequency of spinal fusion operations [35].

Another aspect impacting litigation is communication between the patient and physician

prior to surgery. Making sure patients are fully informed about the possible risk of postoperative vision loss before the operation is to take place allows patients the opportunity to discuss any questions or concerns they might have. This also allows the physician the chance to discuss how any risk can be mitigated both prior to and during the procedure. The concept of informed consent is not novel and has evolved over many years. In 1957, Professor Allan H. McCoid of The University of Minnesota Law School published an article following the decision of the California District Court of Appeals for the First District in Salgo v. Leland Stanford, Jr. University Board of Trustees. Both recognized that under certain circumstances, a physician could be liable to a patient for failure to disclose sufficient information prior to undertaking treatment [40]. Subsequently, it was further defined in 1972 in Canterbury v. Spence. The plaintiff, Canterbury, suffered a ruptured disc in 1958 and was operated on by Dr. Spence. As a result of the procedure and a fall in the hospital, Canterbury suffered from partial paralysis below the waist. Canterbury brought suit stating that Spence failed to inform of the possibility of paralysis prior to surgery. The court concluded that "the standard measuring performance of that duty by physicians, as by others, is conduct which is reasonable under the circumstances. Reasonable care requires disclosure of all risks that are 'material' to the patient's decision and what disclosures fall within the scope of the obligation is to be left to the jury. A risk is material when a reasonable person, in what the physician knows or should know to be the patient's position, would be likely to attach significance to the risk in deciding whether to forego the proposed therapy" [41]. A survey of patients who recently underwent prolonged prone spinal cases within the Mayo Clinic hospital system revealed that 86% of responders would prefer to have POVL discussed with them face-to-face prior to the day of surgery [42].

2.6 Conclusion

POVL is an uncommon but devastating complication of surgery. Many hypotheses have been proposed, but the pathophysiology of POVL is incompletely understood, suggesting that multiple factors may contribute to injury [4].

The eye consists of three layers, the outer made up of the cornea, sclera, and limbus; the middle including the iris, ciliary body, and choroid; and the inner, consisting of the sensory portion, the retina. The optic nerve exits the posterior aspect of the eye and transmits signals from the retina to the occipital lobe [6]. The vascular supply of the eye arises from the ophthalmic artery. The central retinal artery and long and short posterior ciliary arteries supply the retina, with both sources being required for normal vision [4].

Injuries to the visual pathway include anterior and posterior ischemic optic neuropathy, central retinal artery occlusion/retinal vascular occlusion, cortical blindness, and posterior reversible encephalopathy syndrome. Anterior ischemic optic neuropathy is painless vision loss after surgery due to insufficient blood supply to the optic nerve and disc. Posterior optic neuropathy is painless vision loss due to a vulnerable vascular area or infarct at the optic nerve posterior to the lamina cribrosa. Both anterior and posterior ischemic optic neuropathies are normally observed directly following a procedure. Posterior ischemic optic neuropathy often results in complete bilateral blindness [10]. Central retinal artery occlusion/retinal vascular occlusion is the result of occlusion by embolus or inadequate blood supply to the optic disc and retina and normally presents with painless monocular vision loss. Cortical blindness results from lack of sufficient blood flow to the occipital cortex via the posterior cerebral arteries. This condition is more associated with the potential of recovery of some degree of the vision lost. Posterior reversible encephalopathy syndrome is characterized by vision loss with associated headache, confusion, and seizures. Pathogenesis is unclear, but vasoconstriction and hypoperfusion leading to ischemia and vasogenic edema have been proposed mechanisms [43].

Prevention of POVL is paramount as in many cases no treatments have proven to be effective in improving impairment. In 2005, the ASA created the Perioperative Visual Task Force and released a practice advisory to prevent POVL with the prime focus on prone spinal procedures [5]. The task force summarized that there are no specific patient characteristics that would identify a patient as high risk. Risk is deemed higher when procedures are prolonged and involve an anticipated large volume of blood loss. Patients who are to undergo higher-risk procedures should

be kept at a neutral spine with the head kept at or above the level of the heart. Serial hematocrit should be checked, and central venous pressure monitoring can be used to monitor volume status. Volume resuscitation can be done with colloids, crystalloids, and blood products to maintain euvolemia [5].

Postoperative vision loss claims have increased with the growing number of spinal fusion surgeries [35]. In a survey conducted of patients following prone spinal surgeries, 86% of patients stated they preferred to have to risk of POVL discussed with them face-to-face prior to the day of surgery [42]. More severe injury to the visual pathway correlates with increase in payment when injury is brought to suit [39].

2.7 Review Questions

1. Posterior reversible encephalopathy syndrome is characterized by all but which of the following:
   A. Seizure
   B. Headache
   C. Loss of consciousness
   D. Confusion

2. Which of the following provides blood supply to the posterior optic nerve?
   A. The pial branches of the ophthalmic artery
   B. The posterior ciliary arteries
   C. The central retinal artery
   D. The anterior ciliary arteries

3. All of the following increase a patient's risk for postoperative vision loss except:
   A. Prone positioning
   B. Large volume fluid shifts/blood loss
   C. Prolonged surgical time
   D. Female gender

2.8 Answers

1. C – Posterior reversible encephalopathy syndrome is characterized by vision loss, seizure, headache, and confusion. Loss of consciousness does not characterize posterior reversible encephalopathy syndrome.

2. A – The posterior ciliary arteries and central retinal artery supply the retina. The posterior ciliary artery supplies the anterior optic nerve.

3. D – Female gender has not a known risk factor for postoperative vision loss.

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Substance Abuse

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_3

Key Points

- 24 million Americans have abused an illicit drug.
- Cannabis is the most frequently abused drug.
- Some physicians underestimate the prevalence of alcohol dependence in certain populations, e.g., women and younger patients.
- Tight control of opioids in patients who are exposed to medication for the first time during the perioperative period is important to prevent the development of opioid-dependence and associated drug overdose and death.
- Any surgical patient that smokes has a 20% increased risk of hospital mortality and 40% increased risk of complications.
- Detailed patient history and screening can help to elucidate whether a patient is acutely intoxicated or a chronic substance user and can help a healthcare provider choose the best treatment approach for the patient.

3.1 Introduction

23.5 million persons aged 12 or older needed treatment for an illicit drug or alcohol abuse problem in 2009 (9.3% of persons aged 12 or older) according to the Substance Abuse and Mental Health Services Administration's (SAMHSA's) National Survey on Drug Use and Health. Of these, only 2.6 million (11.2% of those who needed treatment) received treatment at a specialty facility. Additionally, substance abuse is costly totaling over $740 billion annually related to crime, lost work productivity, and healthcare. Major drugs of abuse include but are not limited to alcohol, opioids, stimulants, cannabinoids, hallucinogens, and nicotine.

Acute and chronic substance abuse in patients introduces unique challenges to the healthcare provider and healthcare team. Patients can present with respiratory, cardiovascular, central nervous system, hematological, renal, and hepatic system distress. Some procedures may have to be delayed in the presence of certain substances, while other situations may necessitate urgent decision-making. There is no cure for addiction, but there are effective treatments for addiction, and there are ways to manage patients that are addicted to substances. Therefore, healthcare providers should be aware of the variety of drugs of abuse that can present in patients and of how to treat these patients.

Healthcare providers have opportunities to help make positive and supportive changes in the lives of their patients who abuse substances. Healthcare providers can screen their patients to identify signs of drug abuse or dependence and talk with patients about the negative effects of misusing prescription drugs. They can also talk with the families of patients who abuse substances to facilitate a support network. Overall, the healthcare provider should not only be aware of ways in which to treat a patient who presents with substance abuse but also how they might be able to foster the health of the patients after they leave the operating room. This chapter will discuss a variety of drugs that a healthcare provider may encounter in the operating room and how to properly treat a patient that has abused/presented with the substance.

3.2 Screening for Substance Use and Abuse

Many patients with substance use disorders (SUDs) have a higher risk for adverse events such as postsurgical complications, infections, and death. However, only a small percentage of patients will volunteer information regarding prior substance use. In approximately 66% of patients using illegal substances, anesthesiologists were unaware of their use prior to surgery [1]. This presents potential problems for both the surgeon and the anesthesiologist in managing these patients.

It is therefore recommended that physicians regularly screen all patients for substance use or abuse, even if it is not overtly evident that the patient is using or abusing substances [2]. The goals of screening patients include identifying those who have a substance use disorder, diagnosing related disorders, and developing a plan for management of the disorder [2].

Initial screening can include interviews, laboratory tests, and specific screening questionnaires. When conducting interviews, the physician must be cautious in their approach. Many times, these patients are hesitant to reveal information secondary to embarrassment or distrust.

When comparing various substances, patients will admit nicotine use and dependency more often than other drugs [3]. There are two common methods to evaluate this in more detail: standardized questionnaires such as the Fagerström [4] and the COHb biomarker [5] for acute smoking. Postoperative pulmonary and/or cardiovascular complications, as well as wound infections, are higher in patients who smoke. Therefore adequate screening is recommended [6].

It is also possible that some physicians underestimate the prevalence of alcohol dependence in certain populations, e.g., women and younger patients [7]. One screening tool for alcohol dependence is the CAGE or AUDIT questionnaires which can have higher rates of detection when approaching the patient on multiple occasions prior to their surgery. The second tool is laboratory tests including carbohydrate-deficient transferrin (CDT) + gamma-glutamyl transpeptidase (CGT) for males while adding mean corpuscular volume (MCV) when testing females. Surgery can activate the HPA axis (the stress response), and this response can be further strengthened in patients with alcohol dependence [3], again demonstrating the need for screening.

Patients that use illegal substances are not only at a higher risk because of the potential complications mentioned above but also because of the comorbidities that they possess. These comorbidities include psychiatric, chronic infections with possible multiresistant strains and combined usage with legal substances such as alcohol or tobacco [3]. As previously mentioned, some patients. Therefore, the physician taking the social/drug history should stress confidentiality and warn of potential risks.

Lastly, opioid use disorders pose a significant problem with postoperative analgesia requirements. The baseline therapy is replacement treatment with methadone. These patients face a slightly increased risk for relapse, followed by an increased risk of death when tolerance decreases [3]. Screening for opioid dependence includes objective instruments such as COWS (Clinical Opiate Withdrawal Scale), subjective physician interviews, physical examination, and nonspecific laboratory evaluations [2].

The surgeon and anesthesiologist's awareness of substance use disorders in their patients will allow them to individualize and adjust the patient's care pre-, peri-, and postoperatively. This will improve the patient's quality of care including minimizing complications, shortening or avoiding ICU length of stay, and improving outcomes.

3.2.1 Overall Perioperative Considerations

While screening patients for substance abuse ahead of time is necessary and important, not all patients that present to the operating room will be medically optimized. In fact, many patients that present to the emergency room under the influence of substances are trauma patients, and many are also polydrug users, meaning they are under the influence of many substances at one time, which complicates their treatment regimen [8]. When the healthcare provider is developing a plan there are several characteristics of substance use/abuse that can pose similar problems in the operating room, regardless of substance. These are outlined in ▶ Box 3.1, below. Each of these factors must be considered when a patient presents to the hospital with substance use or abuse. Regardless of the substance, these phenomena can occur with all of the substances discussed in this chapter and can all produce distinct side effects and/or challenges for the healthcare team.

Box 3.1 Perioperative Considerations for Substance Abuse

- Withdrawal
- Tolerance
- Difficult pain control management
- Acute toxicity vs chronic toxicity
- Patient compliance issues
- Patient judgment impairment

3.2.2 Individual Drugs of Abuse

3.2.2.1 Alcohol

Incidence

When considering alcohol as a potential risk factor for surgical complications, one must consider how prevalent these patients are. It is well known that sometimes physicians underestimate and may overlook alcohol abuse in certain patient populations, including women, younger patients, higher income/education, and private insurance. At least one in ten surgical patients has some level of alcohol abuse/dependency [7]. Alcohol use disorders fall on a spectrum, ranging from abuse to harmful and dangerous use involving others. These disorders are under-detected, making it difficult to prevent surgical complications [7].

Perioperative Complications

Patients with alcohol abuse are at a higher risk for perioperative complications. There are inconsistent opinions on whether the severity of the alcohol use plays a role in the likelihood and severity of the complication [9].

These complications are broken into various categories. Surgical field (e.g., surgical site infections (SSIs), graft failure), infections other than SSIs (pneumonia (PNA), urinary tract infection (UTI), sepsis), pulmonary, and general morbidity complications have statistically higher risk of occurrence, while cardiovascular (myocardial infarction cardiac arrest), neurologic (stroke, coma, delirium), postoperative bleeding, and general mortality have not been found to have any increased associations [9].

Studies have also demonstrated that patients with low-to-moderate alcohol use do not have the same risk as patients with high alcohol consumption (defined as AUDIT >5–8, >2 drinks most days, and/or alcohol abuse/dependency diagnosis). Additionally, surgery type (abdominal, thorax, head and neck, orthopedic, transplant, etc.) may be a factor but does not appear to have a direct association with alcohol consumption and further risk [9].

There are potential theories as to why patients with high alcohol consumption are at increased risk of these complications. Alcohol reduces the immune response, decreases coagulation, and has an enhanced effect of HPA activation (the stress response) during surgery. It is important to understand that alcohol abuse patients are not all the same (low vs moderate vs high consumption) and complication risks change based on their clinical profile. Knowing this information will help the physician advise the patient on how to minimize their risk. To lower these risks for patients with high alcohol consumption, some suggest that the patient abstain from alcohol for 4 weeks prior to surgery [10], while others advise that risk could remain high for up to 1 year prior [11]. Regardless, the patients who are at high risk must be identified prior to surgical preop so that the patient can reduce/eliminate their drinking and possibly receive treatment.

Treatment

In one study, alcohol withdrawal syndrome was noted in 82% of patients with chronic alcohol abuse, and they had a greater than 50% rate of various postoperative complications [12]. As alcohol withdrawal and associated morbidity is a feared complication following surgery, one possible treatment option is single-agent benzodiazepine prophylaxis, specifically lorazepam [12]. Current treatments target mainly the symptoms of alcohol withdrawal syndrome and not the actual dependency. Other symptomatic treatments include alpha-2-agonists, neuroleptics, and olanzapine. Some anti-craving medications are also available: acamprosate, naltrexone, or disulfiram [13]. However, all of the treatments listed above may not decrease risks of other postoperative complications, so further studies must be continued to find other prophylactic options [14].

3.2.2.2 Benzodiazepines

Incidence

Benzodiazepines are frequently prescribed for a variety of conditions including anxiety, insomnia, and epilepsy. They are also commonly used during procedures, providing anxiolytic and amnestic effects. Interestingly, the number of benzodiazepine prescriptions has decreased in the last 20 years, while the quantity of drug -per -prescription has increased [15]. This points to overuse or misuse, as benzodiazepines are not indicated for long-term use, defined as >6 months. The population of benzodiazepine users is heterogeneous, comprised of younger adults purchasing street drugs as well as elderly patients using the same class of drugs to improve sleep. Some predictors

for who will use benzodiazepines include females, elderly, history of smoking, and insurance coverage [16]. Concurrent use of benzodiazepines and opioids has increased in the last 10–15 years. However, there is also evidence that patients use alcohol or OTC medications for sleep in conjunction with benzodiazepines [17]. Alprazolam is commonly prescribed and also commonly abused [15]. Other benzodiazepines include clonazepam, lorazepam, midazolam, and diazepam. The prescription is usually written as PRN, meaning the patient can take as many (or as few) as they wish.

Perioperative Considerations

Benzodiazepines (BZDs) can be used preoperatively as an anxiolytic + sedative or perioperatively as an amnestic agent. Midazolam is a common choice due to its rapid onset, short duration of action, and short elimination half-life.

Pediatric patients can also use midazolam, keeping in mind the dosage requirement may be lowered [18]. Additionally, elderly patients metabolize and eliminate drugs less efficiently, which could result in BZD build up and accumulation of toxic metabolites. Amnesia and further complications may occur even if these patients were appropriately prescribed. Additionally, concurrent use of other substances (opioids, alcohol, etc.) in a patient of any age can result in unwanted additive or synergistic effects. Therefore, physicians must be cognizant and cautious of these potential factors.

Treatment

Discontinuation and maintenance therapy are two main treatment approaches for benzodiazepine dependence. The choice relies on multiple factors including whether the patient is a low or high risk of harm and relapse [15]. The discontinuation approach involves gradual weaning, as abrupt cessation is not recommended due to potential life-threatening seizures and other complications. This approach is suggested for low-risk patients who may have a less severe dependence, who are not currently using other drugs or alcohol, and who have never attempted this previously [19]. The process of tapering is not standardized, but there are suggestions based on the risk of relapse, expected duration, and tolerability. Maintenance therapy is reserved for higher-risk patients who are already on diazepam substitution, who have concurrent drug abuse, or who are psychiatrically unstable. If these patients have comorbid medical conditions or history of seizures, inpatient services may be recommended.

Patients may experience benzodiazepine withdrawal syndrome, which includes general withdrawal symptoms such as palpitations, sweating, and tremors as well as specific symptoms related to the neurological/psychological and gastrointestinal systems.

Other management strategies which can be performed simultaneously with the mainstay treatment include staged dispensing (only small quantities), benzodiazepine substitution (usually with a longer half-life drug such as diazepam), patient monitoring (awareness of doctor shopping), pharmacotherapy, and psychotherapy [15]. Both pharmacotherapies like anticonvulsants and psychotherapies such as CBT can be used for the treatment of withdrawal symptoms.

3.2.2.3 Opioids

Incidence

In 1999, pain was introduced as a fifth vital sign along with body temperature, pulse, respiration, and blood pressure [20]. Since then, in parallel with the dramatic increase in opioid prescriptions, the rate of admission of treatment-seeking patients for opioid addiction and opioid-overdose death nearly quadrupled in 2010 [21]. In 2012, approximately 16,000 deaths were linked to prescribed opioids, while in 2015 this number increased to 52,000 deaths [22]. It is estimated that 46 people die every day from prescription opioids and that opioid analgesics are linked to more deaths than deaths from cocaine and heroin combined or from both suicide and motor vehicle crashes. The CDC recommends prescribing opioids to patients with the most serious cases of pain, such as cancer and end-of-life care. However, in the USA doctors routinely prescribe opioids for more common ailments like arthritis and back pain. A recent study of prescriptions dispensed during 2008 by 37,000 retail pharmacies revealed geographic areas in the USA with the highest opioid prescription rate: counties located in Appalachia and in the southern and western states [23]. Authors found a positive correlation between opioid prescription rate and proportion of the "population that is white non-Hispanic or African American, poor, uninsured, and living in urban areas." The strongest correlation was found between the rate of

opioid prescription rate and the number of physicians practicing in a certain area, especially surgeons and pediatricians. According to the Express Script report, the number of opioid prescriptions dropped by 9% between 2009 and 2013. However, patients on prescribed opioids take a higher dose of opioid and for a longer period. Almost 30% of patients on opioids are also using other prescription drugs that may lead to a harmful combination (e.g., benzodiazepines).

Perioperative Complications

Considering that the opioid epidemic is associated with morbidity and mortality, it is important to minimize the amount of perioperative opioid administration to control pain. Tight control of opioids in patients who are exposed to medication for the first time during the perioperative period is important to prevent the development of opioid-dependence-associated drug overdose and death. In surgical patients with a history of chronic pain and prolonged administration of opioids, it is important to take into account their drug tolerance and to find the adequate scheme of opioid administration for analgesia preventing overdose. Recently, concern regarding the effect of chronic opioid exposure on neurologic complication has emerged. A toxic effect of opioids on the central nervous system (CNS) has been described in a growing number of studies. Leukoencephalopathy, axon demyelination, and lesions in white matter have been documented not only for heroin abusers but also for methadone [24–26], morphine [27], and oxycodone [28] overdosed patients. In 2016, the CDC published guidelines for prescribing opioids by primary care clinicians to "improve the safety and effectiveness of pain treatment, and reduce the risks associated with long-term opioid therapy, including opioid use disorder, overdose, and death" [29]. However, since there is currently no commonly accepted surgical guideline for the management of perioperative pain, surgeons and residents rely mostly on their experience and training [29, 30].

Treatment

Use of non-opioid adjuvant medication and regional anesthesia was suggested as a part of perioperative pain treatment to decrease opioid use. Among non-opioid adjuvants, dexmedetomidine, clonidine, ketamine, pregabalin, lidocaine, and esmolol are recognized for their perioperative opioid-sparing effects [31]. It was emphasized that different surgical procedures might require a unique combination of these non-opioid adjuvants. Regional anesthesia (including peripheral and neuraxial blocks) and analgesia were also associated with lower opioid use and decreased PONV [31–33].

3.2.2.4 Stimulants

Incidence

Cocaine and methamphetamine abuse continue to be a worldwide problem. The world drug report states that there are currently 33 million methamphetamine users and 19 million cocaine users. The US Drug Abuse Warning Network (DAWN) monitors cocaine- and methamphetamine-related emergency room visits. In 2011, DAWN reported 505,224 cocaine and 102,961 methamphetamine-related emergency room visits. Furthermore, methamphetamine visits have nearly doubled since 2007. Stimulant use disorder is a diagnosis in the DMS-IV and refers to a variety of problems associated with cocaine and methamphetamine including impaired control, risky use, social impairment, tolerance, and withdrawal. A recent study compared cocaine-related emergency room visits to methamphetamine-related emergency room visits and treported that out of 3103 urine toxicology screens and 20,203 emergency room visits, the prevalence of methamphetamine use was seven times higher than cocaine [34]. Stimulants can be divided into two major categories: amphetamine stimulants and non-amphetamine stimulants. Amphetamines are both direct releasers and reuptake inhibitors of dopamine, norepinephrine, and epinephrine. Non-amphetamine stimulants block the reuptake of dopamine and norepinephrine. The distinction between these mechanisms is important clinically, as amphetamines tend to cause a much more rapid and larger increase in the release of catecholamines than non-amphetamines. Stimulant drugs also have peripheral alpha and beta actions, for example, oral administration of amphetamine can increase systolic and diastolic blood pressures and reflex bradycardia [35]. Stimulant CNS effects include increased alertness, stimulation of respiratory centers, decreased fatigue, and euphoria. Cocaine blocks electrical impulses in nerve cells which can produce a local anesthetic effect. It does so by blocking sodium channels, thus preventing

neuronal cell's ability to undergo depolarization, and this is also evident in the cardiac system. Cocaine-induced sodium-channel blockade can predispose patients to QT interval prolongation, which may result in torsades de pointes [36]. Chronic abuse of stimulants leads to tolerance, and cross-tolerance to other sympathomimetic drugs can also occur.

Perioperative Complications

Intraoperatively, patients will require a decrease in sympathetic tone. Amphetamines can reduce the patient's sympathetic reflex integrity, via down-regulation of endogenous catecholamines, and as a result, refractory hypotension can result [37]. Postoperative hypotension can also occur. Of particular concern to the anesthesiologist is the patient's decreased response to ephedrine after chronic amphetamine use. Interactions between stimulants and other drugs commonly used by anesthesiologists in the operating room may be unpredictable and can lead to cardiovascular collapse. A 1979 case report discussed a patient who underwent a cesarean delivery and was also a chronic amphetamine abuser. The patient died of cardiac arrest, suggesting patients who abuse amphetamine may have a predisposition to cardiovascular instability [38]. Furthermore, a 2008 report of a ten-year-old child on long-term methylphenidate therapy for ADHD presented a cardiac arrest during induction of general anesthesia with sevoflurane [39]. There is also evidence for an interaction of amphetamine with atropine, where a patient taking fenproporex without a prescription (to lose weight) was administered atropine and which caused supraventricular tachycardia, arterial hypotension, and acute lung edema [40]. Amphetamines can also cause deleterious physical effects. "Meth mouth" is a side effect of chronic methamphetamine abuse and is caused by xerostomia, poor oral hygiene, and poor diet. Patients can present with loose or missing teeth that can be further dislodged during intubation or extubation.

There is controversy regarding the safety of cocaine-positive patients undergoing general anesthesia. A 2006 non-randomized, blinded study investigating 40 UDS cocaine-positive patients compared to an equal number of drug-free controls found that cardiovascular stability during general anesthesia was not significantly different between the groups [36]. Another study by the Veterans Association further solidified that on the morning of surgery, patients who presented with a positive urine drug screen for cocaine were not an indication for canceling a case [41]. On the other hand, a 2012 study of 300 patients who underwent elective surgeries reported that over half of the cocaine-positive patients required vasopressors and antihypertensives intraoperatively [42]. Cocaine can also cause physical problems. Chronic nasal cocaine administration can cause septal destruction and soft palate necrosis, nosebleeds, and reduced blood flow to major organs leading to tissue necrosis [43].

Treatment

The management of children on chronic amphetamine therapy should involve avoidance or careful titration of cardiac depressor anesthetic drugs [44]. Direct-acting vasopressors, e.g., epinephrine or phenylephrine, are preferable because of possible cross-tolerance to other indirect vasopressors such as ephedrine. Premedication or pre-treatment with atropine may also be useful. And in the case mentioned above, the amphetamine-atropine interaction can be treated with noradrenaline and milrinone. There is recent surprising evidence that methylphenidate can speed recovery from general anesthesia in an animal study. Rats receiving IV methylphenidate 5 min before discontinuation of isoflurane recovered faster than controls [45]. The experiment further showed the methylphenidate-induced signs of arousal in rats that continued to receive isoflurane at a dose sufficient to maintain unconsciousness.

Nitroglycerin treatment can be used for cocaine-induced cardiac arrhythmia [46]. Patients that present with hypertension or tachycardia can be treated with furosemide, a loop diuretic, which may decrease preload in patients with cardiomyopathy. Phenylephrine is a selective alpha-1 adrenergic receptor agonist and is the drug of choice for hypotensive patients.

3.2.2.5 Nicotine

Incidence

According to the CDC, 15% of adults 18 years and older (16.7% of men and 13.6% of women) were current cigarette smokers in 2015. Characteristics of current smokers include males 25–45, living below the poverty line, has a GED, either uninsured or on Medicaid, and history of disability or psychological diagnosis [47, 48]. Each day, over

3000 kids (<18 years old) start smoking cigarettes. However, the CDC reports that almost 70% of adults do want to quit. Approximately one in three patients is reported to have a nicotine use disorder (NUD) [3]. If the physician suspects NUD, they are encouraged to pursue screening as these patients are more likely to admit this when compared to other drugs of abuse.

Perioperative Complications

Any surgical patient that smokes has a 20% increased risk of hospital mortality and 40% increased risk of complications [49]. Patients with NUD are more commonly admitted to the ICU following surgical procedures and tend to result in cardiopulmonary complications or wound infections. Certain surgical procedures generally have higher risk in these patients: hernia procedures > orthopedic prostheses > cholecystectomy (laparoscopic) [50].

Smoking cessation is recommended in these patients for at least 4 weeks prior to surgery until 4 weeks post procedure, which is the minimal time period shown to decrease the risk of postoperative complications [50].

If the patient did not stop smoking prior to surgery or they are not using any intervention/treatment, physicians should consider physostigmine to avoid postoperative nausea/vomiting (PONV) complications and treat postoperative pain. This is a cholinergic agent that crosses the blood brain barrier, inducing analgesia alone or as an adjuvant to opiates [51].

Treatment

It is suggested that the patient detox and/or abstain from nicotine use for at least 4–6 weeks before surgery [3]. One option is nicotine replacement therapy (NRT) which is a first-line treatment for decreasing nicotine use but can also be used pre- and postoperatively for PONV. NRT comes in a variety of forms including a transdermal patch, acute dosing products, gum, lozenge, sublingual tablet, oral inhaler, and nasal spray. These therapies serve to lower motivation and usage of tobacco products, as well as lower the subsequent withdrawal symptoms that result [52]. Nicotine preloading is a more recent therapy involving starting NRT while the patient is still smoking (pre-cessation therapy) [53]. Another recent, yet somewhat controversial therapy, is a true pulmonary inhaler. This would deliver nicotine directly to the lungs, allowing for tapering to occur [54]. However, the unknown abuse potential and difficult product design make this a less desirable first-choice treatment. The final potential treatment for nicotine dependence is a new nicotine vaccine being studied [55]. The antigen is linked to a carrier, introduced into the body, which then stimulates the immune system to mount a response against the nicotine.

3.2.2.6 Cannabis

Incidence

According to the National Survey on Drug Use and Health report, cannabis is the most commonly used illicit drug in the USA [56]. Cannabis is most often consumed in the form of "marijuana" plant or hashish (the delta-9-tetrahydrocannabinol [THC]-containing resin of the inflorescences). In 2013, almost 20 million people of 12 years old and older in the USA used cannabis in the preceding month [56]. A gateway analysis revealed that the use of cannabis leads to an increased risk of abusing other illicit drugs, especially among the adolescent population, but it rapidly declines with age. A recent review by the National Academies of Sciences, Engineering, and Medicine (NASEM) indicates the use of cannabis at young ages, or heavy daily use of cannabis, is associated with various adverse effects [57]. There are two major syndromes associated with intensive use of cannabis: the cyclic vomiting syndrome (CVS) in adults [58, 59] and the cannabinoid hyperemesis syndrome (CHS) [60, 61] that are characterized by recurrent episodes of nausea, vomiting, and crampy abdominal pain. Also, prolonged use of even low doses of cannabinoids may lead to the development of drug dependence, psychosis, panic and anxiety attacks, a deficit of attention, concentration, learning and memory, coordination impairment, and development of signs of withdrawal.

Perioperative Complications

Medical cannabis is proposed to be used in pain management with inhaled cannabis been more tolerable than oral cannabinoids. Several meta-analyses indicated that orally administered cannabinoids and inhaled cannabis provide moderate benefits in the treatment of chronic pain and spasticity associated with neuropathy, cancer, diabetes, and multiple sclerosis [62–67]. However, there is

no commonly accepted guideline for the use of medical cannabis in each specific case. According to the 2017 NASEM report, "there is conclusive or substantial evidence to support cannabis being effective for the treatment of chronic pain in adults, moderate evidence that cannabinoids (primarily nabiximols) are effective for improving short-term sleep outcomes in individuals with chronic pain associated with obstructive sleep apnea syndrome, fibromyalgia, chronic pain, and multiple sclerosis" [57]. However, there is limited evidence supporting the correlation between cannabinoids and better outcome after a traumatic brain injury or intracranial hemorrhage [57]. Moreover, the report indicated a statistical association between cannabis smoking and worsening respiratory symptoms, motor vehicle crashes, and increased risk of overdose injuries in the pediatric population, as well as the development of schizophrenia or other psychoses [57]. Oral cannabinoids do not reduce acute postoperative pain and are therefore not currently useful during the postoperative period. More research is needed to explore the potential benefits of cannabinoids during the perioperative period.

Treatment

There are several cannabinoid-based therapies utilized in the clinical settings: Cesamet® (nabilone) is prescribed to treat nausea in cancer patients, Marinol® (dronabinol) is prescribed to treat nausea in patients undergoing to chemotherapy [68], and Sativex® is prescribed to patients with multiple sclerosis with moderate to severe spasticity [65].

3.2.2.7 Hallucinogens

Incidence

Hallucinogens are a group of drugs that alter the state of consciousness associated with mystical experience, vivid images, and synesthesia and could lead to confusion, violent behavior and psychosis, paranoid reactions, and depression. According to the National Survey on Drug Use and Health, more than 15% of US population aged 12 or older has used hallucinogens in their lifetime in 2016 [69]. The most popular hallucinogens are lysergic acid diethylamide (LSD) and phencyclidine (PCP), and ketamine. Although the abuse potential of hallucinogens is low, their use is associated with toxic effecst. LCD could lead to fever, tachycardia, tachypnea, and hyperglycemia [70]. Inhaled PCP is associated with nystagmus, tachycardia, and hypertension and even could lead to cerebral hemorrhage and coma [71]. Toxic effects of ketamine include nystagmus, apnea, severe bladder toxicity, and cardiovascular dysfunction [72].

Perioperative Complications

Prior physical examination of the patient for the presence of signs associated with the use of the hallucinogens such as confusion, violent behavior, nystagmus, or tachycardia will help the physician to estimate whether to perform drug screening test for this patient. If the patient has tested positive for the hallucinogens and the surgery is not urgent, then the operation should be delayed. Also, since ketamine is a PCP derivative, patients intoxicated with PCP should not be treated with ketamine.

Treatment

If the operation cannot be delayed or placing the patient in a quiet environment is not effective to suppress psychosis, there are several agents that can be used to calm the patient. Benzodiazepines (lorazepam or diazepam) are the medication of choice since they suppress the activity of the central nervous system (CNS) by enhancing the action of gamma-aminobutyric acid (GABA). Antihypertensive agent clonidine decreases the severity of hallucinogen persisting perception disorder (HPPD). Clonidine also suppresses sympathetic activity stimulated by LSD use. The neuroleptic agent haloperidol can produce a significant improvement in hallucinogen-induced anxiety, hallucinations, and cognitive confusion [73]. However, haloperidol has adverse psychomimetic effects and is not indicated in LSD intoxication. Chlorpromazine is more efficient at reducing somatic and psychological tension in PCP-induced psychosis [73].

3.2.2.8 MDMA/Ecstasy

Incidence

Ecstasy is the common name for MDMA, 3,4-methylenedioxy-methamphetamine. The use of MDMA has decreased in 12–17-year-olds in recent years but remains steadily used among adults. In 2014, 50% of over 500,000 adults surveyed were current ecstasy users. The National

Survey on Drug Use and Health 2014 survey reported that 7% of individuals age 12+ had tried MDMA at least once in their lifetime, 1% of the population had used it in the past year, and 0.2% had used it in the past month [74]. MDMA is abused because it produces feelings of euphoria, pleasure, and heightened emotional and sensory experiences. MDMA works through a variety of mechanisms that alter dopamine, serotonin, and norepinephrine signaling. It can be administered orally in pill or capsule form and is often cut with other substances like caffeine, atropine, ketamine, and diphenhydramine [75].

Perioperative Complications

MDMA is a derivative of amphetamine, which is why these drugs share many similar effects, e.g., increased heart rate, hyperthermia, tachycardia, sweating, and increased impulsivity [76]. Clinically, patients with exposure to MDMA will present with tachycardia, hypertension, confusion, mydriasis, ataxia, dry mouth, nystagmus, sweating, and bruxism. There is an association between MDMA and cerebral hemorrhage, cerebral venous sinus thrombosis, and aplastic anemia [77]. MDMA is also associated with pneumothorax, pneumomediastinum, and esophageal tear [78]. There is limited evidence for the etiology of MDMA-associated sudden death. However, it is likely that the sympathomimetic effects of the drug contribute to dysrhythmia, which can ultimately lead to death. There is also evidence for hyperpyrexia, rhabdomyolysis, and multiple organ failure [79]. These occurrences are likely due to excessive exertion and inadequate fluid replacement which could disrupt thermoregulation.

Treatment

Dantrolene has been used to treat MDMA-induced hypyrexia [80]. And while there is varying evidence for the effect of dantrolene on the rate of cooling in patients that experience heat stroke independent from MDMA [81], there is evidence to suggest that more rapid cooling of patients with MDMA-induced hyperpyrexia was achieved in the presence of dantrolene [82]. Serotonin syndrome is another complication associated with MDMA. This syndrome is characterized by a rapid onset of confusion, diaphoresis, diarrhea and cardiovascular instability, increased muscle tone, rigidity, tremor, and myoclonus. These patients are particularly at risk if a MAO inhibitor and a serotonin reuptake inhibitor are also on board. Some of these agents include opioids, pethidine, tramadol, methadone, dextromethorphan, and propoxyphene, which all inhibit serotonin reuptake [83, 84]. Serotonin syndrome can also exacerbate hyperthermia in MDMA users, and in severe cases, the healthcare provider should provide the following to the patient: deep sedation, paralysis, and ventilation. Patients may also present with hyponatremia and cerebral edema, which can be treated with fluid restriction, or in the case of a severely ill patient, a hypertonic saline solution may be required [85]. Acute MDMA toxicity can be managed with activated charcoal up to 1 h post-ingestion and should be followed by vigilant fluid replacement to prevent hypotension.

3.3 Summary

Substance abuse and addiction are a worldwide problem. Anesthesiology healthcare providers should be aware of this problem and the risks that substance abuse can impose on patient care. Patients of all types may present with substance abuse including emergency room patients, pregnant women, children, and the elderly. Minimization of pre-, intra-, and postoperative risks associated with anesthesia and substance abuse are of the utmost importance, and detailed patient history and screening can help to elucidate whether a patient is acutely intoxicated or a chronic substance user. Healthcare providers should remain vigilant regarding new information related to drugs of abuse and respective healthcare implications.

3.4 Review Questions

? 1. A 38-year-old male has an appointment with you, his orthopedic surgeon, to determine if he is a candidate for elective surgery. As the surgeon, you are performing a comprehensive history and physical exam to obtain a general assessment of the patient and determine if he is a good candidate for this procedure. Which of the following is the best approach to his appointment?

A. Because he is a well-educated, Caucasian man who appears well spoken and with no overt symptoms of abuse or withdrawal, you decide that you will quickly ask some general questions about the use of various substances and then move on with the exam.
B. You begin to ask questions regarding substance use, and the patient denies using any substances, including alcohol, tobacco products, and opioids. Nonetheless, you continue with CAGE and Fagerström questionnaires, as well as laboratory tests for benzodiazepines, alcohol, and opioids. You don't want to miss anything.
C. The patient admits to occasional alcohol use and smokes cigarettes socially, but he denies dependency or use of any other substances. After explaining to him the importance of this history regarding surgical risk and postoperative complications, he admits to smoking more frequently than he previously stated. At this point, you proceed with further questionnaires and potentially work with him on cessation of substances prior to surgery.
D. The patient denies use of any substances rather quickly and appears defensive. This is a red flag to you, so instead of proceeding with further questionnaires, you decide it would be best to lecture him on all the possible cardiopulmonary postoperative complications he could have, including a prolonged stay in the ICU. This scare tactic should certainly lead him to be more honest, even though you fail to mention anything about confidentiality or trust.

2. He is requesting that the surgery be scheduled for 3 weeks from today, as he has a ski trip planned in 2 months and wants to be healthy and healed by that time. What do you recommend regarding his newly diagnosed NUD (nicotine use disorder)?
A. Tell him to quit smoking prior to surgery and that he can try prophylactic lorazepam or drink alcohol to relieve his anxiety about not smoking every day.
B. Stress to the patient that smoking cessation is very important in decreasing his postsurgical complications, and you are willing to help him achieve this with use of NRT (nicotine replacement therapy). You do suggest pushing the surgery back to 4 weeks, which should still leave him enough time to heal, especially if there are fewer complications.
C. Advise that the nicotine vaccine is the newest and most common treatment for smoking cessation. If he uses this, you would even be willing to do the surgery in the next 2 weeks.
D. Tell him that nicotine use doesn't interfere with surgical outcomes; since most people these days smoke, surgeons have come up with ways to prevent any complications in these patients. You counsel him that smoking cessation may be a good goal for the future, but there's no rush for him to quit in the next few weeks.

3.5 Answers

1. C

2. B

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Awareness

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_4

4

4.1 Awareness, Recall, and Dreams

Awareness under general anesthesia (AAGA) is infrequent and occurs when patients become conscious while undergoing surgery and may result in recall of their surroundings, events, and, at times, pain related to their surgery postoperatively. Awareness generally occurs where there is an imbalance between the depth of anesthesia being provided and the degree of stimulus to which a patient is being exposed. Although the incidence of awareness or recall may be reduced with preventive measures, it may not possible to completely obviate the risk. In the absence of pain, awareness is less traumatic for patients. Additionally, inability to move due to muscle relaxation also has a profoundly stressful effect on patients.

Recall is defined as the patient's ability to retrieve stored memories and maybe exhibited as either explicit or implicit memory. Explicit memory refers to the patient's ability to recall specific events while under general anesthesia. On the other hand, implicit memory refers to alterations in patient behavior without being able to recall specific event. It is important to note that dreaming is not considered a form of intraoperative awareness and important to differentiate this from true intraoperative awareness and recall. Dreams have been excluded from the definition of intraoperative awareness by the ASA Practice Advisory for intraoperative awareness [1].

4.2 Incidence

Studies have shown a large variability in the incidence of AAGA. This could be possibly due to the various risk profiles of patients, the variation in anesthetic plan which may be influenced by surgical requirements, and different methodologies involved in the assessment for awareness postoperatively [2]. For example, the fifth National Audit Project (NAP-5) in the United Kingdom, a very large retrospective study that did not include patient interviews, reported incidence of awareness to be 1 in 19,000 anesthetics [3]. The most common tool used to establish the incidence of AAGA has been the Brice interview, conducted immediately after surgery and often repeated up to three times within a month [4]. Studies have consistently shown the incidence of AAGA to be between 1 and 2/1000 general anesthetics [5–10]. A higher incidence has been reported in cardiac (1:43), pediatric (1:135), and obstetric anesthesia (1:384) [11–13]. The significantly lower incidence in the NAP5 audit could possibly be explained to the lack of patient interviews and the dependence on anesthesiologist's recollection of events and reliance on retrospective data when conducting the survey.

4.3 Risk Factors for Awareness

Elucidating the specific risk factors for intraoperative awareness is a complex task, given the small relative incidence of awareness. Current prospective studies are largely underpowered, and the vast majority of published literature is based on case reports and case series studies.

According to epidemiological studies, the risk factors for accidental intraoperative awareness during general anesthesia (AAGA) can be classified or categorized in three main groups:

1. Patient related
2. Surgery related
3. Anesthesia technique related

Alternatively, in one of the largest studies performed in the United Kingdom, NAP5 audit [3] categorized the risk factors based on the three main phases of anesthesia: induction of anesthesia, maintenance of anesthesia, and emergence from anesthesia.

4.3.1 Patient Related

4.3.1.1 Gender

Female patients have been shown to have a higher risk for AAGA. Domino et al. [14] after reviewing 4183 anesthesia-related claims in the United States found that 77% of claims involved female patients. Mihai et al. [15] analyzed closed claims in the United Kingdom and revealed a similar finding. The NAP5 audit [3] comparatively analyzed 300 reports of AAGA and found that 65% occur in women.

Numerous other studies have concluded a higher incidence of AAGA in female patients. Morimoto et al. [16] reported after surveying 172 anesthesiologists, 24 cases of AAGA in which 76%

were women. Ghoneim et al. [17] reviewed 271 cases of reported AAGA and found that aware patients were more likely to be female. Other studies quoted an incidence at least 3 times higher in the female gender [18–20].

4.3.1.2 Age

Studies have shown a higher incidence of awareness in children versus the adult population (1% vs 0.2%) [21]. In a prospective cohort study involving 864 children aged 5–12 years who had undergone general anesthesia, 28 reports were generated for an incidence of 0.8%. In another prospective study, data obtained from interviews with 410 children (aged 6–16 years) confirmed the incidence of awareness was 1.2% [22]. Cited reasons for a dramatic increase in incidence in children in the above studies include the use of induction rooms with transport to the operating room and patients who required increased airway manipulation. In an attempt to negate institutional procedural bias, Malviya et al. showed a similar incidence of 0.8% when evaluating a cohort from three different institutions [23]. Predisposition to awareness in children under anesthesia could possibly be due to the differences in anesthetic pharmacology in children and differences in the practice of pediatric anesthesia when compared to adult anesthesia. For example, it has been found that a threefold higher minimum alveolar concentration of sevoflurane is needed to maintain a BIS value below 50 (MACBIS50) in children when compared to adults [24].

There are conflicting results as to whether age of the adult patient may have a bearing on the incidence of intraoperative awareness. Due to the inherent variability in study methods (high variability in age cutoffs), it is difficult to come to a definite conclusion if there is a difference in incidence in the younger adult population versus the geriatric population.

The ASA closed claims database showed a higher incidence of AAGA in those younger than 60 years of age (89%) [14]. The NAP5 audit (fifth National Audit Project (accidental awareness during general anesthesia)) reported an increased incidence in younger patients (25–55 years old) [3]. Similar results were seen in a study by Errando et al. who reported that patients with intraoperative awareness tended to be younger (mean (sd), 42.3 (20.5) years old vs 50.0 (18.1) years old) [25].

In contrast, a questionnaire survey conducted via the Internet involves 85,156; a majority of patients reporting awareness (67%) were older than 50 years old [16]. Additionally, Pollard et al. [26] showed that in 211,842 anesthetics delivered to adult population, there were 6 cases of AAGA with a higher incidence in older patients (55.5 versus 46 years).

4.3.1.3 Previous History of Awareness Under General Anesthesia

A previous history of AAGA is a predominant risk factor that increases the incidence of a new episode [1, 7, 18, 27]. Ghoneim et al. [17] in 2009 described that history of awareness was present in 1.6% of reported cases. Morimoto et al. [16] found that 8.3% of the cases of AAGA had previous episodes. Avidan et al. [6] described in a study with high-risk population, 11.1% had some history of previous AAGA. The NAP5 audit reported up to 5% of the cases may have had an intrinsic basis, given personal previous episodes or strong family history of AAGA [3]. Other observational study noted an adjusted fivefold higher incidence in patients with previous AAGA [28].

4.3.1.4 History of Other Medication and Substance Use

Selected specific patient populations might be "resistant" or require a greater amount of anesthetic drugs and therefore could be more at a higher risk of AAGA. These patients include but not limited to a younger age, tobacco smoking, or long-term use of specific substances (alcohol, opiates, cocaine, benzodiazepines, or amphetamines) [1, 19, 28–32].

Chronic analgesic use (opioids especially, in the setting of high doses) might translate to inadequate analgesia during a surgical procedure, resulting in a higher level of cortical stimulation that may increase risk of AAGA [1, 7, 33].

Chronic alcohol use has been shown to increase the MAC requirements of several inhaled anesthetics; this has been proposed as the mechanism causal of higher risk of AAGA in this specific population [29, 32, 34, 35].

The "resistant" patient population has been studied by Ezri et al. [36]. Investigators concluded that in patients with different genetic backgrounds, the immobilizing dose of anesthetic may vary by as much as 24%.

4.3.1.5 Physical Condition and ASA Physical Status Classification

Several studies have demonstrated increased risk of AAGA in patients with ASA class greater than 2 [8, 37]. Sebel et al. [8] showed an increased risk of AAGA in ASA Classification III and IV patients undergoing major surgery. Likewise, a prospective study [26] described a higher incidence of AAGA in patients with ASA Classifications III, IV, and IVE.

Similarly, the incidence of AAGA is greater in patients who are given a lower dose of anesthetic drug due to comorbidities such as hemodynamically unstable, hypothermic, chronically ill, or acutely intoxicated patients [38–40].

The ASA Practice Advisory for Awareness [1] acknowledges that ASA physical status of IV or V and limited hemodynamic reserve are high-risk conditions for AAGA.

In contrast, other studies showed no relationship between higher ASA physical status classification and risk of AAGA. In the United Kingdom NAP5 audit [3], after studying 167 cases of AAGA (including medication errors and ICU cases but excluding MAC/sedation cases), ASA physical status was not associated with increased risk of AAGA. Another prospective study with 4001 anesthetic cases [25] (with a reported crude 1% incidence of AAGA) found that ASA physical status had no influence on the incidence. Another large prospective study [10] with 11,785 anesthetic cases found 19 cases of AAGA, with an ASA physical status mean of 1.36 (range 1–3, median 1).

4.3.1.6 Difficult Airway

The overall population incidence of difficult airway is fairly significant, reported somewhere between 4.5% and 7.5% [41]. Although the degree of difficulty in securing the airway contributing to AAGA is unclear, several authors report it as being a risk factor [1, 18, 19, 33].

In Ghoneim et al. [17] in a review of AAGA cases, prolonged laryngoscopy and difficult intubation were present in 4.5%. There was a significant high proportion of AAGA cases associated with failed, prolonged, or difficult airway management in the NAP5 audit [3]. Additionally in 10.5% of patients with AAGA reported by Sandin et al. [10], AAGA was deemed secondary to a difficult airway. And in a more recent prospective observational study, 8% of the AAGA cases had difficult intubation related to the episode [25].

The ASA Practice Advisory for awareness [1] states that patients at increased risk for awareness include those with a history of difficult intubation or anticipated difficult intubation.

Conflicting evidence was reported by Avidan [6] where none of the reported 27 cases of AAGA had a history of or anticipated difficult intubation.

4.3.1.7 Weight: Body Mass Index

Weight or more specifically body mass index (BMI) is a controversial risk factor.

It was previously believed to be a risk factor [19, 29]. Presumed causes are often difficult airway, prolonged time for induction, hesitation on dosing guided by total body weight, and use of light anesthesia given presence of restrictive pulmonary disease or cardiovascular comorbid conditions.

However most recent studies suggest this might not be the case. Ghoneim et al. [17] reviewed 271 AAGA cases and found no association with obesity when comparing to historical controls. In Avidan et al. [6] study, BMI was not statistically significantly different in patients with AAGA than those patients without AAGA. Another retrospective study [28] found that higher BMI was associated with AAGA but only in unmatched, unadjusted analysis.

In contrast, the recent, in NAP5 audit [3], investigators found that obesity was in fact a risk factor for AAGA, particularly in the obstetric population, mentioning that over three times, as many obese patients experienced AAGA than generally undergo anesthesia. Likewise, a prospective study [26] described that 50% of their AAGA cases occurred in obese patients (BMI > 30).

4.3.2 Surgery Related

4.3.2.1 Obstetric and Gynecologic Surgery

One of the concerns of general anesthesia in obstetric cases is the effects of anesthetic drugs on the fetus/newborn and on the uterine muscle before and after delivery. A common practice is to limit anesthetic drug delivery to negate these effects. Obstetric surgery has been amply described as a risk factor for AAGA [17, 7, 30, 32, 38, 42–44]. Obstetric surgery has an increased incidence of AAGA, described from around 0.26% to as high as 28% [38, 42, 43, 13, 45, 46]

significant fluctuation in incidence based on era, type of obstetric case, and reporting bias.

Both elective and emergency surgeries have increased risk of AAGA in the obstetrics population [42, 46]. Additionally, specific to gynecologic surgery, there is a reported higher AAGA risk reported by some authors [17].

NAP5 audit [3] confirmed that obstetrics anesthesia is a high risk for AAGA (it was the surgical specialty most overrepresented in the AAGA cases sample). This finding was supported by Errando et al. [25], who prospectively investigated 4001 anesthetics and reported that Cesarean section was a statistically significant factor associated with AAGA ($p = 0.019$).

Multiple explanations for this increased risk have been established and mostly are related to other previously described risk factors for AAGA. These include, but not limited to, utilization of low-dose anesthetic to avoid some of the tocolytic effects, hemodynamic instability or acute bleeding, rapid sequence induction (RSI), universal utilization of NMBD, omission of opioids on a significant portion of the anesthetic, difficult airway management, obesity, and high incidence of emergent/urgent cases, among others [1, 3, 17, 44, 13, 45]. This might explain why the use of regional anesthesia has dramatically increased in recent years, with a simultaneous decline in the use of general anesthesia for obstetrics cases [47] (Birnbach and Browne [96]).

4.3.2.2 Cardiothoracic Surgery

Cardiothoracic surgery by itself has been described as a risk factor for AAGA [1, 17–19, 48]. Additionally, it might be related to patient comorbidity (see "Physical Condition" above) and the need for cardiac surgery patients to be under cardiopulmonary bypass (CPB).

Upon review of the published cases of AAGA, Ghoneim et al. [17] found an increased incidence during cardiac surgery. Pollard et al.'s [26] study in academic centers also revealed increased risk and incidence in cardiac surgery.

Incidence of AAGA during cardiac surgery has been reported to be 1.14–23% [38, 48, 49]. Ranta et al. [50] reported an incidence of 4% AAGA, particularly in young population undergoing cardiac surgery. But after introduction of some preventive techniques, there was an incidence reduction to 1.5%, in the 303 cardiac surgery patients. Subsequently in a larger study, the same group [11] demonstrated an AAGA incidence of 0.5% in about 1218 cardiac surgery patients.

Dowd et al. [51] demonstrated the lowest incidence of AAGA in cardiac surgery patients undergoing CPB (0.3%), achieved by balanced anesthetic technique providing continuous inhaled (isoflurane) or intravenous (propofol) anesthetic before, during, and after CPB.

More recently Myles et al. [7] reported an incidence of about 0.45% AAGA in cases where the majority underwent coronary artery bypass grafting (CABG). Wang et al. [52] reported that an incidence of awareness of patients who received off-pump CABG, CABG under cardiopulmonary bypass (CPB), and septal repair or valve replacement under CPB was 9.6%, 4.7%, and 4%, respectively. Authors concluded that the majority of AAGA occurs before bypass grafting or CPB.

In summary, cardiothoracic surgery has been and continues to be considered as a high-risk factor for AAGA. Incidence has been declining in recent years, perhaps due to changes in anesthetic management, education, and vigilance. Despite this it still has an overall incidence that is much higher than reported in non-cardiothoracic surgery.

4.3.2.3 Trauma and Emergency Surgery

Major trauma and emergency surgery are frequently associated with hemodynamic instability that occasionally necessitates reducing the dose of anesthetic given. Additionally, hypothermia, hypovolemia, acute intoxications, brain trauma, and multiple injuries are factors present that may affect the anesthetic dose administered.

Bogetz et al. [39] demonstrated that the incidence of AAGA of surgery in victims of major trauma is considerable, ranging from 11% to 43% in the cases studied, particularly in cases where anesthesia is interrupted or severely reduced. Interestingly AAGA occurred despite significant hypotension, thought to be protective due to the proportional decrease in cerebral perfusion pressure. Myles et al. [7] studied high-risk AAGA patients, which included acute trauma with hypovolemia. Ghoneim et al. [17] also found an increased incidence during trauma surgery. The NAP5 audit [3] revealed (after reviewing 110 certain/probable cases of AAGA) that emergent/urgent surgery ($p < 0.0001$) and out-of-hours

surgery ($p < 0.0001$) were also risk factors. Out of hours surgery was also reported by other studies as a significant risk factor for AAGA ($P = 0.013$) [25].

4.3.2.4 Other Types of Surgeries/ Procedures

Other types of surgery have been described as a risk factor for AAGA. Surgery types also reported to be of higher risk, including cervical, cranial, facial surgery (including otorhinolaryngology) and bronchoscopy/jet ventilation procedures [7, 53, 54]. Possible reasons include the use of total intravenous anesthesia (discussed below), which is common especially when neuro-monitoring is utilized as in neurosurgery or when airway management by the pulmonologist or surgeon precludes the use of inhalation agents, for example, during the use of jet ventilation.

4.3.3 Anesthesia Related

4.3.3.1 Total Intravenous Anesthesia (TIVA)

TIVA is considered a significant risk factor for AAGA. However, studies have shown contrasting results.

The first reported case of AAGA under TIVA was a patient undergoing repeat emergency cardiac surgery, where they utilized high-dose fentanyl combined with diazepam and oxygen [55]. Subsequently, there have been other reports of an increased incidence of AAGA when anesthesia was maintained only with high-dose fentanyl [56] or utilizing intermittent IV boluses [29].

A repeatedly cited case of AAGA during propofol TIVA was Kelly et al.'s [57] description of a patient undergoing a micro-laryngeal surgery. But this is not an isolated event; multiple studies have been published that relate AAGA with TIVA, providing support for the high-risk statement.

Miller et al. [58] developed a randomized double-blinded clinical trial to study the effects of midazolam on a specific TIVA protocol, but the study was halted due to an increased incidence of AAGA (19.1%).

Domino et al. [14] reviewed close to 4200 anesthesia related claims in the United States and showed that cases of AAGA were more likely to involve anesthetic techniques using no volatile anesthetic (OR = 3.20, 95% CI = 1.88–5.46).

In the largest prospective observational study with 4001 patients, Errando et al. [25] showed higher incidence of AAGA in patients administered with TIVA, in comparison with those administered with a balanced anesthesia (intravenous induction drug plus a halogenated inhaled agent).

Morimoto et al. [16] after surveying 172 anesthesiologists and reviewing 85,000 cases reported 24 cases of AAGA. In 21 cases (88%) TIVA was used, whereas inhaled agent was used only in 2 cases where AAGA was reported (9%).

NAP5 audit [3] also demonstrated that TIVA (including target-controlled, manually controlled infusion and fixed-rate infusions as well as bolus techniques) resulted in increased number of AAGA incidences. In particular, when switching inhaled anesthetics to TIVA for transport, the highest risk profile was found to be when TIVA was associated with neuromuscular blocking agents.

In contrast, a large study of patients receiving TIVA (propofol- and opioid-based anesthesia) [59] for short-stay surgical procedures found no occurrence of AAGA in a cohort of 5216 cases. Although only 7% of the cases required neuromuscular blocking drugs (NMBD). Supporting the previous statement, a prospective study [60] analyzed 1000 cases of TIVA (propofol, alfentanil, and NMBD) and found the same incidence of AAGA as general inhaled anesthesia with NMBD (0.2%). Sandin et al. [61] also published a review of five cases of AAGA under TIVA and concluded that all of them were caused primarily by lack of experience and could have been prevented.

The general consensus is that TIVA is considered a risk factor of AAGA, mainly related to delayed infusion starts delay in achievement of therapeutic levels, inadequate induction doses, suboptimal administration modes, failure of delivery mechanism, and/or inexperience with this anesthetic technique.

4.3.3.2 Neuromuscular Blocking Drugs (NMBD)

NMBD are considered one of the largest risk factors for AAGA. If complete muscle paralysis is present, a somewhat useful sign of anesthetic depth is abolished which in turn infers an increased risk for AAGA. In fact, probably the first report of AAGA was using a NMBD (Curare) [62].

In the NAP5 audit [3], the incidence of AAGA was 1:8000 when neuromuscular blockade was

used and 1:136,000 without the use of neuromuscular blockade.

The association of NMBD and AAGA was stablished long before large studies like the NAP5. Hutchinson [63] review of 656 patients found eight cases of AAGA mainly in patients receiving nitrous oxide and large doses of NMBD. Similarly, Guerra et al. [29] presented several cases of AAGA with the use of inhaled nitrous oxide and NMBD alone. In the 1990s, nitrous oxide was used less frequently, and Liu et al. [27] reviewed more than 1000 anesthetics and found only two cases of AAGA, and both were related to NMBD shortly after induction. Domino et al. [14] after reviewing 79 cases of AAGA demonstrated that those cases were more likely to involve anesthetic techniques using NMBD (OR = 2.28, 95% CI = 1.22–4.25).

More recently, Sandin et al. published a study [10] involving 12,000 Swedish patients; AAGA incidence was 0.10% in the absence of NMBD, compared with 0.18% in the presence of NMBD. This was again supported by Sebel et al. [8], where 65% cases of AAGA received NMBD.

Although the risk of AAGA with NMBD and its association has been established, it is important to note that there are many reports of AAGA in the setting of no NMBD being administered.

4.3.3.3 Light Depth of Anesthesia

A commonly cited risk factor for AAGA is light anesthesia, intentionally performed in conditions where higher doses are not achievable (see "Physical Condition" above). But cases of AAGA seemed to be more often related to failure in vaporizers, lack of monitoring anesthetic gas, or clinical knowledge failure [19, 38].

Light anesthesia might also occur when there is failure to recognize the concentration of agent administered and is lower in comparison with the dialed in concentration [19]. This occurs fairly common when gas or vaporizer monitors are not used [14]. A study by Bergman et al. [64] revealed that in cases of AAGA, up to 13% had a failure in nitrous supply or there was no volatile concentration monitoring.

Ranta et al. in 1998 [65] reported that the use of smaller doses than usual (isoflurane and propofol) was seen more frequently in the AAGA group. Ghoneim [19] stated, after reviewing previously published cases, that absence of volatile anesthetic or propofol during maintenance of anesthesia was related to AAGA in 23% of the cases.

4.3.3.4 Failure of Equipment, Misuse, and Mistakes

Defective anesthesia systems or failure of equipment may result in inadequate anesthetic delivery to the patient, posing a risk for AAGA [29, 66].

Equipment failure in developed countries is rapidly decreasing [19]; more frequently the risk of AAGA is more likely related to misuse than failure [14, 66, 67]. Recently Wang et al. [68] demonstrated that not using inhaled anesthetic concentration monitoring increased the risk of AAGA from 0.164% to 1.14%.

Medication error and syringe swaps have also been described as a risk factor for AAGA or even a more frequently direct cause of "awake paralysis" [14].

NAP5 audit [3] reported 17 cases of "awake paralysis," due to drug error/medication swaps. Additionally they attributed a large portion of the cases of AAGA under TIVA to failure to deliver the intended dose of drug, which could be possibly due to a problem with the intravenous cannula or infusion pump.

4.3.3.5 Inhaled Anesthesia: Nitrous Oxide

Other common scenario where there has been an increased incidence of AAGA is when inhaled anesthesia is maintained only using nitrous oxide as a sole agent. This finding has been described multiple times, in case reports when utilizing nitrous oxide as main anesthetic in combination with ketamine [69] or with high-dose narcotics [70] resulting in AAGA. Utting [71] described that, when used alone, inhalation anesthesia with nitrous oxide was associated with a 2% risk of AAGA. Errando et al. [25] also showed increased AAGA in the described mixed anesthesia group (any intravenous induction drug on induction with nitrous oxide with oxygen maintenance). Similarly Hutchinson [63] reported eight cases of AAGA where nitrous oxide was the main inhaled anesthetic.

4.3.3.6 Transport and Remote Locations

Classically induction of anesthesia was performed in the "induction room" or "anesthetic room," a concept that is still used in many countries, including the United Kingdom. NAP5 audit [3] revealed that transfer of the patient from anesthetic room to operative theatre was a major factor in many

AAGA cases; associated factors include emergent induction, rapid sequence intubation, transport or remote locations, use of short-acting induction drugs, trainees delivering anesthesia, presence of a difficult airway, and avoidance of opioid with induction.

Other published literature demonstrated transport as a risk factor [27].

4

4.3.3.7 Premedication

Several studies have shown an association of lack of premedication and AAGA. But overall there is lack of consensus [1].

In a study by Wilson et al. [20], 11% of 490 patients had mental disturbances during anesthesia, of which 1% had AAGA. There was no difference in premedication regimen, anesthetic agent used, type of surgery, or demographics (age, gender) between the cases with and cases without AAGA.

Errando et al. [25] found that benzodiazepine premedication was associated with a lower incidence of AAGA.

Wilson et al. [72] evaluated 150 obstetric cases, 3% had AAGA with narcotic premedication, in comparison with 21% that had AAGA with no premedication, with no other statistical significant difference in the anesthetic care of both groups.

In the cases reviewed by Ghoneim et al. [17], benzodiazepines and pre-induction medications were used less in the AAGA cases.

4.4 Monitoring for Intraoperative Awareness

Immediate detection of intraoperative awareness at the time of occurrence is not feasible. Awareness under anesthesia is usually confirmed postoperatively after obtaining information from the patient. Therefore, anesthesiologists should rely on indirect measurements and observations.

Physiological and motor responses do not accurately indicate the presence of an aware patient. Anesthetic drugs, cardiovascular medications such as beta-blockers, and the use of neuromuscular blocking agents frequently negate the ability to detect awareness based on patient's vital signs and purposeful motor movement.

4.5 Clinical Signs of Awareness

Clinical signs used to evaluate for intraoperative awareness include purposeful movements to command or stimulation, eye opening, eyelash reflexes, pupillary responses, perspiration, and tearing. Vital signs such as the heart rate and blood pressure are more commonly relied upon when the patient has been administered muscle relaxation. However, such signs can be easily masked by the concurrent administration of many drugs either preoperatively or intraoperatively. For example, anticholinergic and narcotics cause either mydriasis or meiosis. Anticholinergics may also reduce secretions, lacrimation, and sweating. Antihypertensives (beta-blockers, calcium channel blockers, ACE-inhibitors) may mask the hypertension and tachycardia manifestations of "light anesthesia." Hypovolemia either from dehydration or from blood loss or the use of neuraxial blockade may lead to hypotension masking the hypertension that may be seen with an inadequate anesthetic depth.

In fact, a closed claims analysis by Domino et al. showed the absence of hypertension and tachycardia in a majority of cases of recall under anesthesia in the database [14]. The author's analysis found that a rise in blood pressure was seen in only 15% of cases, an increased heart rate in only 7%, and motor movements was observed in only 2%. Clinical signs are thus very unreliable in discerning "light anesthesia," and despite presumed adequate depth of anesthesia, awareness under anesthesia may still occur.

4.6 Processed Electroencephalogram (EEG)

Processed EEG has been postulated as a more reliable tool in identifying those patients who may be under-anesthetized. One commonly used device is the Bispectral Index® (BIS; Aspect Medical Systems, Natick, MA, USA). The BIS monitor processes an electroencephalographic signal (using a proprietary algorithm) to calculate a number that provides a measure of the patient's level of consciousness. BIS values range from 0 to 100, the higher number reflecting a more awake patient. BIS values below 40 indicate a deep hypnotic state. BIS values between 40 and 60 have

been advocated to prevent anesthesia awareness [73]. Evidence that these devices detect and prevent intraoperative awareness is contradictory. Ekman et al. compared 4945 anesthetized patients utilizing EEG monitoring with a historical control group without EEG monitoring and showed a fivefold reduction of the risk of awareness [74]. In the B-aware study involving 2500 patients, investigators detected a 82% risk reduction in awareness with EEG monitoring [7]. However, in a recent single center randomized prospective study, in patients at a high risk of awareness, BIS monitoring was not found to be associated with a lower incidence of AAGA or a reduction in the administration of volatile anesthetic [5]. Regarding BIS monitoring, both the National Institute for Health and Care Excellence (United Kingdom) and the Food and Drug Authority (United States) say that the use of BIS monitor "may" help guide anesthetic administration thereby reducing the probability of awareness [75, 76]. The reliability of BIS monitoring in preventing AAGA is thus questionable.

The prediction probability Pk value has been recommended as an appropriate measure for evaluating and comparing the performance of anesthetic depth indicators [77]. Prediction probability has a value of 1 when the indicator predicts anesthetic depth perfectly and a value of 0.5 when the indicator predicts a 50:50 chance. The Pk values for BIS monitor between awake and loss of response ranged from 0.72 to 1.00 and from 0.79 to 0.97 between an anesthetized state and first response [33].

Other spontaneous EEG monitors include entropy (GE Healthcare Technologies, Waukesha, WI, USA) with reported Pk values of 0.83–0.97 for loss of consciousness and Narcotrend (GE Healthcare Technologies, Waukesha, WI, USA) with Pk values 0.93–0.99 between awake and loss of response and from 0.94 to 0.99 between an anesthetized state and first response [33]. BIS is by far the most studied depth of anesthesia monitor.

4.7 Evoked Potential Monitoring

Auditory evoked potentials consist of a series of waves (positive and negative) that represent the transmission and processing of an auditory stimulus from the cochlea, through the brain stem, the auditory cortex, and to the frontal cortex. Mid-latency auditory evoked potentials (MLAEP) occur 10–100 ms post auditory stimulus [78]. Studies have shown a dose-dependent suppression of MLAEP with both intravenous and inhalation anesthetics leading to the notion that MLAEP measurements could be a useful depth of monitoring tool [78, 79]. The effectiveness of MLAEP monitoring in reducing intraoperative awareness in humans needs further validation.

4.8 Intraoperative Awareness and Medicolegal Consequences

Intraoperative awareness is an unwanted outcome for both the patient and the anesthesiologist. Explicit, or conscious, memories experienced under general anesthesia are one of the most important causes of patient dissatisfaction [80]. Fortunately, not every case of recall leads to a malpractice claim. One out of 25 claims resulted from negligent care, and these numbers drop when the standard of care is followed [81–83]. Interestingly, there is a large disparity when comparing the incidence statistics of intraoperative awareness, which now occurs in less than 1 in every 700 general anesthetics [8], and the evaluation of closed claims, which are only approximately 10 per year [84]. It is uncertain why there is such a difference between the incidence and the claims filed with the ASA Closed Claims database, but it is important to note that only one third of anesthesiologists are captured based on claims from liability insurers. Theoretically, this disparity is secondary to both the nature and severity of the injuries associated with intraoperative recall and the compensation of these claims. Not surprisingly, patients who experience this adverse event and do not suffer long-term sequelae choose not to pursue a malpractice suit. As previously studied, an empathetic apology from the provider offers the benefit of both preventing escalation of the situation and is therapeutic to the individual who has suffered [85, 86]. The other protective factor is the requirement of negligence by the anesthesiologist to be proven for the tort system.

Common causes leading to a patient filing a claim against the provider include poor communication, unmet expectations, and financial pressures faced by the individual. Studies have

shown that 50% of patients who filed a claim felt they had a poor relationship with their physician [87]. Thus, this supports the notion that providers who provide open communication with their patients are less likely to be sued. University of Michigan Health System (UMHS) implemented a program that included full disclosure and offered compensation to individuals for medical errors. After implementing this program, a study found that average monthly rate of new claims decreased from 7.03 to 4.52 per 100,000 patient encounters (rate ratio [RR], 0.64 [95% CI, 0.44 to 0.95]) [88]. It is important to remain empathetic, as providers who dismissed the patient's concerns are likely to exacerbate injury and contribute to initiation of a malpractice claim by the individual [85, 89, 90].

The legal system and lawyers act as gatekeepers for malpractice claims. A United States survey found that attorneys are reluctant to take on cases in which expected financial compensation was less than $61,700 (adjusted to 2007 dollars) [87] and a Canadian study found that the threshold was $107,000 dollars (adjusted to 2007 dollars) [91]. This makes sense as the legal system has most plaintiff lawyers work on contingency-fee basis, which means the attorneys are paid with a percentage of the award as a fee and earning nothing if they lose the case.

Data from the Closed Claims Project includes ongoing evaluation of adverse anesthetic outcomes obtained from the files of 37 participating liability insurance companies. Intraoperative awareness only represents 2% of all claims filed. Comparing the recent claims filed in the Closed Claims database and those previously published by Domino et al. in 1999, the majority of patients who filed claims for awareness were female, with an ASA classification I-II, less than 60 years old, and underwent elective surgery [14]. The new data shows that the proportion of individuals pursuing legal action and undergoing obstetric or gynecologic surgery decreased from 30% to 20%, but the proportion of claims associated with cardiac surgery increased from 5% to 21%. This shift creates an unanswered problem, as patients undergoing cardiac procedures have previously been recognized as being among the highest risk for the occurrence of awareness [49]. It is currently unclear why there has been a rise in intraoperative awareness claims with regard to cardiac surgery.

From the Closed Claims Project, we know that the median payment (adjusted for inflation to 2007 dollars) in recent claims was $71,500, with a range of $924 to $1,050,000 [92]. This is a drastic increase from the median payment of $26,065, evident from Domino et al. in 1999 [14]. Again, it is unclear why the payments for awareness have increased, especially since these trends have not been observed for other anesthesia complications.

ASA Committee on Professional Liability initiated the development of the Anesthesia Awareness Registry in October 2007 to help physicians understand the patient's perspective of intraoperative awareness. An important discovery from the Anesthesia Awareness Registry is that some patients contacted the registry after an intraoperative awareness event, but upon review of their medical records, it was revealed that they had received regional anesthesia or monitored anesthesia care [92]. This realization demonstrates that one of the main issues with regard to this adverse event is poor communication between the physician and patient and addressing individual expectations.

4.9 Psychological Sequelae of Awareness Under Anesthesia

Given the context of intraoperative awareness, there are concerns for psychologic sequelae. A study published in *General Hospital Psychiatry* by Osterman et al. found that patients reported intraoperative experiences including an inability to communicate, helplessness, terror, and pain [93]. Post-awareness individuals had significant postoperative distress related to feeling unable to communicate, unsafe, terrified, abandoned, and betrayed. Due to these outcomes, one could expect that patients might develop mental conditions, such as post-traumatic stress disorder (PTSD) as a potential result.

Osterman et al. [93] demonstrated that 9 of 16 subjects (56.3%) met diagnostic criteria for PTSD. Another study by C. Lennmarken [94], demonstrated that four of the nine patients who were interviewed 2 years after intraoperative awareness were still severely disabled due to psychiatric sequelae. These studies demonstrate a high incidence of long-term sequelae following AAGA.

Multiple studies demonstrated a rate of PTSD between 2% and 71% [95]. Further evaluation found that patients with postoperative

psychological sequelae, which may be inclusive of PTSD, ranged from 20% to 84%. The broader psychological sequelae of AAGA included vague complaints including "after effects," "sleep disturbances," and "temporary emotional distress." Leslie et al. in a prospective evaluation of patients in the B-aware trial found that five out of the seven patients who developed awareness and were available for follow-up met the diagnostic criteria for severe PTSD [95]. A significant confounding factor was that the incidence of PTSD in the control population of 25 patients was 12%. Extrapolating to the 2450 non-awareness patients of the B-Aware trial, this incidence would suggest that almost 300 patients developed PTSD after their high-risk surgery, which does not match the current incidence statistics of intraoperative awareness [8].

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Shared Airway: Techniques, Anesthesia Considerations, and Implications

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_5

Key Points

- Shared airway anesthesia refers to the anesthesiologist maintaining the airway and ventilation of the patient as the surgeon performs procedures in the same anatomic space. Shared airway anesthesia is commonly encountered in pediatric surgery, otolaryngology, oral and maxillofacial surgery, and dentistry.
- Minimizing risk during shared airway procedures begins with a thorough preoperative assessment, including a full history, physical, and airway examination.
- Open airway techniques encountered during shared airway anesthesia include (1) monitored anesthesia care, (2) mask ventilation, (3) insufflation with spontaneous respiration, (4) jet ventilation, and (5) laryngeal mask airway.
- Standard cuffed endotracheal tubes are often not ideal for various head and neck procedures. For maxillofacial trauma cases, where maxillomandibular fixation is required, nasotracheal intubation is the preferred airway.
- For shared airway cases with difficult airways, videolaryngoscope-guided intubation, fiber-optic-guided intubation, or a surgical airway may have to be considered as alternatives to standard intubation techniques.
- Shared airway procedures involving lasers require the use of a cuffed laser-resistant tube. The cuff should be filled with saline, which is tinted with methylene blue.
- The emergent surgical airway of choice, in patients older than 12 years, is a cricothyroidotomy.
- Complications encountered in shared airway anesthesia include failed intubation, laryngospasm, foreign body aspiration, surgical fire, and vocal cord paralysis.
- The gold standard for intraoperative monitoring of a patient's ventilation is waveform capnography.
- Throat packs can be used in shared airway anesthesia to prevent aspiration of blood, oral secretions, surgical debris, and instrumentation. However, throat packs must be removed to prevent risk of airway obstruction following extubation.

5.1 Introduction

A shared airway during anesthesia refers to the anesthesiologist maintaining the airway and ventilation of the patient as the surgeon performs procedures in the same anatomic space. This is commonly encountered in pediatric surgery, otolaryngology, oral and maxillofacial surgery, and dentistry under general anesthesia. Sharing the airway during anesthesia, both inside and outside the operating room, with surgeons performing head and neck or intraoral procedures can be challenging and lead to an increased risk for possible complications. This type of situation requires careful planning by both the anesthesia and surgical teams, along with open communication between providers. Head and neck procedures can be performed under the continuum of anesthesia from minor sedation to general anesthetic. Overall, security of the airway for these patients should be seen as an institutional responsibility, and all possible weak points should be identified through all phases of care [1].

According to a closed claims analysis by the American Society of Anesthesiologists, adverse outcomes, within the operating room and during non-operating room anesthesia (NORA), are most commonly associated with respiratory events [2, 3]. Within the operating room and during NORA, they represent 37% and 38% of all injury cases, respectively [2, 3]. Cases occurring outside the operating room most commonly occurred within the gastrointestinal (GI) suite [3]. It is important to recognize that a majority of the published data represents anesthesia administered by anesthesiologists, but does not account for anesthetics performed outside of the operating room by other trained medical professionals. The American Association of Oral and Maxillofacial Surgeons published a 10-year closed claims study, including data from 1989–1998, which showed respiratory events as the highest incidence of adverse events. Considering the additional difficulty associated with shared airway procedures, the focus of this chapter will be to discuss safe practice regardless of provider type or location.

5.2 Patient Evaluation

Preoperative assessment of the surgical patient is imperative in minimizing risk during shared airway procedures. Fortunately, most head and neck procedures are considered "low-risk" anesthetics

and are often performed on healthy patients [1]. The preoperative assessment should include a full history and physical examination. Additionally, a full anesthetic/airway history should be obtained to include any previous complications, difficult intubations, or airway compromise. If available, previous anesthetic records should be reviewed. A previous history of difficult airway management is often the best predictor of future complications and can identify a need for additional planning and precautions [4]. This process should also determine if there are any existing medical conditions that can impact airway management [5].

Any symptoms relating to the head and neck or intraoral procedure to be performed should also be considered as a potential source of airway compromise during anesthesia. Many shared airway procedures are on patients that may have airway compromise such as voice disorders, foreign body aspiration, trauma to the maxillofacial region, papillomas, vocal cord dysfunction, tracheal stenosis, or tumors [6]. When radiological studies are necessary for surgical evaluation or planning, it is often helpful to utilize cone beam computed tomography (CBCT), traditional computed tomography (CT) scans, or magnetic resonance imaging (MRI) to assess the patency and anatomy of the patient's airway. These radiology studies can aid in the planning process when: deviation of the airway exists, tumors or pathology that may alter or decrease airway volume exists, or bony and/or anatomic deformities exist that may impair intubation or ventilation. In certain cases, a three-dimensional volumetric airway analysis can be obtained to further assist in the planning process. The use of cone beam CT is well documented in the orthodontic and oral and maxillofacial surgery literature, describing volumetric airway changes following expansion of the palate and orthognathic surgery for either dentofacial deformities or obstructive sleep apnea.

A recent history of an upper respiratory tract infection (URI), particularly in the pediatric population, is also essential. Recent URI can predispose a patient to having a reactive airway and increases the risk for laryngospasm or bronchospasm during induction or emergence from anesthesia. This can also increase the risk for prolonged intubation following longer surgical procedures. These adverse anesthetic events can further complicate shared airway procedures and possibly postoperative healing. It is controversial whether short procedures should be canceled due to recent URI, but it may be prudent to consider rescheduling longer procedures and those that involve surgical management of the airway [7].

A complete social history to include the use of alcohol, tobacco, or illicit drugs is necessary. Of these, tobacco use is the most relevant during shared airway procedures. Not only does smoking impair healing and compromise the cardiovascular system; it increases the risk of respiratory events during and following anesthesia. In a shared airway procedure or an airway that may be considered difficult, this can have a deleterious effect. Schwilk and colleagues reviewed over 26,000 anesthetic procedures for respiratory events and found an incidence of 5.5% in smokers and only 3.1% in non-smokers. Complications included re-intubation, bronchospasm, laryngospasm, and hypoventilation [8]. Numerous studies have shown that smoking cessation for more than 4 weeks prior to surgery reduces the risk of respiratory and wound complications and, with cessation of over 8 weeks, complication rates approach that of non-smokers [9].

As part of the physical exam, a full head and neck exam should be performed along with a thorough airway evaluation. The airway examination should include at a minimum the maximum incisal opening, Mallampati-Samsoon classification, damaged or loose teeth, range of motion of the neck, thyromental distance, tracheal deviation or neck masses, facial hair, and assessment of tonsillar size. Airway examination features associated with the potential for a difficult airway with potential to escalate into a "cannot ventilate" or "cannot intubate" situation are listed in Table 5.1 [10–15].

5.3 Open Airway Techniques

5.3.1 Monitored Anesthesia Care (MAC) or Intravenous Conscious Sedation (IVCS)

According to the ASA, monitored anesthesia care (MAC) is defined as a planned procedure where local anesthesia is administered, along with sedation and analgesia [16]. MAC produces a similar level of anesthesia as moderate conscious sedation, except the provider must be capable of

Table 5.1 Difficult Airway Risk Factors

Difficult mask ventilation	Difficult direct laryngoscopy
Age >55 years old	Reported history of difficult intubation, aspiration pneumonia, or dental/oral trauma following intubation
Obstructive sleep apnea/snoring	Obstructive sleep apnea/snoring
Previous head and neck radiation, surgery, or trauma	Previous head and neck radiation, surgery, or trauma
A beard	Congenital disease such as Down syndrome, craniofacial syndromes, cleft lip and palate, or Pierre Robin syndrome
Edentulism	Rheumatologic disease such as scleroderma, spondylitis, or rheumatoid arthritis
Body mass index >26 kg/m^2	Obesity
Current head and neck tumor or infection	Poor flexion and extension of neck/cervical spine disease
	History of head and neck burns
	Current head and neck tumor or infection
	Mallampati class III or IV
	Limited maximum incisal opening (<30 mm)
	Dentofacial deformities (high-arched palate, retrognathia)
	Thyromental distance (<60 mm)
	Macroglossia
	Short neck

References: [1–5]

converting to general anesthesia if necessary or rescuing the patient's airway if it becomes compromised at any time. MAC is often administered in the operating room setting by a separate anesthesia provider, but IVCS is often administered during office-based procedures utilizing a team model. Both techniques are commonly employed during shared airway procedures. The anesthesia provider must have a solid understanding of the procedure to be completed and any potential risk to the airway. For example, during dental restorations, there may be a need to irrigate the oral cavity or utilize instrumentation that could possibly be aspirated if precautions are not taken.

A moderate level of sedation and analgesia is often favorable in shared airway procedures because it allows the patient to undergo prolonged or stimulating procedures without significant anxiety, discomfort, or pain. The patient may have a depressed level of consciousness but can still respond purposefully to commands, maintain a patent airway, and support cardiovascular function.

The best way to reduce airway complications is through prevention and early recognition of obstruction. In 2017, the ASA assigned a Joint Task Force to create *Practice Guidelines for Moderate Procedural Sedation and Analgesia* for use by all providers who perform moderate procedural sedation and analgesia in any inpatient or outpatient setting. The task force consisted of fifteen members, to include physician anesthesiologists, a cardiologist, dentist anesthesiologist, emergency physician, gastroenterologist, oral and maxillofacial surgeon, radiologist, an ASA staff methodologist, and two consulting methodologists for the ASA Committee on Standards and Practice Parameters. Of the members, anesthesiologists, dental anesthesiologists, gastroenterologists, and oral and maxillofacial surgeons often perform

shared airway procedures under moderate sedation. Therefore, many of the *Practice Guidelines for Moderate Procedural Sedation and Analgesia* apply to improving safety during these types of procedures or in patients based on scientific evidence. In regard to the actual administration of moderate sedation and analgesia, patient monitoring is probably the most important factor in recognizing and preventing a potential complication. Upon review of the literature, the task force found three supported monitoring techniques: (1) continually monitored ventilatory function with end-tidal carbon dioxide (capnography), which has been shown to reduce the number of hypoxic events as defined as oxygen saturation <90%, (2) pulse oximetry as being effective in detecting oxygen levels during moderate sedation, and (3) electrocardiography which can adequately detect arrhythmias, premature ventricular contractions, and bradycardia. By instituting these recommendations, along with the other parameters relating to the administration of moderate sedation, the practitioner can hopefully prevent any major complications [17, 18].

Other adjuncts that can be utilized during moderate sedation to help maintain a patent airway are oro- or nasopharyngeal airways. Oral airways can relieve obstruction by preventing posterior displacement of the tongue. Unfortunately, oral airways are excellent for mask ventilation but often stimulate a patient's gag reflex during lighter planes of anesthesia. Nasal airways are lubricated and placed through one of the nares. If properly chosen, it should be long enough to traverse the nasopharynx without impinging on the glottis. During moderate sedation or MAC, the nasal airway is often better tolerated as it does not stimulate the gag reflex but still improves airway patency [19].

5.3.2 Mask Ventilation

Mask ventilation can be used as the primary airway management technique during short anesthetics, during the preoxygenation phase, as a temporary measure to help obtain a more definitive airway, as a means to induce anesthesia in the pediatric population, and as a rescue technique when a difficult airway is encountered. One drawback to mask ventilation is that it does not prevent aspiration. Considering mask ventilation is often performed with a chin lift and jaw thrust; one must be cautious in extensive facial trauma cases or when cervical spine fractures are encountered. As discussed previously, the use of oral and nasal airways can be utilized during mask ventilation. If chin lift and jaw thrust fail to open the airway, oral and nasal airways can be utilized as helpful adjuncts to relieve obstruction and improve ventilation during mask ventilation [20].

Mask ventilation is a commonly employed technique in the pediatric population to provide inhalational anesthesia to atraumatically obtain intravenous access. It is also commonly utilized for shared airway procedures as an intermittent apnea technique for short duration cases in an easily ventilated patient, such as suture removal, extraction of primary teeth, nasopharyngoscopy, and frenectomies [20].

Difficulty in mask ventilation is typically encountered when there is either obstruction of the upper airway or inability to maintain a seal around the ventilation mask. Some of these factors are outlined in Table 5.1. If a patient is potentially difficult to mask ventilate, it should not be chosen as the primary mode of airway management [20]. Other potential complications include the lack of control over the airway, potential for aspiration, and soiling of the airway from surgical debris or the oral cavity.

5.3.3 Insufflation/Spontaneous Respiration

This technique combines administration of anesthetic gas along with administration of local anesthesia. The volatile gases are insufflated through either small catheters above the larynx, endotracheal tubes placed through the nose and into the oropharynx, or a port on the laryngoscope to a spontaneously breathing patient. This technique is commonly employed in laser airway cases for subglottic stenosis in the pediatric population. Once the patient reaches an adequate plane of anesthesia, the airway can be manipulated. The complication profile for this technique is similar to that for mask ventilation but also carries a risk associated with airway laser surgery to include laryngospasm or bronchospasm from lighter planes of anesthesia and the potential for airway fires.

5.3.4 Jet Ventilation

Jet ventilation can be administered in a variety of ways and is a common technique when performing surgery in the larynx, trachea, or bronchus. It involves intermittent administration of high-pressure air or oxygen at either a high frequency or low frequency, with rates of 100–150 or 15–25 breaths per minute, respectively [21]. The patient is commonly induced by either inhalational, intravenous, or a combination of techniques. The airway is then insufflated via a subglottic cannula, supraglottic cannula, or transtracheal ventilation or through the endoscopy equipment itself. When a patient with known tracheal stenosis is undergoing an airway procedure, it is important that the patient be under general anesthesia and a rigid scope used for bronchoscopy to perform the procedure and ventilate the patient. Otherwise, the airway can deteriorate into complete obstruction [21, 22].

Jet ventilation requires the anesthesiologist and surgeon to communicate throughout the procedure to ensure successful treatment of the patient and ensure their safety [21–23]. Anesthetic induction is often performed and the airway is maintained with an LMA until the surgeon is ready to start. In the case of subglottic or transtracheal jet ventilation, the catheter is then placed and the LMA removed. For supraglottic jet ventilation, the LMA is removed and the rigid scope with ventilation capability is placed. The depth of general anesthesia is typically maintained via total intravenous anesthesia (TIVA) and paralytics to allow for adducted, motionless vocal cords. Antisialagogues are also administered to control secretions. Once the procedure is completed, the LMA is replaced prior to emergence for a smooth awakening [21].

According to Cozine and colleagues, who performed a multi-institutional study that examined over 15,000 CO_2 laser airway surgeries, jet ventilation was found to have a very low complication rate. Overall, the rate was 1.18%; half of those complications were ventilation-related (pneumothorax 0.25% and hypoxia 0.15%), and the other half were unrelated to ventilation. In comparison to modes of ventilation other than jet ventilation, no single mode was found to be superior. The only death within their study was due to an airway fire during endotracheal intubation [24]. The complication profile for jet ventilation is also dependent on the site in which the catheter is placed as the gas emerges into the airway. These complications are outlined in Fig. 5.1. Shared complications by all three sites include barotrauma, air emphysema, and pneumothorax, though the farther distal the catheter enters the airway, the greater the risk. Regardless of site, jet ventilation does not provide a secure airway and still has potential for aspiration [21–23].

5.3.5 Laryngeal Mask Airway (LMA)

The laryngeal mask airway (LMA) is an intermediate between endotracheal intubation and mask ventilation. It is inserted within the hypopharynx without direct visualization with a laryngoscope [25, 26]. An LMA is used in approximately 1/3 of all surgical cases within the United States and is often chosen when a more secure airway is necessary for shorter procedures [25, 26]. It is an excellent alternative to mask ventilation during shared airway procedures because it eliminates tongue obstruction, has been shown to decrease the number of oxygen desaturations, frees up the hands of the anesthesia provider, does not require administration of a paralytic, and reduces the environmental gas exposure [26–28]. An LMA is also a great option in patients that are obese or difficult to intubate [28]. The LMA can also be used to intubate through blindly or utilizing a flexible scope. During emergence from anesthesia, the LMA can be left in place until the patient has completely recovered and airway reflexes have returned [25, 27]. One drawback to the LMA is that it does not prevent aspiration, and there is the potential for damage to the surrounding mucosa, the vocal chords, or the recurrent laryngeal nerve [25–27]. Another potential drawback may include the inability to access the surgical site within the oropharynx, hypopharynx, or larynx [29]. Although, numerous studies have shown, with proper selection, an LMA can be utilized for procedures in any of these regions of the airway [30–32]. In a study by Gupta et al., properly sized flexible cuff LMAs used for adenotonsillectomy were not visible once the Boyle-Davis mouth gag was placed, and the only time surgical access was impaired was if an LMA was chosen that was too large. [32] There are also numerous studies demonstrating the use of an LMA in oral surgery, dental rehabilitation procedures, nasal and sinus

American Society of Anesthesiologists®

DIFFICULT AIRWAY ALGORITHM

1. Assess the likelihood and clinical impact of basic management problems:
   - Difficulty with patient cooperation or consent
   - Difficult mask ventilation
   - Difficult supraglottic airway placement
   - Difficult laryngoscopy
   - Difficult intubation
   - Difficult surgical airway access
2. Actively pursue opportunities to deliver supplemental oxygen throughout the process of difficult airway management.
3. Consider the relative merits and feasibility of basic management choices:
   - Awake intubation *vs.* intubation after induction of general anesthesia
   - Non-invasive technique vs. invasive techniques for the initial approach to intubation
   - Video-assisted laryngoscopy as an initial approach to intubation
   - Preservation *vs.* ablation of spontaneous ventilation
4. Develop primary and alternative strategies:

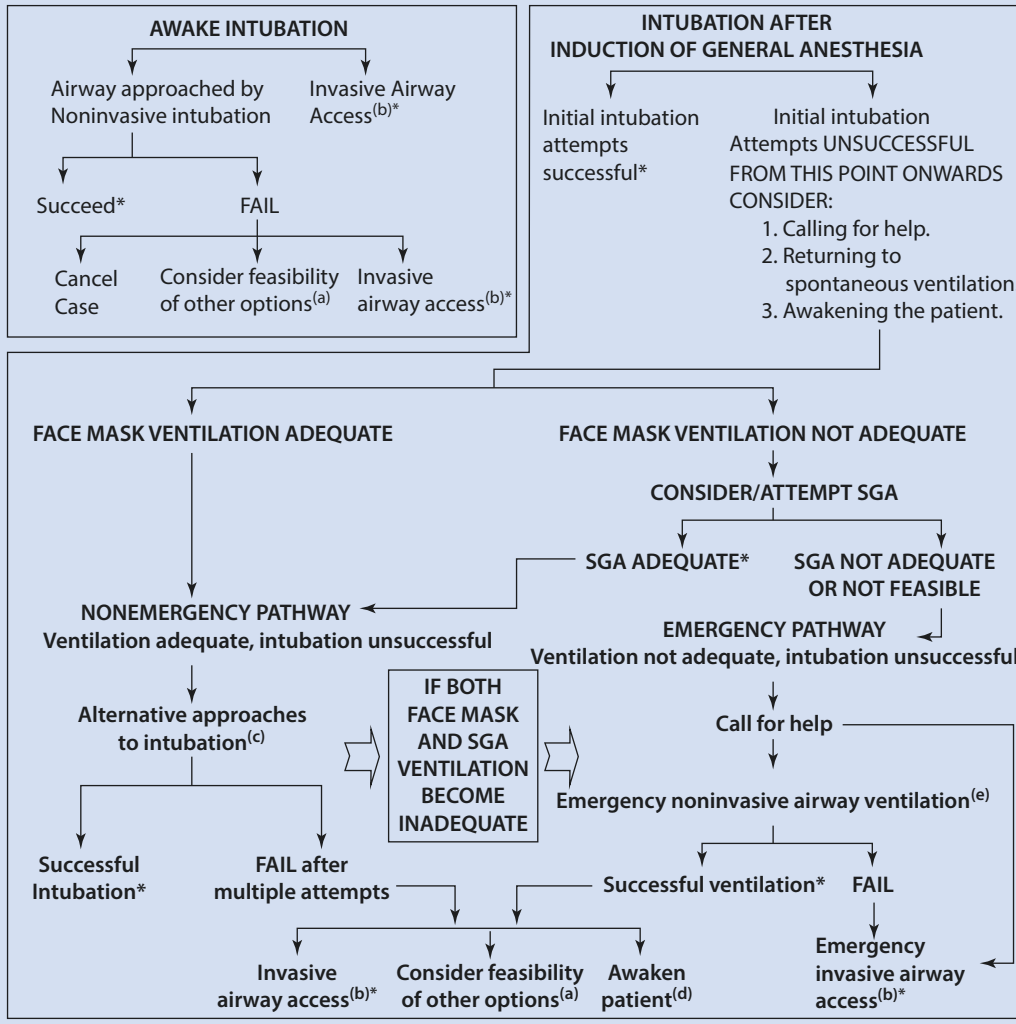


Fig. 5.1 ASA difficult airway algorithm

surgery, and sleep apnea surgery without impeding access to the surgical site and has actually been shown to prevent soiling of the upper airway with blood, irrigation, or contaminates during these types of procedures [27, 33–37].

Safeguarding the shared airway is probably most important in laryngeal surgery. Often times, even small endotracheal tubes can make access to this area difficult. For that reason, there has been emphasis on utilizing an LMA with or without combination with other airway techniques to ventilate a patient during laryngeal surgery. For a simple exam under anesthesia and biopsy of the larynx, it may be easiest to place the LMA and then visualize the area with flexible bronchoscopy [38–40]. Techniques have also been described for laryngeal laser surgery, such as placing a transglottic or transtracheal jet ventilation cannula followed by an LMA. The LMA is used to ventilate the patient during transfer and set up. The LMA can then be removed and jet insufflation employed while the laser is being utilized, followed by replacement of the LMA to maintain ventilation during the recovery phase [25]. The use of the LMA allows the surgeon to have access to the larynx without traumatizing the vocal chords or stimulating the patient and airway [41].

The use of the LMA has also become popular in the difficult airway and was added to the difficult airway algorithm by the ASA in 1996 [28]. There are numerous case reports showing an LMA can be used to maintain or restore ventilation in an adult with a difficult airway and reduced desaturation frequencies in the pediatric population [42]. We find the utilization of the LMA in key points of the ASA algorithm: (1) as a conduit for endotracheal intubation during general anesthesia on a recognized difficult airway; (2) in an unrecognized difficult airway where the patient can be mask ventilated, but intubation has failed; (3) in an unrecognized difficult airway where the patient can be mask ventilated, but the LMA is used as a fiber-optic conduit; (4) in an emergency situation on an unrecognized difficult airway where the patient cannot be mask ventilated, so the LMA is used as a ventilator device; and (5) in an emergency situation on an unrecognized difficult airway where the patient cannot be mask ventilated, so the LMA is used as a fiber-optic conduit [28] (Fig. 5.1). Benefits to the LMA in emergent situations include ease of insertion, a higher insertion success for the inexperienced practitioner, and improved resuscitative efforts in neonates [25].

For some patients undergoing oral and maxillofacial or head and neck surgical procedures, they may have certain physical exam findings (outlined in Table 5.1) delineating them as a difficult airway. An LMA may be the option of choice in this patient population as outlined in the ASA difficult airway algorithm. For example, a patient with features which make them difficult to mask ventilate, such as retrognathia or edentulism, may benefit from elective use of an LMA as a routine airway because the LMA does not require mandibular support and bypasses the obstruction of the tongue [28, 43, 44]. In patients that are obese or have a "difficult airway," the use of an intubating LMA has been shown to be a successful technique as a rescue device or as a conduit for fiber-optic intubation [25, 45, 46].

5.4 Intubation Techniques

Endotracheal intubation is still the technique of choice for most major head and neck procedures, for procedures requiring the patient be placed into maxillomandibular fixation, and for shared airway procedures of longer duration [25]. LMAs are often not secure enough for these longer surgical cases and can alter the neck and pharyngeal anatomy, impairing the ability of the surgeon to perform open procedures [25, 47]. Due to the increased likelihood of a head and neck surgery patient presenting with a difficult airway, standard intubation techniques are often not suitable. There is often a necessity to alter the type or size of the endotracheal tube, improve patient positioning, or use other methods such as videolaryngoscope-guided intubation, fiber-optic-guided intubation, or a surgical airway. The type of endotracheal tube and method for gaining access to the airway should be a discussion between the surgeon and the anesthesiologist that occurs preoperatively.

5.4.1 Standard Endotracheal Tubes

Standard cuffed endotracheal tubes are often not ideal for various head and neck procedures. For laryngeal procedures, they are often too large and prevent the surgeon from being able to work within the larynx. Standard tubes are also prone

to compression when being manipulated within the oral cavity or airway or requiring the use of a mouth gag such as a Dingman or Boyle-Davis. Also, during maxillofacial procedures, where the patient's occlusion will require assessment, these tubes often prevent the surgeon from placing the patient into maxillomandibular fixation. Fortunately, there are a plethora of tube types and sizes to work around these patient and anatomic considerations.

5.4.2 Nasal RAE

Nasotracheal intubation is often the technique of choice for maxillofacial trauma, dentofacial deformities, temporomandibular joint reconstruction, and other procedures requiring maxillomandibular fixation. It can also be employed for procedures requiring improved visualization and access to the oral cavity. For patients with limited mouth opening or undergoing an awake fiber-optic intubation, it is often the technique of choice [48]. A patient can be intubated nasally via direct laryngoscopy, blind intubation, or videolaryngoscopy or with fiber-optic guidance. Though controversial, nasal intubation is generally avoided in base of skull fractures, especially if a cerebrospinal fluid leak is evident. This recommendation is based on a handful of case reports describing intracranial penetration of the nasotracheal tube upon intubation [48–50]. If nasal tube placement is necessary for reconstruction or a surgical airway is contraindicated, the airway can be placed by atraumatically advancing a red rubber catheter through the nose and into the oropharynx to guide the endotracheal tube during placement, or fiber-optic intubation can be used to avoid penetrating the base of skull [48, 51–53].

It is important when using a nasal RAE that the correct size of endotracheal tube is chosen. If the nasal RAE is too short, it may creep superiorly to the vocal chords and impair ventilation during either patient positioning or the surgical procedure. Once the correct nasotracheal tube is placed, a right angle adapter is attached to position the tube superiorly over the forehead. A head wrap is often placed to secure the tube to the forehead, prevent it from dislodging during surgery, and keep it from interfering with access to the surgical field. It is important that the forehead is properly padded when the head wrap is secured

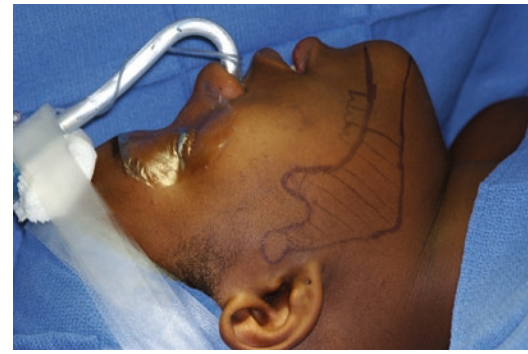


Fig. 5.2 Proper head wrap placement for use of nasal RAE

to prevent a pressure ulcer from forming during long procedures or times of hypotensive anesthesia that is often employed during head and neck procedures (Fig. 5.2). One other drawback of the nasal RAE is that it cannot be used if extended periods of intubation are required due to the possibility of pressure ulcers or necrosis forming within or around the nose.

5.4.3 Microlaryngoscopy Tubes

Microlaryngoscopy tubes are commonly used for endoscopic procedures and typically have a small internal diameter (4–5 mm) but are longer (31 cm) than standard tubes [21]. These tubes are cuffed to prevent manipulation while the surgeon works around them in the airway. Due to their small diameter, increased airway resistance typically occurs. Therefore, these tubes can only be used for short periods of time. Even though these tubes are small and can be worked around, approximately 5% of the time, posterior lesions can be obscured [21].

5.4.4 Laser-Resistant Endotracheal Tubes

The carbon dioxide laser is the most commonly employed laser during shared airway procedures [54]. It is typically used for ablating lesions and resurfacing the mucosa or skin and as an instrument to make very precise incisions with the addition of a surgical handpiece. Utilizing a laser in or around the airway produces a particular dilemma because the three necessary elements for an operating room fire, ignition source, fuel,

and oxidizers, are all in close proximity [54–56]. Previously, metallic tape was used to wrap standard endotracheal tubes transforming them into laser-resistant tubes. Laser-resistant endotracheal tubes are FDA-approved and prefabricated with protective layering. These are all-metal tubes or nonmetal tubes with metallic overlay. These tubes are often used during airway procedures requiring the use of a laser to prevent an airway fire. There are numerous varieties, and most are not necessarily laser-proof, but laser-resistant. It is important to remember that cuffed laser-resistant tubes have vulnerable areas both at the tip and at the cuff. The anesthesiologist must ensure that the cuff remains unharmed, and the surgeon must be cognizant of it to be careful they do not violate it during the surgical procedure. According to the ASA, "the tracheal cuff should be filled with saline rather than air, when feasible." Other good practice measures include (1) tinting the saline within the cuff with methylene blue so that violation can be recognized early, (2) placing the cuff as far away from the surgical site as possible, and (3) placing moist gauze packs around the endotracheal tube and cuff [55, 56].

5.4.5 Reinforced Endotracheal Tubes

Reinforced endotracheal tubes are an excellent choice for shared airway procedures. These ET tubes are commonly utilized during intraoral, major head and neck reconstruction, cleft, and craniofacial procedures. When mouth gags or retractors are used, these tubes are able to better resist compression and prevent lumen occlusion. This is especially important in cleft palate and pharyngeal reconstruction that utilizes the Dingman retractor. In children that have eruption of their lower mandibular incisors, the oral RAE that is used to secure the airway can easily be compressed between the teeth and the retractor. This has the potential to increase peak pressure and decrease tidal volumes.

5.4.6 Videolaryngoscopy

The invention of videolaryngoscopy has greatly improved the ability to visualize difficult airways with direct laryngoscopy and is included in the ASA difficult airway algorithm. In comparison to direct laryngoscopy, these scopes have improved visualization of the larynx and improved success of intubation in the difficult airway [57–60]. There are numerous design variations to mimic existing blade shapes, incorporate channels for endotracheal tube passage, or improve visualization in certain anatomic situations. Regardless of design, no single videolaryngoscope has been deemed superior. Of interest in shared airway procedures where the airway may be considered "difficult" is the GlideScope (Verathon, Bothell, WA). The GlideScope has an acute 60-degree curve to assist in visualization of an anterior glottis without manipulation of the cervical spine or airway. Therefore, this device may be useful in maxillofacial trauma patients, limited interincisal opening or trismus, cervical spine immobility, or patients with a craniofacial or dentofacial deformity.

5.4.7 Fiber-Optic-Guided Intubation

When unable to visualize the airway via direct or videolaryngoscopy, fiber-optic-guided intubation with the flexible fiber-optic bronchoscope is an effective and proven technique for establishing airway access [61]. In its Practice Guidelines for Management of the Difficult Airway, the ASA cites observational studies that report successful intubation via fiber-optic techniques in 87–100% of difficult airways [42]. This technique can be used to achieve endotracheal intubation via either the nasal or oral route. Although fiber-optic intubation can be used after the induction of general anesthesia, in many clinical scenarios, awake fiber-optic intubation (AFOI) with topical or regional anesthesia is the chosen approach for management of a difficult airway. AFOI eliminates the risks associated with induction of general anesthesia prior to securement of the airway. These risks include inadequate ventilation or oxygenation, loss of upper airway patency, and failed intubation. Common indications for AFOI include patients with a recorded history of difficult intubation or any patient with upper airway abnormalities that foretell a difficult airway, such as limited mouth opening, decreased thyromental distance, congenital deformities, head and neck neoplasms, or craniofacial trauma [62].

Once the decision has been made to proceed with an AFOI, further consideration must be given to patient position and preparation, need

for local and/or regional anesthesia, and use of sedatives. In general, AFOI can be performed with the patient supine or seated upright. The nasal approach is preferred for better visualization of the larynx and is often employed in patients with trismus, macroglossia, and retrognathia or when the endotracheal tube cannot obstruct the surgical field. The tissues of the nose, naso- and oropharynx, and larynx can then be numbed with any combination of topical or aerosolized anesthetics as well as regional blocks. These blocks include the glossopharyngeal nerve block, superior laryngeal nerve block, or transcricoid block. Antisialagogues, such as glycopyrrolate, atropine, or scopolamine, can also be used to decrease salivary and mucus secretions in an effort to improve visualization. Lastly, to improve patient tolerance and induce anxiolysis and amnesia, sedatives may be administered to patients undergoing AFOI. Rapid-onset, short half-life sedatives, such as midazolam or dexmedetomidine, are often the agents of choice. These sedatives produce the desired effects while minimizing risk of respiratory depression and ensuring adequate ventilation in the awake patient [62].

5.4.8 Surgical Airways

The establishment of a surgical airway should be considered when endotracheal intubation fails or when traditional endotracheal intubation is not a viable option due to the unique requirements of the case. According to the ASA's difficult airway algorithm, in patients with inadequate face mask and/or supraglottic ventilation along with failed intubation, the final intervention is emergency invasive airway access [42]. Options for invasive access include cricothyroidotomy via open or wire-guided techniques or needle cricothyroidotomy with percutaneous transtracheal ventilation [63].

In the emergent setting, the American Trauma Life Support guidelines recommend the cricothyroidotomy for airway control. This procedure can be done via an open, surgical approach or a wire-guided technique. Surgically, the first step is making a vertical skin incision overlying the cricothyroid membrane followed by a horizontal incision through the membrane itself. The procedure is then completed by dilating the incision with hemostats and inserting the appropriate cannula into the airway [64]. In the wire-guided or Seldinger technique, the cricothyroid membrane is initially pierced by a locator needle, which is then used to insert a guide wire into the trachea. An airway catheter with an internal dilator can be slowly placed into the airway over the guide wire. This alternative approach can be employed with healthcare providers uncomfortable or inexperienced with the surgical approach [63]. It is critical to keep in mind that the cricothyroidotomy is an emergent, temporizing technique and in most cases should not represent long-term, permanent airway management. Lastly, the cricothyroidotomy is contraindicated in patients less than 12 years of age due to the pediatric airway being the narrowest at the level of the cricoid cartilage and the subsequent risk of laryngeal injury [64].

In children, due to the anatomical limitations discussed in the previous paragraph, the preferred invasive airway is the needle cricothyroidotomy with percutaneous transtracheal ventilation. This is achieved by palpating the cricothyroid membrane and inserting an 18-gauge needle through the membrane into the airway. The needle can then be attached to a 3 mL syringe, which is then connected to a ventilator circuit via an adaptor from an endotracheal tube [63]. It is important that this technique not be used in patients, adult or pediatric, with complete upper airway obstruction due to risk of increased intrathoracic pressures and subsequent complications [64].

Outside of the emergent setting, a surgical airway can be electively used for primary airway management in cases where endotracheal intubation is unlikely to succeed. Elective placement is often recommended in certain types of head and neck surgeries. Instances where elective placement of a surgical airway can be indicated include surgeries addressing large tumors of the head and neck, laryngotracheal injuries, maxillofacial trauma, inflammatory swelling of the upper airway, or craniofacial deformities. The preferred approach for the elective surgical airway is the tracheotomy. Exact surgical technique for the tracheotomy may vary depending on surgeon preference, but the ultimate objective is making an incision in the anterior tracheal wall, usually between the 2nd and 3rd tracheal rings, allowing cannulation of the airway [64].

5.5 Complications

In general, respiratory compromise and loss of airway are among the most common reasons for anesthesia malpractice claims [65]. These events have been recorded by the ASA Closed Claims database and contribute to many of the claims for death and brain damage [66]. Complications that can lead to respiratory compromise in the perioperative period include failed intubation, loss of airway due to laryngospasm or foreign body aspiration, surgical fire, and vocal cord paralysis. These complications are not unique to shared airway anesthesia, but their risk of occurrence is certainly heightened in shared airway cases where the surgeon operates in intimate proximity to the airway. Another complication that deserves discussion in relation to shared airway anesthesia is dental injury, which commonly occurs during direct laryngoscopy in patients with poor dentition. For a detailed discussion of this topic, please refer to the chapter on dental injury included in this text.

5.5.1 Failed Intubation

A failed intubation is defined as the inability of the anesthesiologist to introduce an endotracheal tube into the trachea. Fortunately, failure to intubate is an exceedingly rare occurrence [67]. A review of literature places the rate of intubation failure at 0.05% to 0.35% [68]. Failure to intubate in itself is not a fatal outcome, if adequate oxygenation of the patient can be maintained with mask ventilation. However, it is in the "cannot intubate-cannot ventilate" scenarios that catastrophic outcomes can quickly occur. In these scenarios, the airway cannot be secured due to inability to intubate, and mask ventilation is inadequate to support the patient, leading to poor oxygenation and eventual respiratory collapse [69].

Two key factors that can prevent providers from finding themselves in a dangerous "cannot intubate-cannot ventilate" scenario are a thorough preoperative evaluation and a fundamental understanding of the ASA's difficult airway algorithm. As discussed earlier in this chapter, preventing a failed intubation begins with a complete physical exam that includes determining the patient's Mallampati-Samsoon classification and identification of any anatomical features that can complicate ventilation or intubation, such as decreased incisal opening, damaged or loose teeth, limited range of motion of the neck, shortened thyromental distance, tracheal deviation, neck masses, mandibular retrognathia, facial hair, or enlarged tonsils [68, 69]. In the event that a provider encounters a difficult airway, which one study estimated occurs in 15.4% of maxillofacial surgery cases, it is vital that the principles of the ASA's difficult airway algorithm are appropriately applied [42, 68]. Before intubation is attempted, one must consider the merits of electively proceeding with an awake intubation or placing a surgical airway as opposed to traditional endotracheal intubation following induction of general anesthesia. However, if initial attempts at intubation are unsuccessful, the difficult airway algorithm instructs providers to consider calling for additional help, awakening the patient, placing an LMA, attempting alternate forms of intubation, or – if all other approaches fail – placement of a surgical airway [42]. It is imperative that any provider involved with treating the airway be well-versed in the tenets of this algorithm.

5.5.2 Laryngospasm

Laryngospasm is a complication that can be encountered in an anesthetic situation where the airway is not secured with an endotracheal tube. These situations include pre- and post-intubation, open airway general anesthesia, and monitored anesthesia care. Laryngospasm is characterized by a spasm of the intrinsic muscles of the larynx that can lead to sustained closure of the vocal cords. It represents a protective physiologic reflex that prevents aspiration into the lower airway [70]. Laryngospasm is a life-threatening complication that can quickly lead to hypoxia, bradycardia, negative pressure pulmonary edema, cardiac arrest, and death [71]. The classic presentation of a laryngospasm is a high-pitched stridor that is accompanied by oxygen desaturation, difficulty ventilating, and paradoxical rise of the chest and abdomen. It is important to keep in mind that although stridor is considered nearly pathognomonic for laryngospasm, a complete obstruction of the glottic opening can be marked by silence with no high-pitched stridor [70].

The two most common causes of laryngospasm are local irritation of vocal cords and

inadequate depth of anesthesia [70]. Sources of irritants include blood and oral secretions that can contaminate the larynx during otolaryngological or oral surgical procedures. One study reported that nearly 22% of spasms were precipitated by blood and secretions from surgical procedures [72]. Vomiting or regurgitation, airway suction catheters, and instrumentation of the airway have also been reported to irritate the vocal cords leading to spasm. In children, an irritant to be constantly aware of is a recent history of upper respiratory tract infection. Literature shows that children with an upper respiratory tract infection are two to five times more likely to experience a laryngospasm [71]. A spasm can also occur if the airway is stimulated, such as during extubation, while the patient is at an insufficient depth of anesthesia. Thus, extubation should only occur if the patient is either at a plane of anesthesia that is deep enough to blunt laryngeal reflexes or at a point when the patient has awakened from anesthesia and has regained control of their laryngeal musculature [73].

If a laryngospasm is suspected, the following initial steps should be performed (1): remove any irritating stimuli from the mouth or airway (2), provide positive pressure ventilation with a face mask and 100% oxygen (3), and apply chin lift or jaw thrust by placing firm digital pressure bilaterally behind the earlobe along the posterior mandible. Should these initial measures prove inadequate, treatment can be continued by deepening the plane of anesthesia with an I.V. bolus of propofol. Additionally, a small bolus of succinylcholine dosed at 0.1. mg/kg can be given to induce muscle relaxation and break the spasm. If these steps are not successful, the final intervention would be providing an intubating dose of succinylcholine (1 mg/kg) and intubating the patient [70, 73, 74].

5.5.3 Foreign Body Aspiration

Foreign body aspiration is a medical emergency that can lead to immediate airway obstruction [75]. In shared airway anesthesia, where surgeons are often operating in or around the airway with small instruments and fine materials, the risk of aspiration is always present. The risk of aspiration is particularly elevated in open airway anesthesia, such as conscious sedation in the dental office or monitored anesthesia care in the operating room, where there is no endotracheal tube to protect the airway. Dental procedures have been shown to be the second most common reason for foreign body aspiration into the airway [76]. Common objects aspirated during dental or oral surgical procedures include teeth, implant parts and screws, small instruments, burs, restorative materials, impression material, crowns, dentures, and endodontic files [77, 78]. Outside of dentistry, fractured tracheotomy tubes, nasopharyngeal airways, respiratory care equipment, broken instruments, and bronchoscopy parts have been reported as aspirated objects [75]. Beyond the proximity of foreign bodies to the airway, other risk factors for aspiration include supine positioning, sedation, unexpected patient movement, and poor lighting [78].

Common signs and symptoms of aspiration include gagging, choking, coughing, inspiratory stridor, paradoxical breathing, hoarseness, or unilateral wheezing on auscultation. In severe cases of aspiration, with significant airway obstruction, cyanosis, decreased oxygen saturation, and tracheal shift can be observed. Several steps can be taken to prevent iatrogenic aspiration. The cornerstone of prevention has been the pharyngeal screen or throat pack. More on this topic is recorded in subsequent sections of this chapter. Whenever feasible, that patient should be seated upright in a dental chair, or reverse Trendelenburg position should be used in the operating room to limit supine positioning. All small instruments should be ligated with a small length of dental floss, allowing quick retrieval of the instrument upon displacement. Dentures should always be removed [78]. All instruments should be periodically inspected for evidence of fatigue or wear which could make them prone to fracture [75, 79]. Lastly, proper use of surgical counts should be employed to prevent retained foreign objects that could be aspirated.

The first step in the management of a suspected aspiration is determining the stability of the patient. If the patient is stable and showing no signs of respiratory distress, radiographs of the chest and abdomen should be obtained to ascertain location of the object [78]. Two-view chest X-rays (posterior-anterior and lateral) are required to confirm exact location of any object in the airway. If the object has been ingested into the GI tract, the object is usually allowed to pass

naturally unless it is pointed or there is concern for impaction in the esophagus. In these situations, endoscopic retrieval is indicated. Should radiographs reveal the object lodged in the airway, the patient needs to be scheduled for urgent removal via bronchoscopy to prevent sequelae such as obstruction, abscess formation, or pneumonia [79]. Bronchoscopy is effective in more than 90% of cases [77, 79]. If the patient is deemed unstable and exhibiting signs of respiratory distress, the most important step is providing respiratory support until definitive bronchoscopy can be performed. Ventilation can be assisted with face mask and Ambu bag, or if there is concern of complete airway occlusion and inability to ventilate, then an emergent surgical airway must be placed [78]. Following removal of the foreign body, radiographs should be taken to confirm complete removal [79].

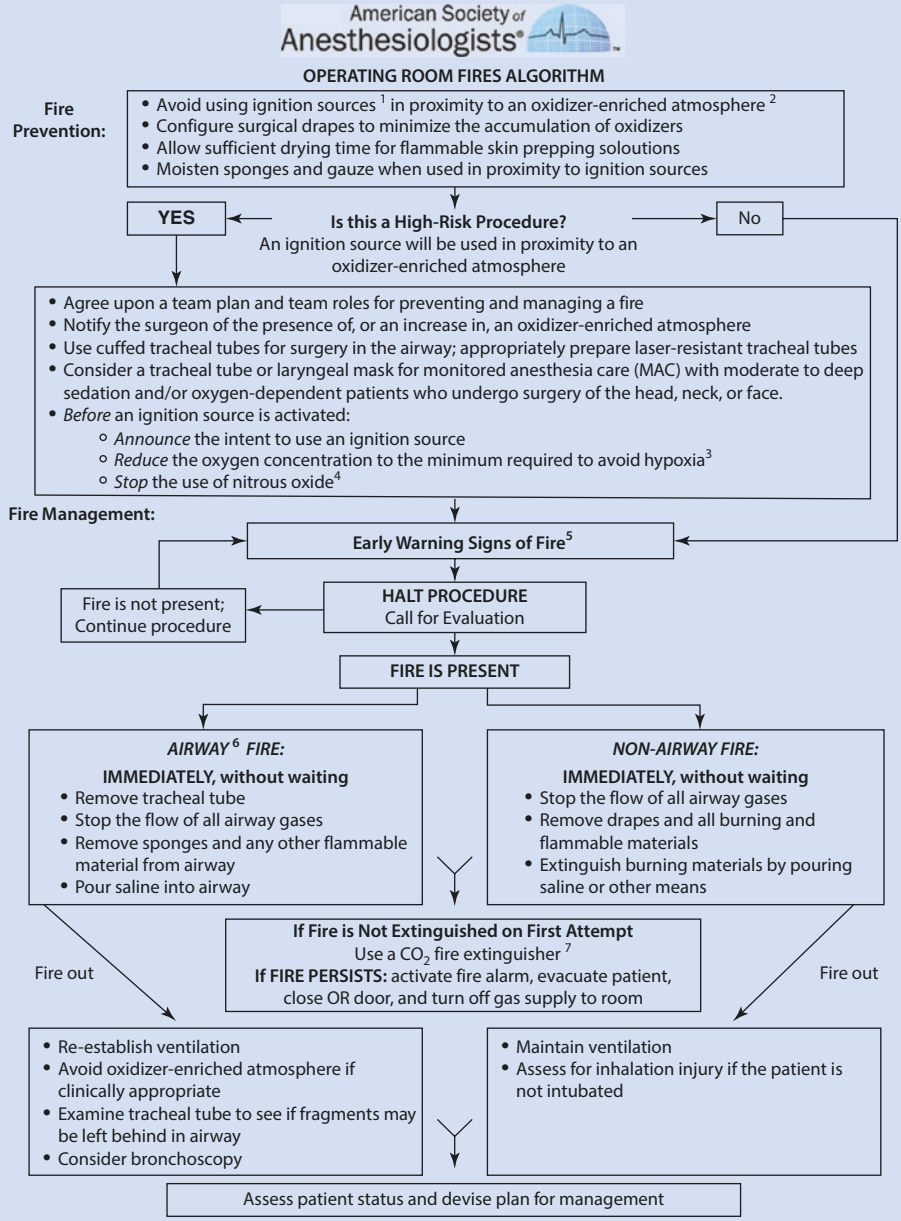
5.5.4 Surgical Fire

In shared airway anesthesia, one of the most feared and catastrophic complications is the surgical fire. Literature reports that the annual incidence of surgical fires in US hospitals is approximately 650 fires per year. Many more cases go unreported or are considered near misses [80]. As expected, these fires are more common in head and neck surgeries where all elements of the fire triad (fuel, oxidizer, and ignition source) are in close proximity. Consequently, head and neck surgeries are considered high fire-risk procedures [81].

In a closed claims analysis of surgical fires, electrocautery was shown to be the most common ignition source (90%). Other ignition sources reported include surgical lasers, heated probes, argon beams, light cables, and defibrillators. Oxygen was the oxidizing agent in 95% of all electrocautery fires. The most common cause of surgical fires was electrocautery-induced fire during monitored anesthesia care, where supplemental oxygen was being delivered via an open delivery system (i.e., nasal cannula or face mask). Electrocautery fires were less commonly reported in general anesthesia cases where oxygen was able to leak out of a closed-circuit system due to an uncuffed endotracheal tube or presence of cuff leak. According to the claims analysis, the majority of these fires occurred during shared airway procedures, such as tracheotomies or tonsillectomies. Common fuel sources reported in the claims analysis included endotracheal tubes, oxygen masks, nasal cannula, gauze, drapes, alcohol-based prep solution, hair, and surgical gowns [82].

Preventing surgical fires depends on managing the limbs of the fire triad. First, attempt to minimize the formation of an oxidizer-rich atmosphere around the surgical site. Since oxygen is the predominant oxidizer in surgical fires, the inspired oxygen concentration – at a minimum – should be kept below 50% [80]. Other steps to limit the amount of oxidizing agents include the use of scavenging systems, sealed gas delivery systems like cuffed endotracheal tubes or LMAs whenever feasible, and moistened gauze or sponges in the oropharynx to trap any leakage of flammable gas [80, 81]. Considerations for ignition source management include never using an electrosurgical source to enter the airway and following laser surgery safety recommendations as described in previous paragraphs of this chapter [81]. Fuel sources can be managed by moistening any form of gauze, sponge, or packing used in the surgical field. Dry forms of these materials demonstrate increased flammability. When lasers are in use, ensure that a laser-resistant endotracheal tube is in use. Lastly, allow sufficient time for alcohol-based skin preps to dry to prevent ignition of volatile vapors produced by these preps [81, 82].

Should a surgical fire occur, the ASA's *Practice Advisory for the Prevention and Management of Operating Room Fires* (Fig. 5.3) outlines the steps required to manage any surgical fire. The first step is recognition of early signs of fire. These warning signs include unexpected smoke, unusual odors, unusual sounds like "pops" or "snaps," discoloration of drapes or breathing circuits, and unexpected flames or sparks. If any of these signs are present, the procedure should be halted immediately and investigated further. If a fire is present in the airway or breathing circuit, the ASA recommends taking the following steps as rapidly as possible: (1) removal of the endotracheal tube or other airway device, (2) halting the flow of all airway gases, (3) removal of all flammable and burning materials from the airway, and (4) pouring of saline or water in the patient's airway. Should these steps not extinguish the fire, the ASA recommends use of a carbon dioxide fire extinguisher in, on, or around the patient. Once the fire is extinguished, reestablish mask ventilation and avoid flammable oxygen and nitrous



1 Ignition sources include but are not limited to electrosurgery or electrocautery units and lasers.

2 An oxidizer-enriched atmosphere occurs when there is any increase in oxygen concentration above room air level, and/or the presence of any concentration of nitrous oxide.

3 After minimizing delivered oxygen, wait a period of time (*e.g.,* 1-3 min) before using an ignition source. For oxygen dependent patients, *reduce* supplemental oxygen delivery to the minimum required to avoid hypoxia. Monitor oxygenation with pulse oximetry, and if feasible, inspired, exhaled, and/or delivered oxygen concentration.

4 After stopping the delivery of nitrous oxide, wait a period of time (*e.g.,* 1-3 min) before using an ignition source.

5 Unexpected flash, flame, smoke or heat, unusual sounds (*e.g.,* a "POP," snap or "foomp") or odors, unexpected movement of drapes, discoloration of drapes or breathing circuit, unexpected patient movement or compint.

6 In this algorithm, airway fire refers to a fire in the airway or breathing circuit.

7 A CO_2 fire extinguisher may be used on the patient if necessary.

Fig. 5.3 Airway fire algorithm

oxide if possible. The endotracheal tube should then be examined to determine if any fragments were left in the airway. Bronchoscopy can be considered if there are concerns of retained foreign material or debris in the airway [81].

5.5.5 Vocal Cord Paralysis

Iatrogenic damage to the airway is a known complication of tracheal intubation. A closed claims analysis of airway injuries by the ASA revealed that the larynx is the most common site of injury (33% of cases). The most common type of laryngeal injury was vocal cord paralysis. Other reported injuries include granulomas, hematomas, and arytenoid dislocation. Eighty percent of the injuries occurred with routine, non-difficult tracheal intubations [83, 84]. Risk factors for vocal cord paralysis include patients over the age of 50, prolonged intubations greater than 6 h, and patients with a prior history of diabetes mellitus or hypertension [84].

Vocal cord paralysis – secondary to damage to the recurrent laryngeal nerve – can present as unilateral or bilateral injuries. Unilateral paralysis can be characterized by dysphonia, vocal fatigue, decrease in vocal range and intensity, and increased risk of aspiration pneumonia. Seventy percent of unilateral cases involve the left cord [85]. Bilateral paralysis can produce acute airway obstruction due to unopposed vocal cord adduction [86]. Damage to the recurrent laryngeal nerve is believed to occur when the anterior branch of the nerve is compressed between the endotracheal tube cuff and the thyroid cartilage. Therefore, to prevent paralysis, it is recommended that the cuff is kept below the cricoid cartilage and cuff pressure be kept to a minimum. Fortunately, the majority of vocal cord paralysis cases run a benign course and resolve spontaneously. Possible interventions, if needed, include voice therapy, medialization of the cords via injection laryngoplasty, and medialization thyroplasty [85].

5.6 Prevention of Complications

The previous section of this chapter discussed many of the most common complications encountered during shared airway anesthesia and steps that can be taken to prevent their occurrence. In the paragraphs below, three more strategies are discussed that can help prevent catastrophic complications.

5.6.1 Capnography

Capnography is the real-time, continuous monitoring of a patient's inhaled and exhaled concentrations of carbon dioxide [73, 87]. It is considered the gold standard for monitoring the patient's ventilation in both intubated and non-intubated cases. The ASA's *Practice Guidelines for Moderate Procedural Sedation and Analgesia* recommends continuous monitoring of ventilatory function capnography to prevent hypoxic events [17, 18].

Capnography provides an indirect assessment of patient's alveolar ventilation, pulmonary perfusion, and gaseous diffusion across the respiratory membrane [87]. Changes in the exhaled concentrations of carbon dioxide can alert an anesthetist to many impending complications. Absence of end-tidal carbon dioxide (ETCO2) following intubation can signal failed intubation due to cannulation of the esophagus. Intraoperatively, abrupt loss of ETCO2 can represent accidental extubation or disconnection of the ventilatory circuit [73]. In open airway cases, loss of ETCO2 can signal loss of airway patency due to laryngospasm or upper/lower airway obstruction [87]. Subtle changes in the amount of exhaled carbon dioxide can also provide valuable information. Increases in ETCO2 are seen in hypoventilation, malignant hyperthermia, sepsis, or rebreathing. Decreasing ETCO2 can signal hyperventilation, low cardiac output, or pulmonary embolism [73].

When using capnography in open airway anesthesia, where carbon dioxide sampling occurs via a nasal cannula, one must be aware of inherent limitation in this system. If ETCO2 sampling is combined with supplemental oxygen administration within the nasal hood, the oxygen can dilute the exhaled carbon dioxide and yield lower ETCO2 readings. Nasal cannulas are also subject to dislodgement, which can inadvertently affect ETCO2 values. Additionally, patients that are experiencing nasal congestion or are obligate mouth breathers may yield artificially absent

ETCO2 readings [87]. All these scenarios must be kept in mind when interpreting ETCO2 values in an open airway system.

5.6.2 Pre-tracheal Auscultation

Another tool used to monitor a patient's ventilatory status is intraoperative pre-tracheal auscultation. This technique involves the use of a weighted chest piece that is placed on the airway above the patient's sternal notch. The chest piece is then connected to an earpiece worn by the physician via plastic tubing or electronically via Bluetooth transmission [88]. The anesthetist is thus able to listen to real-time sounds as air moves through the airway [87]. This provides qualitative input on the status of the patient's airway and allows early detection of impending complications. Audible snoring can signal soft tissue obstruction of the airway. Bronchospasm would be accompanied by wheezing. A complete absence of breath sounds could alert the anesthetist to a complete airway obstruction, such as a laryngospasm [88]. The combination of capnography and pre-tracheal auscultation can provide optimal monitoring of a patient's ventilatory status and help forestall possible complications [87].

5.6.3 Throat Pack

As discussed, throat packs are commonly placed by surgeons working in the oral cavity. They are placed to prevent aspiration of blood, oral secretions, surgical debris, and instrumentation [89, 90]. Additionally, a moistened throat pack can prevent the passage of flammable gas into the surgical field [80, 81]. Despite these perceived benefits in preventing certain complications, throat packs have also been shown to be a source of complication themselves. Literature has revealed that throat packs are a significant source of postoperative throat discomfort and pain. Also, numerous reports have been published describing failure to remove throat packs prior to extubation leading to increased risk of airway aspiration and intestinal obstruction [89, 90]. There is no doubt that throat packs play an important role in shared airway anesthesia; however, one must be cognizant of the fact that if not properly handled, throat packs themselves can cause serious complications.

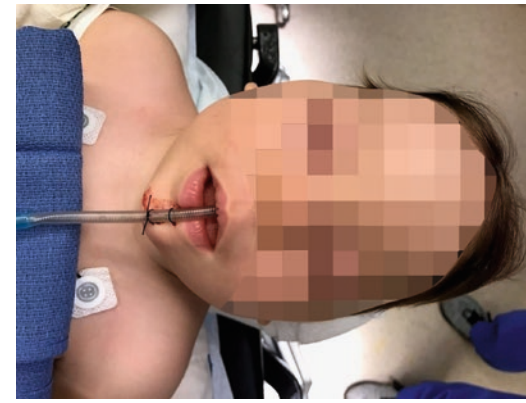


Fig. 5.4 Suturing of armored tube to chin

5.6.4 Suturing the Endotracheal Tube

In shared airway anesthesia, due to the proximity of the surgeon to the endotracheal tube, the risk of tube dislodgement and accidental extubation is always present. This complication can be prevented by suturing the endotracheal tube in place. Reinforced tubes must be used with this technique to prevent occlusion of the tube. The reinforced tube can be placed and then secured to the patient with 2-0 silk suture. When a patient is orally intubated, as the endotracheal tubes exits the mouth, it can be secured to the chin (Fig. 5.4). During head and neck oncologic or free flap reconstruction cases, a standard tracheotomy can be performed and a reinforced tube placed instead of a tracheotomy tube. The reinforced endotracheal tube can then be secured to the chest with multiple 2-0 silk sutures. This secures the tube and prevents migration or dislodgment from the airway.

5.7 Review Questions

1. What technique does the ASA's *Practice Guidelines for Moderate Procedural Sedation and Analgesia* recommend for continuous monitoring of patient's ventilatory status during a moderate sedation?
   A. Pre-tracheal auscultation
   B. Capnography
   C. Respiratory rate
   D. Direct observation

2. Which of the following is not a common practice used to reduce the risk of surgical fire during laser surgery?
   A. Use of laser-resistant endotracheal tubes.
   B. Fill the endotracheal tube cuff with methylene-tinted saline.
   C. Placement of moistened gauze packs around the endotracheal tube.
   D. Use of cuffless endotracheal tubes.

3. Which of the following is not a technique suggested by the ASA's difficult airway algorithm to aid in intubation of a patient after initial attempts have been unsuccessful?
   A. Placement of a laryngeal mask airway
   B. Returning to spontaneous ventilation and awakening the patient
   C. Calling for help from an additional airway-trained colleague
   D. Deepening the level of anesthesia

5.8 Answers

1. B – The ASA's *Practice Guidelines for Moderate Procedural Sedation and Analgesia* recommend (1) continually monitor ventilatory function with end-tidal carbon dioxide (capnography); (2) pulse oximetry is effective in detecting oxygen levels during moderate sedation; and (3) electrocardiography can adequately detect arrhythmias, premature ventricular contractions, and bradycardia.

2. D – All of the statements except use of a cuffless endotracheal tube are indicated during laser surgery. Cuffed endotracheal tubes are indicated to prevent the leakage of oxygen and other flammable gases in the surgical field, which could be ignited by the laser.

3. D – The difficult airway algorithm instructs providers to consider calling for additional help, awakening the patient, placing an LMA, attempting alternate forms of intubation, or – if all other approaches fail – placement of a surgical airway.

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Dental Injury: Anatomy, Pathogenesis, and Anesthesia Considerations and Implications

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_6

Key Points

- Dental injury is the most common complication of airway management for general anesthesia and is the most cited claim in malpractice suits filed against anesthesia providers.
- Mechanical trauma associated with difficulty during direct laryngoscopy remains the most common cause of perioperative dental injury.
- The two most important risk factors are preexisting dental disease and a predicted difficulty with intubation.
- The preoperative assessment should include a full history and thorough clinical dental exam.
- The categories of dental injury include fracture, luxation, and avulsion.
- In the event of an injury, consultation with the providing dental service is always recommended.
- Communication with the patient during the preoperative exam, while discussing dental injury to obtain an informed consent, and postoperatively in the event of an injury, is essential.

Case

A 51-year-old male with a past medical history significant for osteoarthritis, class 1 obesity, GERD, and obstructive sleep apnea presents to day surgery at a teaching hospital for arthroplasty of his left knee by the orthopedic surgery department. He is evaluated by a first year anesthesia resident in the preoperative holding room. His preoperative evaluation noted a BMI of 33.5 kg/m but otherwise unremarkable vitals. He reports having been put to sleep approximately 15 years ago to fix a mandible fracture. He is unaware of any complications from the anesthesia, but he remembers waking up with a sore throat that lasted a few days. The preoperative dental exam documents "no loose teeth" but "multiple dental restorations." The patient confirms that he has a bridge on his "top front teeth," a few "caps on the back teeth," and a few "fillings." He denies any existing loose teeth or fractures. On exam the resident can see part of the patient's uvula and documents a Mallampati 2. He notes a large tongue and a moderate maxillary "overbite." There is no obvious dental disease, but his maxillary central incisors, left maxillary lateral incisor, and left maxillary canine all have fixed dental prostheses. Nothing appears loose or fractured.

As a possible difficult intubation, thought is given to utilizing a Glidescope, but both devices are currently being used in the Labor and Delivery Unit upstairs, and the orthopedic surgeon has politely requested that the case get started as soon as possible as he has clinic in the afternoon. The resident suggests a modified rapid sequence induction, given the patient's history of GERD, and the anesthesia attending gives the resident clearance to proceed to the operating room. The patient is given midazolam IV and transported to the OR where he has minor difficulty moving to the table due to the sedative's effects. Before preoxygenation, his pulse oximeter reads 93%. The patient is induced with standard weight-based doses of fentanyl, lidocaine, and propofol. An RSI dose of rocuronium is given, and after 60 s, the resident attempts direct laryngoscopy but has great difficulty. He sees only part of the epiglottis and none of the arytenoids. He attempts to improve his view by applying more force and unintentionally cranes the blade back onto the patient's anterior maxillary incisors, and a harsh sound is heard. The attending takes over and successfully intubates and ventilates the patient. After confirming placement and then securing the tube, the resident notices that both the right and left central incisors (teeth #8 and #9) have fractured along their incisal edges.

6.1 Introduction

With the multitude of serious complications possible from surgery and anesthesia, most healthcare providers may not intuitively include dental injury as one of the catastrophic complications of the perioperative period. It is likely that most providers would associate "catastrophic" with complications that could lead to permanent and debilitating injuries such as stroke or loss of an extremity. While dental injuries sustained in the perioperative period are not fatal, these injuries are extremely prevalent, and complications may be exacerbated by the hospital provider's inadequate

dental knowledge. The burden of dental injury on providers is the direct result of the large and perhaps unexpected impact these injuries have on patients emotionally and economically. Many patients will suffer emotional distress when an anterior maxillary incisor was chipped or worse avulsed [10]. The need for restorative dental work can also elicit an emotional response with 80% of Americans reporting some dental anxiety and 5–14% reporting intense dental anxiety [11, 12].

Dental injuries are very common throughout the perioperative period, but the vast majority of these injuries occur during direct laryngoscopy [1, 13]. Dental injuries are also the most common claim in malpractice suits against anesthesia providers [1, 13]. Even more significant is the finding that those malpractice claims account for 33% of all confirmed claims [1]. Despite perioperative dental injury being well established as the most common complication of general anesthesia, the incidence reported in the literature varies from 0.04% up to 12.08% [3]. All providers involved in perioperative care should receive training and education focused specifically on dental injury as it remains the most common complication of anesthesia and the most common complaint in medical malpractice suits against anesthesia providers. The topics necessary to educate providers about perioperative dental injury include a review of the etiology and classification of the damage. Identifying risk factors allows the most accurate prediction of injury risk. Additionally, a thorough understanding of dental anatomy and its associated pathology can prove vital in the prevention of this common complication. As medicolegal implications continue to become apparent, the need for a strong dialogue and discussion between anesthesia and dental colleagues alike is important to help best identify preventative strategies and, in the event these complications occur, the different treatment options necessary to minimize morbidity.

6.2 Etiology

Perioperative dental injury can occur during direct laryngoscopy, placement of oropharyngeal airway devices and mouth openers or props, iatrogenic surgical damage during oropharyngeal procedures, excessive masticatory forces in a patient with emergence delirium, or due to a fall during transfer [3]. Trauma to the dentition in the perioperative period is almost exclusively the result of mechanical trauma from a medical instrument [1]. Far and away the most common perioperative procedure causing dental injury is damage to the dentition via traumatic contact with the laryngoscope [5]. Most studies on this topic are limited by small sample size, as well as inadequate dental examination and charting. It was not until researchers from the Mayo Institute published a study which included 600,000 anesthetic cases performed over a 10-year period that a reliable incidence could be established [3]. Their results showed that the incidence of dental injury for general anesthesia was 1:2913. Among the patients who received general anesthesia and with an endotracheal tube, the incidence of dental injury was 1:2805. Patients who received general anesthetics without endotracheal intubation had a dental injury incidence of 1:7390. The combined incidence of perioperative dental injury during general anesthesia cases was 1:4537 [20, 3]. The important take-home point was that the incidence of dental injury increases from 1:7390 to 1:2875 when a patient is intubated [20, 3]. Approximately half of all perioperative dental injuries will occur during direct laryngoscopy and tracheal intubation. Another 23% of dental injuries occur during the general anesthetic, but after intubation [3]. Dental injury during the intraoperative period may be due to an oropharyngeal airway, mouth prop, surgical retractors, fiber-optic scopes, or any number of medical devices used to facilitate oropharyngeal surgery. Only 8% of dental injuries tend to occur during tracheal extubation [5].

Perioperative dental injury will most commonly cause damage to a single tooth, but 13% of cases involve injury to multiple teeth [3]. The teeth most frequently damaged from dental injury are the maxillary central incisors, most commonly the left maxillary central incisor. Other common sites of dental injury include the mandibular anterior incisors followed by the lower posterior teeth [14]. The type of damage sustained from a perioperative dental injury will vary based upon the preoperative dental health status, as well as the amount of traumatic force and location of impact. Being able to correctly identify and diagnose, a dental injury is essential for selecting the most appropriate treatment.

6.3 Risk Factors

One of the most significant risk factors for perioperative dental injury are teeth that have preexisting pathology [4]. It is intuitive that teeth with decay from dental caries or that have become loose from periodontal disease would be more prone to traumatic injury than healthy teeth. Patients with preexisting dental pathology are five times more likely to incur perioperative dental injury [6]. In addition to dental pathology, the anatomic factors increasing the risk of perioperative dental injury include a small mouth opening, large maxillary incisors, or anterior dental crowding [4]. A preoperative dental exam is, therefore, essential in identifying patients with the highest risk.

Dental injury most frequently occurs during a difficult laryngoscopy when the provider fulcrums on a patient's teeth in an attempt to gain a better view (Fig. 6.1).

Therefore, all the factors that are used to predict difficult intubations can also be used to predict the risk of dental injury [4]. These factors would include limited cervical range of motion, previous head and neck surgery, craniofacial abnormalities, and a history of difficult intubation [3].

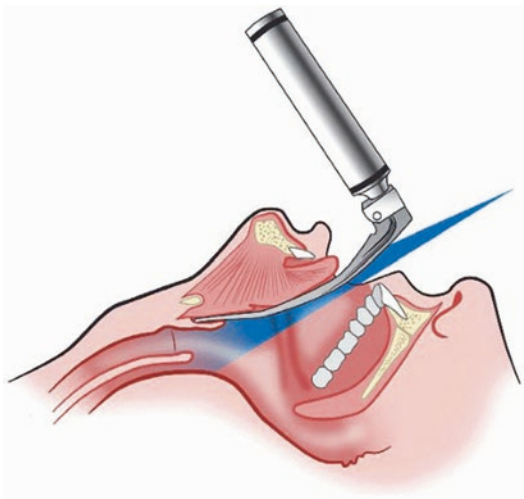

Fig. 6.1 Correct angulation of laryngoscope to prevent damage to dentition

6.4 Prevention

Despite the amount of effort by perioperative healthcare providers, there is not a way to completely eliminate dental injury as a possible perioperative complication [3]. This makes it very important that the perioperative provider understand the constant risk and ensure that everything is done to identify and minimize the risk of dental injury. Below is a discussion of the most important elements for a perioperative provider to understand to prevent their patients from suffering perioperative dental injury.

6.4.1 Preoperative Exam

The preoperative assessment is arguably the most crucial portion of the perioperative period to identify and then minimize the risks of dental injury [3]. The preoperative assessment should be started by obtaining a thorough medical, dental, surgical, and social history. The history provided by the patient should be guided by the provider to include any information that may increase the difficulty of intubation or indicate poor dental health. Important medical history may include congenital diseases or abnormalities of the head or neck, musculoskeletal conditions limiting neck mobility, or a history of cancer. The social history becomes important as smoking and chewing tobacco predispose to a number of dental and periodontal diseases. The dental history would include preexisting dental injuries or trauma, current dental or periodontal disease, usage of dental prostheses, and limitation in mouth opening [1, 3]. The surgical history should include any surgeries of the head and neck, any difficult intubations, and any prior perioperative dental injuries. The previous anesthesia records should be obtained for any patient who admits to previous difficult intubation or perioperative dental injury.

Once a thorough history has been obtained, the next step in preoperative evaluation is the clinical exam. The clinical evaluation must include a full dental exam and also establish the potential for difficult intubation. Most healthcare providers are already adept at performing a clinical exam that assesses the findings associated with difficult intubation. Providers with a purely medical back-

ground, however, may have difficulty completing an adequate dental exam as they often have had little training or experience with the basic principles of dentistry. It is, therefore, essential that dental anatomy, dental disease, and the fundamentals of dental restoration are discussed.

6.4.2 Dental Anatomy

Primary teeth, or baby teeth, begin to develop during the embryo phase of pregnancy and erupt around 6 months of age. A normal primary dentition consists of 20 teeth with 10 teeth on the maxillary arch and 10 teeth on the mandibular arch [15]. The permanent dentition begins to erupt at 6 years of age and ends with the eruption (unless impacted) of the third molars between the ages of 17 and 23 years [15]. The permanent dentition consists of 32 total teeth which include 12 molars, 8 premolars, 4 canines, 4 lateral incisors, and 4 central incisors [15]. The most common method for identifying individual teeth is the Universal Numbering System. This system assigns each permanent tooth a number (1–32) and each primary tooth a letter (A-T) [16]. The numbering system is designed to mimic a clinical view to facilitate documentation into an odontogram (Fig. 6.2) [16].

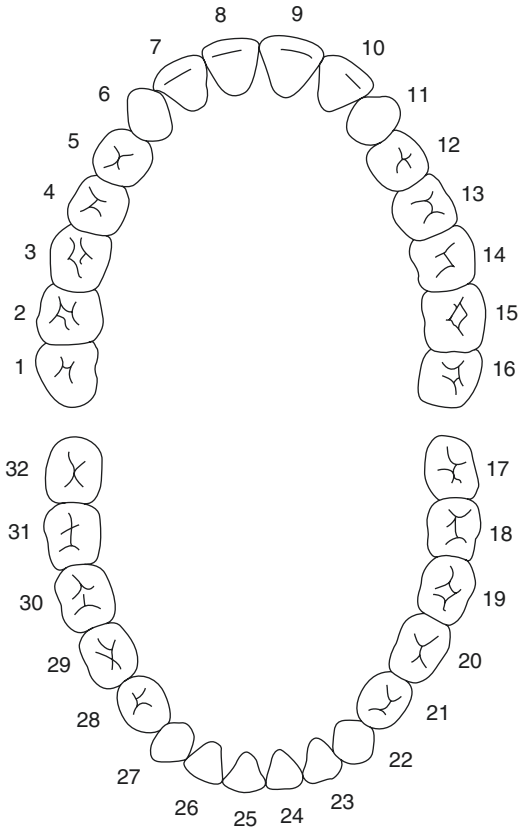

Fig. 6.2 Odontogram demonstrating dental numbering system

All teeth are divided into two anatomic segments: the crown and the root. The anatomical crown is the portion of the tooth visible on a clinical exam. In a healthy dentition, the gum line divides the crown from the root [17]. The shape and number of roots vary by the type of tooth. The anterior teeth (incisors and canines) typically have a single cylindrical root that tapers in an apical direction. The posterior teeth (premolars and molars) may have multiple roots with a surprising variability in shape, size, and internal anatomy [17]. Each tooth is made up of four unique tissues which form easily discernible anatomic layers [18]. The most superficial layer covering the entire anatomical crown is the enamel. Enamel is a very hard and extremely mineralized tissue composed mostly of crystallized calcium phosphate. The layer underneath the enamel is called dentin and is only exposed with pathology [18]. Within the dentin layer are tubules which allow transmission of sensation to the nerves found in the pulp chamber. Deep to the dentin lies the pulp chamber, which extends via canals through each root. These root canals house terminal nerve branches from the inferior and superior alveolar nerves and blood vessels which supply each tooth. The root surface is comprised of the third hard tissue known as cementum. Cementum is softer than both enamel and dentin and made up of both proteoglycans and collagen allowing attachment to the surrounding structures [18]. The tissues which stabilize a support each tooth are collectively known as the periodontium. The outermost layer of the periodontium visible on a clinical exam is the gingiva [17]. The gingival tissue is prone to injury in the form of laceration and periodontal disease in the form of gingivitis. Attached to the root cementum is the periodontal ligament that is then anchored to the alveolar bone. The alveolar bone is an anatomic designation for the tooth-bearing portions of the maxilla and the mandible [17].

6.4.3 Dental Pathology

With a confident understanding of dental and periodontal anatomy, the provider must then become familiar with dental disease. Any disease or injury that affects the teeth, gingiva, periodontal ligament, or alveolar bone increases the risk of perioperative dental injury [4]. There are two very common diseases found in the mouth, dental caries and periodontal disease, both of which have significant relevance and impact on a patient's risk of sustaining perioperative dental injury (Fig. 6.3).

The disease most commonly affecting the dentition is dental caries, also known as tooth decay or dental cavities. Caries is extremely prevalent with the most recent data indicating an incidence of 36% of the worldwide population (2.43 billion people) [19]. Even more impressive was a recent report published by the US Office of Disease Prevention and Health Promotion which concluded that within the pediatric population, caries is five times more common than asthma, making caries the most common chronic disease of childhood [21]. The incidence of caries is also increasing in both the pediatric and adult populations.

Dental caries causes progressive decay and structural breakdown of all dental tissues [4]. The decay is a result of demineralization due to acid produced by bacteria [22]. The most common species of cariogenic bacteria are *Streptococcus mutans* and *Lactobacilli*. These bacteria ferment dietary fructose, glucose, and sucrose into lactic acid. *S. mutans* also has the ability to convert sucrose to the polysaccharide dextran which allows adhesion to the tooth surface as well as protection with the development of a biofilm [23]. Dental caries are typically not difficult to locate and the severity correlates very well with their progression throughout the crown. Early caries will appear as a soft discoloration within the enamel. This breakdown will continue deeper within the tooth until the eventual exposure of dentin followed by the pulp chamber.

The second most important disease related to dental injury is periodontal disease which may affect the gingiva, ligaments, and alveolar bone. Periodontal disease begins as a bacterial infection of the gingiva caused by the presence of bacteria laden dental plaque/calculus [4]. The tissue's response to the bacterial infection results in a painless and slow spreading inflammatory process causing the

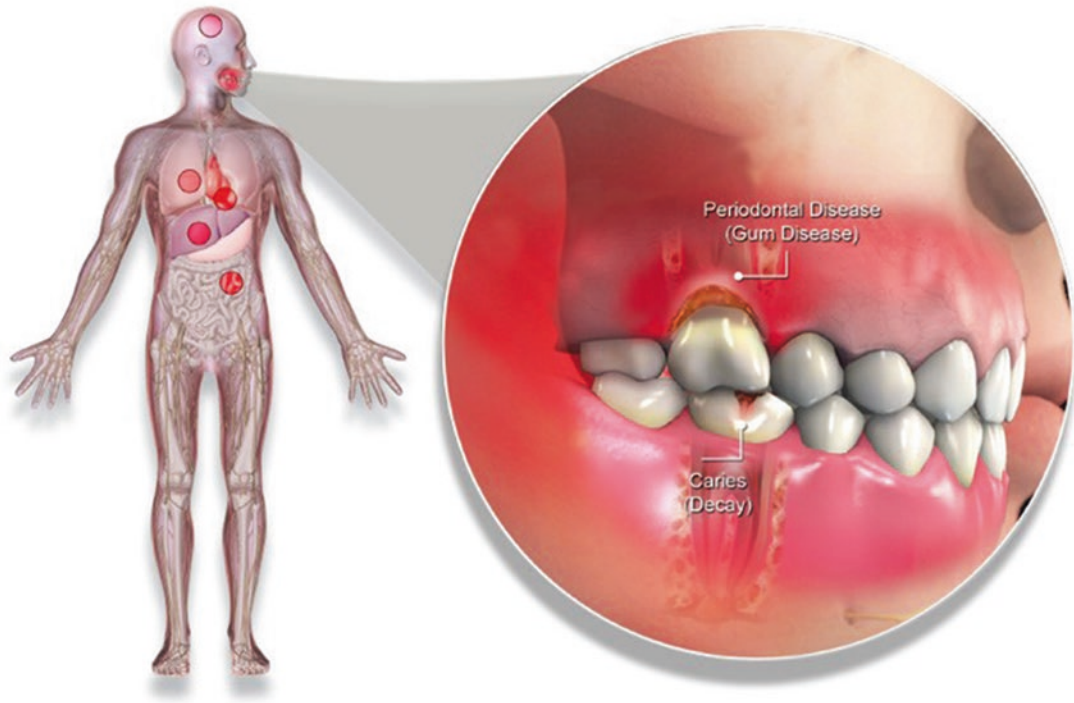

Fig. 6.3 Clinical schematic of dental caries and periodontal disease

dissolution of the gingiva, periodontal ligament, and alveolar bone surrounding the tooth [4, 24]. The earliest clinical signs of periodontal disease include inflamed, erythematous, and friable gingiva and are termed gingivitis [24]. Gingivitis will continue to worsen and spread which can be clinically identified as gingival recession causing root surface exposure. When the inflammatory process causes destruction of the periodontal ligament and then alveolar bone socket, it is termed periodontitis [24]. As damage to the periodontal ligament and alveolar bone increases, the associated tooth will lose stability causing significant dental mobility.

Caries and periodontal disease share common elements including bacterial involvement and destruction of tissues causing loss of stability or loss of structure, and of course, both greatly increase a patient's risk of perioperative dental injury. These diseases differ in that they predispose a tooth to distance types of dental injury. Periodontal disease causes dental mobility which increases the likelihood of luxation or avulsion with dental injury. Caries causes loss of the enamel and dentin which increases the likelihood of crown fracture with dental injury.

6.4.4 Dental Restorations

The rapid advancement of clinical technology including computer-assisted design and in-office 3D printing has enabled dentists to place a greater variety of prostheses at a much faster pace [25]. The perioperative provider performing a preoperative dental exam must maintain a working knowledge of the most common types of dental restorations and prostheses in a constantly changing field. A tooth with a restoration will always be more prone to dental injury than a healthy tooth [4]. A familiarity with dental restorations and prostheses will allow the provider to properly take a dental history, identify and correctly document restorations and prosthetics in the chart, and assess the level of damage in the event of dental injury causing damage to a restoration or prosthesis.

6.4.4.1 Amalgam and Resin-Based Composite Fillings

Localized defects of the anatomical crown caused by trauma or carious decay are typically restored with an amalgam or resin-based composite filling. Amalgam fillings, sometimes called silver fillings, are easy to identify visually and will only be placed in a posterior tooth. Composite fillings have an impressive variety of shades and opacities allowing the creation of nearly invisible restorations. These restorations can also be placed anywhere on the dentition making identification very difficult [26].

6.4.4.2 Removable Prosthesis

The single most important characteristic of a dental prosthesis for the purposes of identification and documentation is whether or not it can be intentionally removed and replaced by the patient. A removable dental prosthesis fabricated to replace missing teeth is termed a denture. A denture, sometimes called a plate, may provide partial or full replacement of teeth in the maxillary or mandibular arch. Partial dentures are typically made of acrylic or resin and are retained by metallic clasps which attach to adjacent healthy teeth. A partial denture is typically easy to identify by the examiner and easily removed by the patient. A full denture is made of acrylic and ceramic and is stabilized by either mechanical retention, denture adhesive pastes, or by attachment to surgically placed dental implants. Full dentures are also typically easy to identify and remove. It is important to note that the surgically placed dental implants are osseointegrated into the patient's jaw, while the denture can be removed [26].

6.4.4.3 Fixed Single-Tooth Restorations and Fixed Multiunit Restorations

Large dental defects involving a majority of the anatomical crown may no longer be possible to adequately restore with a dental filling. Such large defects are replaced with a wide variety of techniques and materials but are alike in that they are permanently affixed to the remaining healthy dentition. The fixed prostheses which restore a partial defect include inlays, onlays, and veneers [29]. Veneers are uniquely important for perioperative providers given their hazardous placement on the facial and incisal surface of the anterior teeth. When the fixed prosthesis provides full coverage, it is termed a crown or colloquially, a cap. Partial and full coverage fixed prostheses are nearly all retained via dental cement. Fixed dental prostheses can also be used to replace missing teeth with an artificial tooth connected to the adjacent teeth and may be referred to as bridges

[29]. These prostheses involve the placement of a pontic (or false tooth) which sits above the gingiva of an edentulous space and is suspended by its rigid attachment to an anterior and posterior full coverage crown. These multiunit fixed restorations can be used to replace very large edentulous gaps caused by the loss of multiple teeth.

Fixed restorations which were once nearly all fabricated using gold, later transitioned to porcelain, ceramic, and leucite. Gold restorations are easy to locate and properly document. The ceramics have become increasingly esthetic and may be difficult to identify without asking a patient's dental history. These restorations are particularly relevant due to the likely chance of full displacement, the significant aspiration risk, and high cost of replacement. Due to all these factors, fixed dental restorations require special attention both during documentation and in the perioperative period [26].

6.4.4.4 Dental Implants

A dental implant is a threaded titanium medical device which is surgically drilled into the maxilla or mandible providing excellent stability for a number of dental restorations [30]. The dental implant is drilled to a depth that allows little to no protrusion of the implant beyond the height of the alveolar bone. The implant is then covered by gingival tissue concealing it from clinical view. During this time the implant osseointegrates into the bone, and after a surgeon-dependent period of time, is uncovered to allow attachment of a prosthesis. The dental implant can be used to support single tooth replacements, multiunit prostheses, and, as aforementioned, removable partial and full dentures. It is important for the perioperative provider to recognize that the surgically placed dental implant is a separate component from possible dental prosthetics it can support. Since there are a variety of implant-supported restorations, it is necessary to determine if the patient's restorations are fixed or removable and to subsequently determine the number of dental implants and their relative location and if they show signs of disease or failure [26].

6.4.5 Damage to Restorations

Damage sustained to a prosthesis typically results in loosening or displacement. Displacement of these prostheses results from failing dental cement, underlying decay, or mechanical trauma. Dental prostheses of any size pose a great risk for aspiration if displaced and require immediate attention. Damage to a simple restoration, such as an amalgam or composite filling, will likely lead to material fracture or deterioration with the possibility of tooth fracture.

6.4.6 Proper Technique

Intraoperatively there are a number of strategies to reduce the risk of dental injury. The use of a protective dental guard, or occlusal gutter, can help to reduce forces acting directly on the maxillary incisors during laryngoscopy [4, 27]. These gutters are most effective when they are custom made preoperatively by the patient's dentist. These gutters may be most appropriate for patients with costly fixed dental prostheses of the anterior maxillary incisors. These gutters should be cautiously used in patients with a predicted difficult intubation as they limit mouth opening and may decrease visualization, thereby worsening the conditions for intubation [4, 27].

Proper technique also involves ideal positioning of the patient's head and neck through the utilization of blankets, positioning devices, or adjustment of the operating table. Correct positioning will increase the distance between anatomical obstacles, including the teeth, and decrease the difficulty of laryngoscopy and intubation [3, 4]. An experienced provider should become immediately aware of dental contact during laryngoscopy and immediately consider change in technique including optimizing patient position [32, 4].

During laryngoscopy it is essential that the blade be held in the provider's left hand close to the junction of handle and blade. The provider's right hand is used to carefully scissors open the patient's mouth with pressure on the most stable and posterior teeth to allow safe maximum mouth opening. The blade is then introduced slowly into the right side of the patient's mouth while the provider is careful to adjust the geometry of entry based upon constant visualization of the patient's lips, gingiva, and teeth [7]. The blade and tongue are swept to the left and then advanced toward the larynx as the provider continues to avoid contact with the dentition. Once an adequate depth and position (based upon the type of blade selected)

has been achieved, the provider's left wrist is held rigid resulting in a lifting force along the axis of the handle that will displace soft tissue and allow visualization of the vocal cords [7]. The force applied should be in an anterior and superior vector sometimes described as a pulling force toward the junction of the operating room's far wall and ceiling. While lifting there should be no rotation of the wrist causing contact with gingiva or dentition. Trainees are apt to pull the laryngoscope in a superior and cephalad direction unintentionally using the maxillary incisors as a fulcrum. A novice is also more likely to use excessive forces combined with prolonged time of intubation greatly increasing the risk of dental injury.

6.5 Dental Injury

In healthy dentition, dental injury most commonly causes enamel fracture of the crown. A more severe fracture can penetrate to the layer of dentin and may cause exposure the pulp chamber [31]. These fractures are most severe when they involve preexisting dental cracks undiscovered during the preoperative exam [4]. An injury causing fracture of the tooth root is less likely than a fracture of the crown due to increased structural strength and protection from the alveolar bone. The root is also less likely to be weakened by dental caries [31]. Root fractures do still occur and can be diagnosed with either detachment or significant mobility of the entire crown.

Injury that causes traumatic movement of a tooth is termed luxation [2]. These injuries represent damage to the ligament or socket which act to stabilize the tooth. The mildest form of the injury is termed subluxation and represents a nondisplaced tooth with minor mobility and bleeding [31]. The more severe form of the injury leads to visible displacement of the tooth in a lateral, intrusive, or extrusive direction. When dental injury causes a tooth to be completely displaced from the socket, it is termed an avulsion. This is the most severe form of dental injury, and in addition to a poor restorative prognosis, it has the extra risk of displacement into the airway or esophagus. The risk of traumatic movement from dental injury is greatly increased with periodontal disease. Whereas difficult intubation remains the most common cause of dental injury to maxillary teeth with periodontal disease, mandibular teeth with periodontal disease are more prone to damage from biting an oropharyngeal airway, endotracheal tube, or supraglottic device [4, 8].

6.6 Treatment

The most common dental injury of the perioperative period is enamel fracture to the maxillary central incisors [3–5]. These injuries are typically small without major immediate risk allowing the airway to be secured and the patient stabilized. The site of fracture should be evaluated to ensure that the remaining dental structure is stable and poses no risk of aspiration. A large fractured segment of tooth or dental prosthetic or an entirely avulsed tooth needs to be found. A thorough examination of the oral cavity, oropharynx, and hypopharynx may be warranted. If the displaced segment is not found, then radiographs of the head, neck, chest, and abdomen should be obtained to ensure that the fractured segment was not aspirated into the lungs or lodged in the esophagus or stomach [7]. If the fragment is visible in the mouth or oropharynx, a concerted effort should be made to maintain visualization as these fragments are very easily displaced necessitating a time-consuming and difficult search. The patient should be kept sedated so as to prevent displacement of the tooth from the patient swallowing, coughing, or bucking in response to laryngeal stimulation. When attempting to retrieve the dental fragment, the patient should be optimally positioned to reduce the risk of posterior displacement down the pharynx. If possible, a piece of gauze should be opened to its maximum size and placed posterior to the fragment to act as an oropharyngeal screen. The displaced segment should be grasped using a Magill forceps or similar surgical instrument. A frantic hand attempting to secure a small fragment located in the back of the throat will often lead to accidental displacement.

If dental injury causes luxation of a tooth or dental prosthetic, the mobile segment should quickly be stabilized to avoid damage to nearby structures or the complete avulsion of the tooth. A non-dental provider should avoid removing the mobilized segment until dental consultation is obtained. The exceptions to this guideline would be a situation where the mobile segment poses an emergent threat to the patient's health or in a situation where a dental provider will not be available before emergence or discharge.

All dental injuries sustained in the perioperative period warrant consultation to the on-call dental service. For minor dental injuries, it is acceptable for the evaluation of the patient to be performed in the PACU or even outpatient as determined by the consultant [7]. Dental injuries causing luxation should prompt consultation to the dental team and evaluation of the patient in the OR before emergence. When a tooth is fully avulsed, the dental team should urgently present to the OR for possible replantation of the tooth. Consultation not only allows evaluation and treatment of the injury by specialists but it may also provide legal protection in the not uncommon event of future litigation.

6.7 Medical Legal Implications

Perioperative dental injuries are both the most frequently cited complaint in medical malpractice against anesthesiologists and the most common forensics claim related to all of anesthesia [4]. The financial burden is especially significant with estimates of most claims averaging $2000 [1]. While only a third of perioperative dental injuries result in filed complaints, the overall frequency maintains a very high impact. At the preoperative appointment the findings on the dental exam should be verified and corroborated with the patient. Involving the patient not only allows more accurate identification of well-concealed dental restorations but will also notify the patient of the existence of any undiagnosed existing dental disease [1]. Many institutions have benefitted from the use of a structured preoperative dental assessment which facilitates the provision of information to patients, improves clinical documentation, and reduces overall liability [1]. It is then important to specifically discuss the patient's individual risk of dental injury and the possible outcomes stemming from an injury. This information should also be included in the anesthesia and relevant surgical informed consent [4].

For patients at particular risk of dental injury or in whom dental injury may be particularly costly, the preoperative involvement of the patient's dentist may allow corrective or preventive measures to reduce risk of dental injury and may minimize the chance of legal action in the event of subsequent dental injury [28]. In the event of dental injury, immediate consultation by the hospital's dental service is always advised from a legal standpoint. Dental consultation reduces the risk of further injury and will help minimize the chance of a patient feeling abandoned or interpreting the provider's actions as negligent. As with all medical legal issues, thorough documentation and open communication will always improve legal protection.

6.8 Summary

Dental injury is a significant perioperative complication due to its overwhelming frequency, financial burden, and stressful impact on both provider and patient. With an ever-increasing amount of operative procedures coupled with more frequent placement of costly dental restorations, this complication will only become more significant in time. It is crucial that providers, including those without formal dental education, understand the elements involved in perioperative dental injury to best prevent these complications. The most common perioperative dental injury involves direct laryngoscopy causing dental fracture to the maxillary central incisors. The most relevant risks include preexisting dental disease and the factors predicting difficult intubation. These risks must be assessed during the preoperative evaluation by obtaining a thorough history and detailed dental exam. The findings and risks must be well communicated to the patient to allow a valid informed consent and then accurately documented by the provider. The provider should make every attempt to prevent trauma but also must be adept at the indicated treatment both in the acute and postoperative phases of injury. In the event of perioperative dental injury, the provider is expected to be able to quickly diagnose the injury, take immediate action to prevent further injury, and then determine the appropriate urgency of consultation. Even with dental consultation, the perioperative provider should continue to provide care for the patient and remain actively involved until its resolution. It is impossible to predict with certainty when a complication will lead to legal action, but providers who are meticulous about documentation, prevention, and patient communication will undoubtedly afford themselves the highest level of legal protection.

6.9 Review Questions

1. What is the most common perioperative dental injury during direct laryngoscopy?
   A. Subluxation of mandibular central incisors
   B. Enamel fracture to the maxillary central incisors
   C. Intrusion of maxillary molars
   D. Laceration of gingiva

2. Name three anatomic risk factors associated with possible dental injury during anesthesia?
   A. The presence of dental pathology
   B. A small mouth opening
   C. Large maxillary incisors
   D. All of the above
   E. A and C only

3. What should be done in the event of a dental fracture or avulsion during anesthesia?
   A. A thorough examination of the oral cavity, oropharynx, and hypopharynx.
   B. Keep the patient sedated to prevent displacement of tooth from swallowing, coughing, or bucking.
   C. Use of gauze along posterior oropharynx to act as screen.
   D. All of the above.
   E. B and C only.

6.10 Answers

1. B – The most common perioperative dental injury during direct laryngoscopy is enamel fracture to the maxillary central incisors during a difficult intubation when the provider fulcrums against the maxillary dentition in an attempt to gain a better view.

2. D – Anatomic risk factors associated with possible dental injury during anesthesia include the presence of dental pathology, a small mouth opening, large maxillary incisors, and/or anterior dental crowding.

3. D – During the unfortunate event of a dental fracture or avulsion during anesthesia, once recognized, the provider must first perform a thorough examination of the oral cavity, oropharynx, and hypopharynx. If the displaced segment is not found, then radiographs of the head, neck, chest, and abdomen should be obtained to ensure that the fractured segment was not aspirated into the lungs or lodged in the esophagus or stomach. If the fragment is visible in the mouth or oropharynx, effort should be made to maintain visualization. The patient should be kept sedated so as to prevent displacement of the tooth from the patient swallowing, coughing, or bucking in response to laryngeal stimulation. When attempting to retrieve the dental fragment, the patient should be optimally positioned to reduce the risk of posterior displacement down the pharynx. If possible, a piece of gauze should be opened to its maximum size and placed posterior to the fragment to act as an oropharyngeal screen. The displaced segment should be grasped using a Magill forceps or similar surgical instrument. An immediate consult to the dental service should be obtained for further evaluation.

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Complications of General Anesthesia

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_7

7.1 Introduction

The need of general anesthesia for conducting surgical procedures is without question. Complications from general anesthesia can range from benign (i.e., sore throat) and common (i.e., postoperative nausea and vomiting) to debilitating but rare (i.e., stroke or death), as well as everything in between. Due to their rarity, tracking many of these occurrences is difficult and often the product of multi-year, single-center retrospective analyses, a small group of surgical center reports, monitoring via closed claims projects, or based on more dated studies. Predicting the individuals susceptible to complications of general anesthesia and having an adequate perioperative anesthetic plan have improved, but it is the unpredictable complication that concerns practitioners. Patients are also concerned about such unpredictable complications. The prospect of undergoing general anesthesia is frightening to roughly 33% of surgical patients [1]. These fears primarily manifest themselves distinctly from the operative procedure and include awareness under anesthesia, not waking from anesthesia or sensing pain and discomfort from the procedure and being unable to communicate this concern. A more empathetic preoperative visit and acknowledgment of these issues can go a long way in assuaging these concerns and even improve postoperative pain and hospital length of stay [1, 2]. This chapter aims to provide an overview of some of the complications arising from general anesthesia and the direction providers can potentially expect in the future.

The modern anesthesiologist has an ever-improving number of monitoring tools at their disposal. This stands as the cornerstone to good anesthetic practice, so much so that the American Society of Anesthesiologists (ASA) continually evaluates and updates their Standard of Practice Parameters on standard and nonstandard anesthetic monitoring guidelines [3]. The basics of this include Standard I, qualified anesthesia personnel, and Standard II, monitoring of oxygenation, ventilation, circulation and temperature, and frequency of monitoring and alarm requirements. A detailed description of the utility and validity of these monitors is beyond the scope of this chapter, but the value of these tools should not be underestimated in reducing the morbidity and mortality of complications of anesthesia. Alterations in EKG waveforms, pulse oximeter saturations, blood pressure readings, end-tidal carbon dioxide (ETCO2) values, or any of the other monitoring devices in use can lend hints to what may be occurring and provide insight into whether the interventions chosen are driving improvement in the patient's condition.

Many factors can be suggestive of potential anesthetic complications: family history, perioperative comorbidities, and type of surgical procedure, among others, and it takes the dedicated and diligent anesthesia provider to tease out these subtleties to provide the safest anesthetic possible. However, even the most detailed preoperative review cannot account for some unexpected outcomes such as unknown muscular dystrophies or mitochondrial disorders, an undetected coronary artery stenosis or first time malignant hyperthermia event. The relative risk of complications from general anesthesia is very complex to interpret. One must consider inpatient versus outpatient surgery, type of procedure, length of procedure, ASA score, as well as the way the data was collected. Even when basing data on the well-known ASA scoring system, there is some variation in how anesthesiologists score the same patient and making its use as a fixed variable questionable [4]. Regardless, studies do bear out that the higher the ASA score, the higher the incidence of death, which becomes even more profound when factoring in age [5, 6]. To overcome these limitations, standardization practices of data collection and follow-up were established, including the ASA closed claims project (ASA-CCP), Cochrane reviews, and the guidelines established by the National Surgical Quality Improvement Program (NSQIP), a large surgical registry where outcomes are collected for 30 days postoperatively for a wide range of surgical procedures. With the increasing use of electronic medical records (EMRs) nationwide, data mining and more precise assessment of anesthetic complications and even predictive factors will become more easily accessible.

7.2 Death

Death from anesthesia was initially common, 1 in 2680 (0.03%) cases in 1954. By the mid-1980s, estimates from the landmark CEPOD study showed risk of death ranging from 1 in 13,000 to

1 in 185,000 [7, 8]. More recently, studies show 11–16 deaths per 100,000 persons from anesthesia alone (0.01–0.016%) [9, 10]. This varied greatly with the ASA physical status of the patient undergoing the surgical procedure [5, 6, 11]. Researchers still grapple with defining and measuring death solely from anesthesia versus other complicating factors. Furthermore, while the practice of anesthesia and the tools are improving, patient acuity is also increasing, allowing for the relatively stagnant levels of risk of death from anesthesia from the 1980s till present. It is important to note, however, that the risk of death from anesthesia is on par with death as a result of pregnancy and that even seemingly benign procedures (i.e., cholecystectomy) carry a higher risk of mortality as compared to general anesthesia alone [12–15]. Thus, although death from anesthesia is a known complication, it is less common than the majority of procedures in which the requirement for anesthesia is warranted.

7.3 Respiratory Complications

One of the central tenants of anesthetic practice is airway and ventilatory management. Therefore, it should come as little surprise that significant morbidity and mortality are associated with complications of the respiratory system. In studying the causative factors involved in perioperative morbidity and mortality, several etiologies have been examined. Using the ASA-CCP, reviewers noted that the largest class of injury (~34%) was respiratory events, with death or significant brain injury occurring roughly 85% of the time. Inadequate ventilation, esophageal intubation, and difficult tracheal intubation were the leading causes of reported respiratory events with majority of these deemed preventable [16, 17]. There are similar results when comparing general anesthesia with monitored anesthesia care (MAC), but in regard to causative etiologies during MAC cases, overdose of sedative or opioid medications are the primary cause [18].

Inadequate ventilation was typically associated with MAC cases, but also postoperatively following general anesthesia cases. While it's difficult to quantify total numbers of observed respiratory depression and inadequate ventilation complications among all anesthetic cases, a meta-analysis review of roughly 20,000 patients demonstrated a 0.1–37% rate of observed respiratory depression. The large distribution depended upon the type and route of opioid administration and variations in defining and detecting respiratory depression [19]. A review of the ASA-CCP, however, showed that the majority of respiratory depression events occurred within 24 h of surgery (88%) and that 97% were deemed preventable, an unfortunate amount of which resulted in death or severe brain damage [20]. Interestingly, patient-controlled analgesia (PCA, 53%) and neuraxial anesthesia (39%) were the most cited modes of pain management techniques noted in the claims. Recognition of patient factors (i.e., history of obstructive sleep apnea, age, and debility), reduction in total opioid administration, ETCO2 monitoring, and more frequent nursing checks, especially within the first 2–3 h, are possible approaches to preventing these potentially devastating events.

Similar to respiratory depression, esophageal intubation was a major source of patient injury in the 1980s [17]. Counting for roughly 6% of all anesthesia-related closed malpractice claims and nearly 18% of those specifically associated with adverse respiratory events since the ASA-CCP monitoring began, esophageal intubation remains a serious concern [17]. This is especially important as nearly 98% of those claims resulted in severe brain damage or death. Prior to 1991 and the introduction of ETCO2 as well as its subsequent adoption by ASA as a standard monitoring practice, 3–8% of claims per year were made for esophageal intubation. Despite a marked improvement to 1–2% per year following that landmark discovery, the persistence of these occurrences is primarily secondary to human error, including fixation error, confirmation bias, and overconfidence [3, 21, 22]. It's important to note that a portion of these claims included intubation complications during resuscitative efforts outside the OR where ETCO2 detection devices and monitoring may not be available; however, use of good communication and an open mind to multiple potential causes of ventilatory difficulties can lead to a decrease in such adverse events.

Difficult tracheal intubation is more complex to study due to the relative ambiguity of the definition for a difficult airway [23–25]. Some have described it as vaguely as that in which an expert anesthesiologist or anesthetic provider struggles to ventilate or intubate, whereas others

use more specific definitions such as three or more attempts or taking longer than 10 min to establish an airway [26]. Regardless, the reported incidence of difficult airways is 1.1–3.8% [24, 27]. From the Mallampati airway grading scale to the entirety of the standard airway exam (mouth opening, neck extension, thyromental distance, etc.), many have examined predictive factors associated with difficult intubation [28, 29]. Alone, many diagnostic exams are only moderately sensitive, yet fairly specific; but in combination, especially the use of the Mallampati score and thyromental distance, accuracy of predicting difficult intubations improves without much loss in specificity [24, 30]. The ASA routinely updates practice guidelines and difficult airway algorithms to address such issues [26]. As an entity of respiratory complications, closed claims analysis noted that over half of difficult intubations resulted in death or brain damage, though the incidence has noted a downward trend, likely owing to improved equipment and training [31]. Nevertheless, anesthesia providers should familiarize themselves with both the difficult airway algorithm (Fig. 7.1) and the on-site equipment available for airway emergencies. In conjunction with a good history and physical exam assessment, appropriate airway management planning will provide a safer avenue for patients undergoing general anesthesia.

7.4 Awareness

Unintended awareness during a general anesthetic (UAGA) is the presence of consciousness and explicit recall while receiving treatment modalities that should eliminate both [32]. These criteria are most useful when the anesthetic provider observes objective patient demonstrations of meaningful interaction with their environment or can corroborate the specific events the patient recalls. It becomes difficult to assess when UAGA has occurred if the provider of record cannot verify the recollections or conscious behavior. Additionally, intraoperative dreaming, in which the subconscious manifests reasonable scenarios that occur during surgery, can be difficult to distinguish from explicit recall. These factors make the identification and study of UAGA challenging. An established standardized questionnaire to identify UAGA is the Brice interview [33]. Several studies have used this questionnaire or variations of it to identify UAGA in conjunction with operative records when available. The operative records are evaluated for consistency between patient-reported and practitioner-documented events and the presence of descriptors that objectively imply particular levels of consciousness. Accounting for the previous considerations, the incidence of UAGA ranges from 0.005% to 0.2% [34–36]. Factors that independently increase the chances of intraoperative awareness are use of neuromuscular blocking agents (NMBs), female sex, emergency procedures, obstetric and cardiothoracic surgery, obesity, age, and increased operative time [33]. UAGA most frequently occurs during the induction and emergence phases of anesthesia. The occurrence of UAGA during maintenance is most often associated with a light plane of anesthesia and is correlated in some studies with low end-tidal anesthetic gas and MAC. UAGA is not always unpleasant for patients but the majority report anxiety, fear, and discomfort. The most frequent elements of recall are auditory events [35]. Patients who report UAGA should have their concerns acknowledged and questions answered at the time of reporting, and further discussion should be centered on the patient's experience. A retrospective patient-centered report of UAGA found patient dissatisfaction primarily arose from lack of dialog with anesthetic caregivers and conversations that appeared to shift blame to the patient for their experience [34]. Preoperative discussion of the possibility of UAGA in instances where there are numerous patient and operative risk factors can potentially mitigate some concerns should UAGA occur. Judicious use of NMBs and efforts to maintain adequate anesthetic depth based on MAC when available, and multimodal approaches when not, should minimize controllable risk factors. Use of proprietary algorithmic neuro-monitors that interpret EEG, EMG, or AEP signals as surrogates for anesthetic depth (BIS, M-Entropy, aepEX) should be used on a case-by-case basis. There is evidence to suggest that in patients at high risk for UAGA, use of these monitors can reduce its incidence. However, in cases where end-tidal anesthetic gas is available and maintained >0.7 MAC and compared to BIS, there is no difference in the incidence of UAGA [33].

American Society of Anesthesiologists®

DIFFICULT AIRWAY ALGORITHM

1. **Assess the likelihood and clinical impact of basic management problems:**
   - **Difficulty with patient cooperation or consent**
   - **Difficult mask ventilation**
   - **Difficult supraglottic airway placement**
   - **Difficult laryngoscopy**
   - **Difficult intubation**
   - **Difficult surgical airway access**
2. **Actively pursue opportunities to deliver supplemental oxygen throughout the process of difficult airway management.**
3. **Consider the relative merits and feasibility of basic management choices:**
   - **Awake intubation *vs.* intubation after induction of general anesthesia**
   - **Non-invasive technique vs. invasive techniques for the initial approach to intubation**
   - **Video-assisted laryngoscopy as an initial approach to intubation**
   - **Preservation *vs.* ablation of spontaneous ventilation**
4. **Develop primary and alternative strategies:**

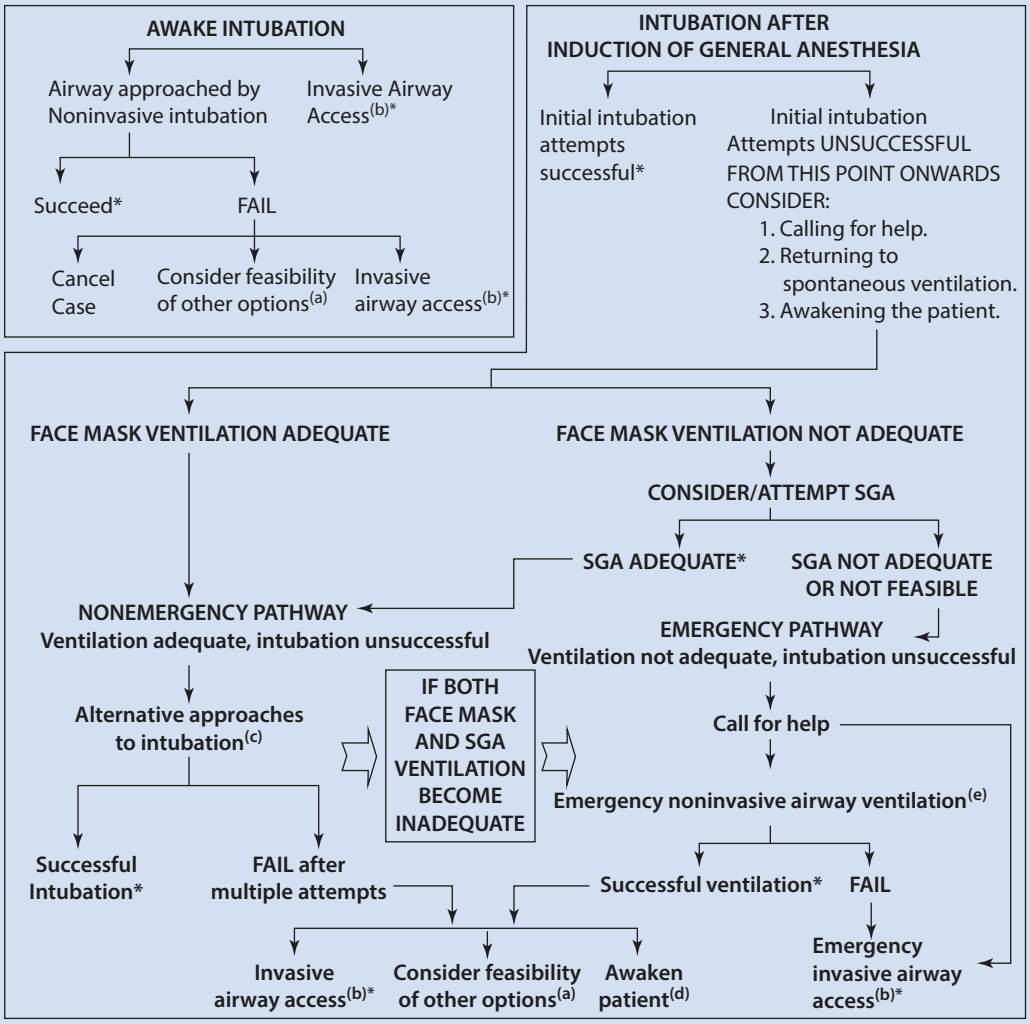

Fig. 7.1 Difficulty airway algorithm. (From Apfelbaum et al. [26])

7.5 Stroke

Stroke can be defined as end-organ damage to a CNS component resulting from a vascular event. The primary mechanism of stroke in the perioperative setting is ischemic, most often the result of embolism, rather than hemorrhagic [37]. The increased risk of perioperative stroke (PS) for patients undergoing cardiac and vascular surgery has been well established [38]. While the incidence of PS is lower in those receiving nonvascular, non-cardiac surgery, it continues to carry significant patient morbidity and mortality [39, 40]. Inherent risks exist both due to patient population and the performed surgical procedure. The most significant patient risks for PS are age >70, history of previous stroke, ESRD requiring dialysis, and atrial fibrillation. MI is a significant risk factor within 6 months of the event, and the risk of perioperative cardiovascular events should be weighed against the necessity and benefit of procedure. Generally nonvascular, non-cardiac surgeries carry a risk of PS risk of 0.08–0.9%. Head and neck dissection for tumors are the exception and carry PS risk of about 4.8% [39]. Preoperative assessment of patients at high risk for PS should focus on optimizing the medical management of comorbid conditions prior to surgery. The incidence of an intraoperative cerebrovascular accident is difficult to assess under general anesthesia due to the inability to perform an interactive neurologic examination with the patient. The POISE trial demonstrated that initiation of metoprolol in beta-blocker naïve patients with significant cardiovascular risk factors led to an increased incidence of PS [41]. While the trial included pre- and daily postoperative doses, many practitioners avoid the use of metoprolol for intraoperative heart rate control in naïve patients. Intraoperative and postoperative predictors of PS that were clinically significant are hypotension, hemorrhage, and new-onset atrial fibrillation. Intraoperative hypotension may be less important than postoperative as an etiologic factor, although 30% decreases in MAP from baseline have been demonstrated to be associated with postoperative PS but not causative. Additionally, very few documented cases of PS are watershed and primarily embolic [42, 43]. There are no proven ventilation strategies or specific volatile or intravenous anesthetic agent regimens proven to reduce the risk of PS for general anesthetics [44]. Arterial and venous catheterization pose the risk of introducing emboli by dislodging existing arterial plaques, instigating thrombus formation that can later dislodge, or causing the introduction of air. Most studies assessing PS demonstrate its occurrence in the postoperative period after PACU recovery. In one study, only 10% of PS was identified on emergence from anesthesia with the majority being detected on postoperative day 0 or 1 [45]. Patients at higher risk of PS should receive a thorough neurologic examination immediately post-op as part of their PACU assessment.

7.6 Cardiac Complications

Cardiac events surrounding the perioperative period for non-cardiac procedures have been well studied and are known to be a major cause of morbidity and mortality [46]. The revised cardiac risk index (RCRI) is the most widely used tool to identify patients at increased risk of a major adverse cardiac event (MACE) defined as myocardial infarction, cardiac arrest, ventricular fibrillation (VF), complete heart block (CHB), or cardiogenic pulmonary edema [47]. Omitted from the definition of MACE and not included in the predisposed risks to MACE are dysrhythmias. Evidence at the time of the RCRI creation suggested patients with controlled atrial fibrillation or asymptomatic dysrhythmias, including ventricular ones, did not confer a larger risk of MACE compared to normal patients [48]. However, newer studies have demonstrated that a patient with atrial fibrillation may have an increased risk of MACE, possibly greater than those with coronary artery disease (CAD) [49]. There may also be an increased risk of MACE in patients who develop frequent premature ventricular contractions (PVCs) or runs of non-sustained ventricular tachycardia.

Both tachycardic and bradycardic dysrhythmias are commonly seen in the perioperative period. Patients with a known history of dysrhythmias are more likely to experience them in the perioperative period [50]. PVCs or episodes of non-sustained ventricular tachycardia predispose patients to developing sustained perioperative dysrhythmias but have not been shown to increase MACE. Patients with a history of abnormal cardiac conduction, such as prolonged QTc

or Wolff-Parkinson-White (WPW) syndrome, are predisposed to dysrhythmias in the presence of medications or abnormal serum chemistry values. The nature of the surgical procedure also contributes to this risk. Thoracotomies carry risk specifically for atrial fibrillation; ophthalmic surgeries can precipitate the oculo-cardiac reflex; and pneumoperitoneum and vagal manipulation can precipitate a multitude of dysrhythmias. There are many other risk factors that can contribute to the development of perioperative dysrhythmia.

The identification of specific dysrhythmias and their management are complex subjects that will not be discussed in this chapter but being able to do so is essential for perioperative management of patients. Preoperatively, the goals of management should be medical optimization of any existing conduction abnormalities or electrolyte derangements. Intraoperatively, maintenance of adequate hemodynamics is most important. Treatment of dysrhythmias may involve pharmacologic intervention, electrical cardioversion, transvenous or transcutaneous pacing, or simply pausing the current surgical manipulation. Postoperative management is similar to pre- and intraoperative management strategies with plans for long-term patient follow-up.

Perioperative MI (PMI) can be a devastating complication. It can be defined as any perioperative ischemic myocardial event causing tissue necrosis with or without a reduction in cardiac function and with or without clinical symptoms of ischemia [51]. Of patients at increased risk for MACE based on the RCRI, the incidence of PMI is estimated to be between 1.1 and 3.3% [52]. Without clinical symptoms and obvious changes to patient hemodynamics, it can be difficult to identify PMI and many will go unnoticed. PMI can be divided into two mechanisms: Type I which represents a thrombotic/embolic event causing myocardial ischemia and necrosis and Type II which represents hypoperfusion of coronary circulation causing ischemia and necrosis. Type II is far more common than Type I in the perioperative setting [53]. The use of troponin testing postoperatively to help identify PMI in patients without symptoms or hemodynamic changes is currently debated. European guidelines suggest their routine use postoperatively for patients at higher risk of PMI, but the current American guidelines do not suggest routine utilization. Patients with a history of MI, chronic stable angina, CAD, ischemic EKG changes preoperatively, and severe aortic stenosis are at greater risk of PMI for non-cardiac procedures than other patients [54].

Management of patients with significant risks for PMI or recent PMI can be challenging. Preoperatively, those with known CAD or valvular disease and history of cardiac dysfunction should have a recent evaluation with echocardiography. Those with severe dysfunction may need further stress testing, cardiac surgery, or even revascularization prior to their elective non-cardiac procedures to minimize their risk. These patients should also be medically optimized. For nonelective procedures, the risk of MACE in the setting of PMI should be less than the risk of morbidity/mortality of forgoing the procedure before proceeding [55]. The intraoperative management of PMI is supportive care. Intra- and postoperatively, avoidance of events like prolonged hypotension, persistent tachycardia, uncontrolled hypertension, severe anemia, and hypoxemia are all strategies that reduce the risk of PMI in susceptible patients.

7.7 Conclusion

Complications of general anesthesia are broad and potentially devastating. Description of the myriad of potential issues is beyond the scope of a single chapter. However, while the risks are real and patient concerns of these complications are valid and should be addressed, anesthesia remains one of the safest forms of medical practice. With the advancement of technology and practice management techniques, along with the introduction of safer and broader pharmacological options, the risk related to anesthesia has decreased dramatically over the last several decades. Death, stroke, MI, and other commonly feared complications are rare, and the field continues to work toward further reduction in the morbidity and mortality associated with general anesthesia. The role of anesthesia providers to adequately assess and manage patients is essential throughout the entire perioperative period. Effecting change at a systems level, and in conjunction with their surgical and ancillary counterparts, improving both long- and short-term care for surgical patients will continue to be the central tenant of anesthesiologists and anesthetic providers.

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Pain Management

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_8

8.1 Introduction

Pain control represents an important and often difficult aspect of the perioperative management of surgical patients. Postoperative pain is associated with increased morbidity, longer hospital stays, and higher costs, whereas, conversely, better pain control is associated with earlier mobilization, faster discharge, and faster patient recovery. Opioid analgesic agents are commonly used to treat perioperative pain, and while they are effective, their use is associated with many side effects, including postoperative nausea and vomiting, sedation, respiratory depression, decreased gastrointestinal motility, and other complications, all of which can ironically lead to longer hospital stays, partially or completely offseting the potential benefits of effective perioperative pain control [1–4].

For the anesthesiologist, pain control is a significant part of delivering a safe and balanced anesthetic [5]. Even under general anesthesia, the pain response can manifest as light anesthesia, resulting in labile hemodynamics, or patient movement during surgery, which can create technically difficult or even dangerous conditions for the procedure and can carry over into difficulty with postoperative pain control [6, 7].

In an effort to minimize the use of opioids for the treatment of perioperative pain, some anesthesiologists are using a multimodal approach to pain management. This can include the use of nonsteroidal anti-inflammatory drugs (NSAIDs), acetaminophen, ketamine, and anticonvulsants such as gabapentin [8]. The use of regional and neuraxial blockades has also shown to be useful in some cases, and recently, local infiltration with liposomal bupivacaine in the surgical field has become popular for some procedures as well [1, 4].

In this chapter, we will discuss the implications of perioperative pain, not only in the postoperative period but also preoperatively and intraoperatively, as well as the effects of various inhalational and intravenous anesthetics on the pain response. We will discuss the subjective attempts to evaluate pain, both qualitatively and quantitatively, and some of the difficulties associated with this. We will also discuss how the choice of pain control modality may have both short- and long-term implications for the patient in terms of length of hospital stay, recovery, and central sensitization and chronic pain development, as well as other implications of inadequate perioperative pain control.

8.2 Preoperative Pain

Many patients presenting for surgery do so because of some kind of pain experience and trust that the surgical procedure will provide some degree of pain relief and/or functional improvement. Adult patients, and even more mature pediatric patients usually understand that some pain associated with the surgery itself should be expected but also expect this to be of a relatively short duration and hopefully rather minor in its intensity. They also generally expect this surgery-related pain can be managed with medications administered during the first few days of their post-op experience, regardless of whether this is in an inpatient or outpatient setting. Surgically induced neuropathic pain (SNPP) is a significant clinical problem, with persistent pain estimated to occur in 10–50% of individuals after common operations [9].

Failure to achieve the expected pain relief may be experienced by the patient as a catastrophic surgical or perioperative event, even though in the traditional sense, this may not be considered by healthcare personnel as anything that is "catastrophic." Guidelines from the American Society of Anesthesiologists state "adverse outcomes that may result from the *undertreatment* of perioperative pain include (but are not limited to) thromboembolic and pulmonary complications, additional time spent in an intensive care unit or hospital, hospital readmission for further pain management, needless suffering, impairment of health-related quality of life, and development of chronic pain. Adverse outcomes associated with the *management* of perioperative pain include (but are not limited to) respiratory depression, brain or other neurologic injury, sedation, circulatory depression, nausea, vomiting, pruritus, urinary retention, impairment of bowel function, and sleep disruption" [10].

Pain, first of all, must be recognized as a subjective experience. Despite attempts to describe the experience of pain and to communicate to others the nature and magnitude of this experience, there exists no adequate means to communicate the entire nature of this experience to others. Also,

currently there is no objective means of assessing an individual patient's pain experience, so we are left with just asking the individual patient to communicate his or her subjective experience to us. Even then, language often fails us in pain assessment, as it is difficult to find words to adequately describe the unpleasant experience. We select words like "cutting," "burning," "stinging," "aching," etc. in an attempt to communicate the nature of the pain, without being able to truly communicate the entire experience. We also use a scale (typically linear of 1–10) to describe the intensity of the experience. These limitations interfere with our ability as "healthcare providers" to truly understand the individual patient's experience and limit our ability to provide the most effective management of this problem. It is recommended, in part due to these limitations, that anesthesiologists and other healthcare providers should use standardized, validated instruments to facilitate the regular evaluation and documentation of pain intensity, the effects of pain therapy, and side effects caused by the therapy.

There have been various scales devised, such as a linear numeric rating scale, usually graduated in 0–10, with greater magnitude of pain being communicated with higher numbers. These scales are usually used with adults and children greater than 10 years old. Unfortunately, patients with severe pain frequently will select numbers that are beyond the magnitude of numbers offered on the scale. How often have any of us working with pain patients heard one of them describe their pain as something like 16 when the scale only goes to 10?

Another system devised to communicate the magnitude of the pain experience was the Wong-Baker Faces Pain Rating Scale [11]. This was initially intended for use with children who could not understand a number system, but who could recognize a picture of a face exhibiting pain, and match the pictured expression to the sensation of pain experienced by the child. Again though, like the limitations of the numeric rating scale, this does not adequately convey the subjective experience of the pain (Fig. 8.1).

Yet another system, the McGill Pain Questionnaire (also known as the McGill Pain Index) was developed at McGill University by Melzack and Torgerson in 1971. This attempted to group words to allow individuals to give their physicians a good description of the quality and intensity of their pain experience by picking words from groups of words to establish seven words that were most descriptive of the patient's pain experience.

One of the limitations in all these pain scales is that the patient must be able to communicate effectively. The Abbey Pain Scale was developed as an instrument to assist in the assessment of pain in patients who are unable to clearly articulate their needs [12]. This assesses vocalization suggesting pain such as whimpering, groaning, or crying, facial expressions, changes in body language, and changes in behavior, physiology, and physical changes such as skin tears, contractures, etc. Although more useful for the noncommunicative patient, the problem with this system is that it relies totally on an observer's thoughts and opinions rather than obtaining direct information

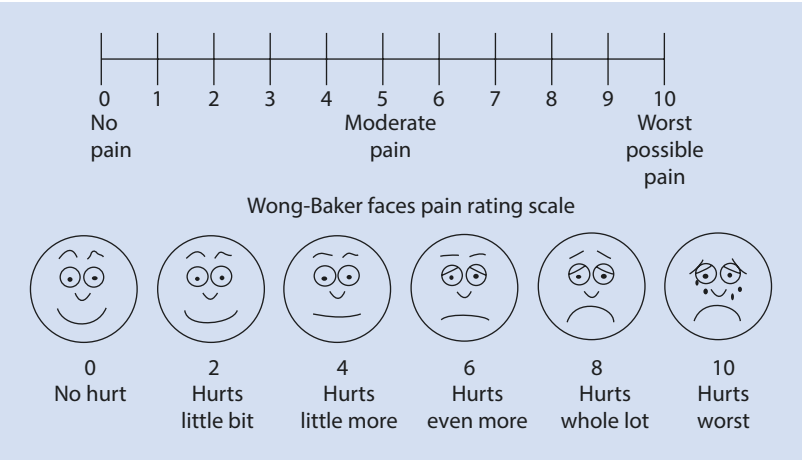

Fig. 8.1 Numeric pain rating scale

from a patient who may or may not be experiencing pain. Additionally, it does not differentiate between distress and pain, which may be totally separate concerns in these patients.

Despite the utility and specific applications of these various systems, we are still left with inadequate means of truly communicating the totality of the pain experience to others.

Often, when trying to assess pain, especially chronic pain, and its effects on an individual, we are left with trying to determine not only the subjective nature, quality, and intensity of the pain but also how it impacts the person's life. Does the pain limit activities of some kind? We may ask what the individual can no longer do because of the pain and seek some desired improvement in this activity as an indication of some degree of pain relief. In other words, we may settle for getting the patient to describe some activity this individual can now accomplish after pain therapy, that they were not able to accomplish prior to therapy, and use this surrogate as an indication of success. Pain may be of short duration, as expected with an injury, that resolves as the injury heals. But pain may also be a chronic, lasting experience of long duration, even many years, that has no obvious injury associated with it.

So, when a patient presents for a surgical procedure, or following a surgical procedure, with complaints of pain, how should we proceed? What should we tell the patient about current pain and future pain? Physical preparation for the patient primarily entails getting the patient ready for the administration of anesthesia. If a regional anesthetic is appropriate for the surgical procedure, and the patient's complaint of pain originates from the area of the body to be anesthetized via a regional block, the administration of the regional block may eliminate the pain, at least temporarily, for the duration of the surgical procedure and for some amount of time afterward. By interfering with transmission of neural impulses from a painful extremity, we may be able to provide not only analgesia and anesthesia for the surgical procedure, but may also reduce or eliminate pain originating from that area as well. In other words, one significant advantage of regional anesthesia over general anesthesia is that the analgesia provided by the regional anesthesia may provide a sensory loss that exceeds the duration of the surgical procedure itself.

It has long been recognized that inhalational anesthesia does not provide analgesia, even though a state of general anesthesia and unconsciousness can be produced by these agents. "Indirect evidence suggests that inhaled anesthetics have limited analgesic properties at anesthetizing concentrations. At 0.2 MAC, enflurane, halothane, and sevoflurane do not influence pain perception in healthy volunteers."[13] "Nitrous Oxide does raise the pain threshold, at least in experimental animals, and it is assumed to do the same in humans. In rats, an antianalgesic effect is produced by 0.1 MAC isoflurane or nitrous oxide." [14] When considering non-opioid analgesics such as diclofenac, acetyl salicylic acid, dipyrone, acetaminophen, and the COX-2 inhibitors, it has also been recognized that there is limited evidence to suggest the combined use of two non-opioid analgesics provides any additive analgesic effect [15]. If a prolonged sensory loss at a painful area is desired following the surgical procedure, use of a regional anesthetic which covers the area of the body where the surgical procedure is to be performed may provide an additional benefit that is beyond the intended primary benefit of the anesthesia, by at least temporarily relieving the perception of pain originating from that area.

Extremes of age may also influence the risks and perioperative complications of anesthesia. The emotional component of pain is particularly strong in infants and children. Absence of parents, security objects, and familiar surroundings may cause as much suffering as the surgical incision. Children's fear of injections makes intramuscular or other invasive routes of drug delivery aversive. Even the valuable technique of topical analgesia before injections may not lessen this fear. Likewise, elderly patients exhibit changes in distribution and metabolism of analgesic drugs and local anesthetics. This makes it more likely that they may experience symptoms consistent with drug "overdose" or excessive somnolence when a drug is administered in what would otherwise be a "normal" dose [10].

In patients undergoing total hip arthroplasty or total knee arthroplasty, well-performed regional anesthetic blocks, with a long duration of action, resulted in patients being able to demonstrate greater joint range of motion, and their postoperative hospital length of stay was shorter. But at the same time, care must be exercised when administering these or other "nerve blocks." Often, the regional anesthetic agent of choice is bupivacaine, since it provides a more long-lasting regional anesthetic effect than most other regional anesthetic agents. During the injection,

care must be taken to assure this medication *is not injected intravascularly*, since if injected there, it can also provide a long-lasting blockade of the heart's conduction system, frequently leading to cardiovascular collapse that is resistant to resuscitation measures. It has been discovered that a bolus of 1.5 mg/kg (lean body mass) of a 20% lipid emulsion (Intralipid), administered over 1 min via IV as soon as possible after recognizing that an intravascular injection of a local anesthetic has occurred, reduces many of the symptoms from the unintended intravascular injection. This should be followed by a continuous infusion of 0.25 ml/kg/min, with an increase to 0.5 ml/kg/min if the blood pressure remains low. This infusion should be continued for at least 10 min after obtaining circulatory stability. Additionally, the initial bolus can be repeated once or twice for persistent cardiovascular collapse [16].

However, even properly administered "nerve blocks" may have side effects that may be considered "complications" of the procedure. It is well recognized that epidural morphine, while improving pain relief, also results in a higher frequency of pruritus and urinary retention when compared with intramuscular or intravenous injection [9]. Additionally, the motor weakness that accompanies "nerve blocks" often becomes an adverse effect. This problem is most notable when motor weakness of the lower extremities interferes with a patient's ability to ambulate soon after a surgical procedure, since lack of ambulation is associated with a greater likelihood of development of deep vein thrombosis, which in turn can lead to pulmonary embolism.

In patients with burns or other injuries, there is frequently a strong component of apprehension in addition to the pain. Drugs such as morphine, meperidine, fentanyl, and most other opioids are effective drugs to relieve both the pain and the associated fear and anxiety. But the dose of morphine, meperidine, fentanyl, or other opioids should be carefully titrated, and the patient should be continually monitored since some extent of respiratory and cardiovascular depression accompanies the administration of this class of medications. The careful administration of small repeated amounts via intravenous injection, along with continuing monitoring of the patient, accomplishes the desired pain relief while reducing the potentially catastrophic risks of respiratory and cardiovascular depression. The unrecognized respiratory depression that accompanies opioid administration is a much greater threat to the life and continued well-being of the patient than the pain itself. Although the opioid drugs help reduce pain and provide a generally reduced feeling of psychological distress in an injured patient, it is generally felt that the best psychological preparation is the presence of another caring human, preferably with the necessary training and skills to manage medical problems, that the patient can trust.

8.3 Getting Informed Consent

For the injured patient, obtaining informed consent may present some challenges. A fundamental concept of the legal basis of obtaining informed consent is that the patient has the capacity to grant or withhold consent. A competent patient has virtually an absolute right to consent to, or to refuse, any proposed procedure or treatment. When treating minor children or adults who have been legally judged to be incompetent, a physician must obtain consent from the parent of the minor or the incompetent person's legal guardian. The injured patient may or may not remain competent to provide this informed consent. In an emergency situation, defined as any problem posing imminent danger to life or limb in an apparently incompetent person (e.g., an unconscious person, a patient with delirium tremens, or senile patients with gangrenous limbs who do not have a guardian), informed consent is assumed to have been granted.

In anesthesia practice, it has been well recognized traditionally that administration of anesthesia poses some risks. There are particular areas that present significant risks, such as the use of invasive monitoring, the decision to initiate a transfusion, and risks relating to the use of specific anesthetic agents or techniques. Many of these may differ from patient to patient, from operation to operation, and surgeon to surgeon. Although many would assume that a surgeon's consent for surgery would imply a consent for administration of anesthesia to accomplish the surgical procedure, current legal thought demonstrates that a separate consent for administration of anesthesia should be obtained. While attempting to disclose all possible complications related to anesthesia administration is probably not possible, in purely elective cases, a very complete

disclosure of risks related to administration of anesthesia should be made.

One set of risks that should be disclosed in each case of general anesthesia relates to potential complications due to the necessary instrumentation around the mouth. As an example, patients who have one or more porcelain crowns on incisor teeth should be cautioned about the potential for damage to these crowns or to the underlying tooth from instrumentation required for the intubation process. The planned use of invasive monitoring also presents special problems with obtaining informed consent. Significant risks exist with placement of arterial lines, central venous catheters, and pulmonary artery (Swan-Ganz) catheters. Multiple reports of complications with each of these devices can be found in a literature search, even though most of the time, when used skillfully by well-trained professionals, there are no complications. Discussion of risks with placement of any of these devices should be considered very important, especially in the elective case, but a truly emergent case may not provide the opportunity for this preoperative discussion.

However, the recommendation to discuss risks related to anesthesia, and the recommendation to obtain an informed consent, does not include a discussion of risks that would be expected to occur in only due to negligence. There is no need to discuss risks that would occur only if the anesthesiologist or nurse anesthetist was negligent, since courts have long held that a healthcare provider cannot employ a consent form to insulate oneself from liability due to negligence.

As suggested already, elderly patients may present special problems in trying to properly assess and treat pain. While some elderly patients remain totally lucid, others may have compromised mental capabilities which interfere with their ability to communicate pain issues effectively. Disease processes that cause hearing difficulties or mental decline in the elderly may further exacerbate this problem. Also, due to a decline in mental processing capabilities in some elderly patients, unique difficulties in trying to obtain a proper informed consent for any medical therapy may be present. In this situation, it is important to have a properly designated surrogate, preferably a close family member or legal guardian, who can understand the discussion of risks and can make informed consent decisions for the elderly patient [17].

8.4 Intraoperative Pain

Adequate pain control in an anesthetized patient undergoing surgical procedures is an essential aspect of anesthetic care as it helps to avoid intraoperative stress, hemodynamic disturbances, perturbations with tissue oxygenation, and to decrease the risk of intraoperative awareness. It allows for comfortable environment for the patient and surgeon, faster return of function, and prevention and early resolution of ileus, helps to reduce significant discomfort, and decreases opioid requirements postoperatively. Poor pain control during surgery may lead to lingering and difficult to control pain in the postoperative period. Awareness under general anesthesia which results from inadequate depth of anesthesia is a rare but frightful intraoperative complication that is frequently accompanied by moderate to severe pain sensation that patients describe afterward. Altogether these factors may precipitate physiologic and emotional distress and result in development of post-traumatic stress disorder [18]. Tissue injury causes acute inflammation and release of pro-inflammatory mediators and neurotransmitters that activate nociceptive signaling. If left untreated, additional input from dorsal horns ensues, leading to amplified nociceptive response, central sensitization, and development of hyperalgesia or chronic pain in the long-term perspective.

Unfortunately, there is no direct way to recognize pain evoked reactions in anesthetized patient, which poses unique challenges to the clinicians and makes them rely solely on indirect signs. Hemodynamic changes have been traditionally thought to be associated with intraoperative stress; however this may not be a consistent trend in certain groups of patients. Hypovolemia, preoperative beta-blocker therapy, and heart dysrhythmias may all distort hemodynamics, making these variations inaccurate predictors of insufficient pain control. Along similar lines, anesthetic drugs themselves, especially in high doses, alter vascular and cardiac responses. Several studies evaluated various subjective indicators of poor pain control. Skin- and eye-associated manifestations of pain including moisture, stickiness, changes in skin temperature, pupil reaction, and lacrimation are all considered proper but inexact indicators of stress [19]. Several standardized scales were created to help with provision of effective pain control in the anesthetized patients.

A specifically designed Anesthetized Patient Pain Scale (APPS) was validated by multiple authors and was demonstrated to correlate well with decreased postoperative pain levels [20, 21]. This scale determines hemodynamic, physiologic, and behavioral responses (blood pressure, heart rate, respiratory rate, facial expression, muscle tension, body movement) then after the appropriate number of points (1–3) is assigned for each parameter, the resultant score is then calculated. Score of >15 correlates with poor pain control.

Use of muscle relaxants and high doses of volatile anesthetics limit monitoring options as muscle contractions and movement are abolished and autonomic responses are inhibited making the visual assessment impractical. Several attempts have been made to create an automated apparatus that could predict pain level in a more objective fashion. The latest study compared the validity of several newly developed devices which generate scales identified as "Analgesia Nociception Index" and "Surgical Pleth Index". The Analgesia Nociception Index issues a numerical index from 0 to 100 resulting from the patient's heart-rate variability which is captured and processed by a special device. The Surgical Pleth Index is calculated based on waveform finger plethysmography data which is then processed by proprietary algorithm. Results were compared to routine physiologic changes (pupillary dilation, hemodynamic alterations) and also information obtained from bispectral index analysis [22]. Both indices and pupillary dilation monitoring appeared to accurately predict changes in pain levels after tetanic stimulation in a well-correlated manner, and demonstrated superior results to hemodynamic changes alone. The study also postulated that bispectral index did not show it was either sensitive to nociceptive stimuli, nor to analgesic administration, and thus should not be considered as a reliable indicator of intraoperative pain control. These techniques are less accurate in the setting of complex combination of baseline analgesic use and preexisting comorbidities, altering pain perception.

The concept of preemptive analgesia was introduced in attempt to avoid formation of central sensitization and pain amplification [23] (Fig. 8.2). It warrants administration of antinociceptive medications prior to surgical stimulation. While there is a body of basic science

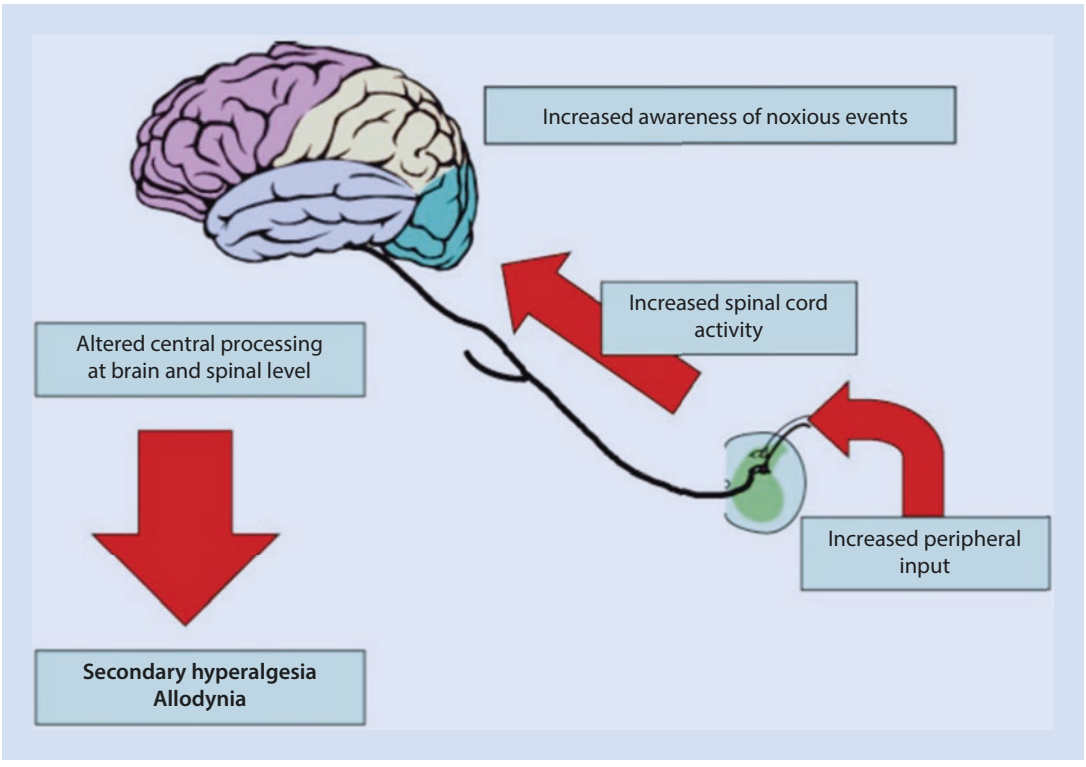

Fig. 8.2 Central sensitization pathway. (Adapted from ▶ wiley-vch.e-bookshelf.de)

research supporting this phenomenon, there is no direct clinical evidence that pre-incisional analgesia adds significant benefit in terms of less chronic pain development. Thus, a broader and more appropriate concept for avoiding pain centralization known as preventive anesthesia has emerged. It is not time constrained and encompasses a multitude of efforts to reduce postoperative pain and opioid consumption by administering treatment throughout the perioperative period.

Intraoperatively, administration of opioid medications remains the cornerstone of pain control in the anesthesiologist's armamentarium. They are known to be exceedingly effective in attenuating hemodynamic marks of stress while remaining virtually devoid of cardiac depression properties. Short-acting synthetic opioids including fentanyl, sufentanil, and fentanyl are given in bolus doses or infused for immediate analgesia in the operating room. When general anesthesia is employed and transient hemodynamic instability is not acceptable, the typical regimen involves a large opioid induction dose to facilitate endotracheal intubation; often, further boluses throughout the case are administered as needed. Continuous IV infusions may be utilized for procedures associated with high level of surgical stress and severe pain (spine fusion). Fentanyl or sufentanil provides excellent level of analgesia. Remifentanil is an ultrashort-acting agent that is known for its fixed, brief, context-sensitive half-life regardless of the duration of the infusion, and is an excellent choice for surgical opioid infusions. Long-acting opioids such as morphine, hydromorphone, or meperidine can also be used intraoperatively. However, these commonly used compounds are less popular in the intraoperative setting due to slow onset, increased postoperative nausea and vomiting, and concern for prolonged emergence, especially when given during relatively short procedures. Nonetheless, postoperative pain scores were reported higher in patients who received only fentanyl in the study that compared intraoperative pain control with morphine to fentanyl. Also the fentanyl group showed longer opioid requirement period in the post discharge stage [24]. Agonist-antagonist opioid compounds may be advantageous due to limited effect on respiratory depression, which is particularly valued when spontaneous ventilation must be preserved, though a ceiling effect limits their analgesic potential. Despite apparent advantages opioids are notorious for causing a range of adverse effects including respiratory depression, delayed emergence, prolonged sedation and recovery from anesthesia, and an increased risk of postoperative nausea and vomiting. Immediate negative postoperative effects include development of opioid-induced hyperalgesia (OIH) and acute tolerance which contributes to morbidity, patient dissatisfaction, and increased hospital costs. There is empirical evidence that even transitory exposure to opioids may increase the risk of opioid-induced hypotension (OIH) [25]. Furthermore, potent- and short-acting opioids (remifentanil) were demonstrated to have a propensity to cause rapid OIH even after brief infusion [26]. One of the suggested mechanisms for this phenomenon is activation of NMDA receptors, as a result of alternative nociceptive signal propagation [27]. Chronic pain patients receiving preoperative opioids usually present additional challenges to the anesthesiologist, as opioid requirements intraoperatively are a lot higher and unpredictable. In a recent retrospective study, it was shown that patients on chronic methadone therapy who underwent liver transplantation required significantly higher doses of fentanyl compared to opioid naïve group (3175 μg vs 1324 μg). In a nutshell, a patient's baseline opioid regimen should be maintained perioperatively including any transdermal patches. While one may anticipate increased opioid requirements (50–300%), patients should be judiciously monitored for signs of overmedications, and spontaneous ventilation should be achieved early (as allowed by the nature of the procedure). Adjunctive medications including NMDA inhibitors may be extremely beneficial under these circumstances.

There are several analgesic adjuncts that can be administered in addition to opioids and help achieve stable surgical course, smooth emergence, and decreased postoperative pain and opioid requirements. Multimodal anesthesia involves use of two or more medications with distinctive mechanisms of action and designed to maximize efficacy of multiple drugs while abolishing potential opioid-associated side effects.

Ketamine is an N-methyl-D-aspartate (NMDA) receptor antagonist, potent analgesic known to be particularly effective in treatment of neuropathic pain. Low-dose ketamine infusion has been successfully employed by clinicians for the long period to enhance opioid-based analgesia

and helps to decrease the frequency of OIH and reduce postoperative opioid requirement. It is hypothesized to counteract central sensitization effect and so-called windup phenomena, which is experienced after repetitive nociceptive stimuli. Effectiveness of this combination was revealed by multiple studies. For instance, it was reported that addition of subanesthetic doses of ketamine infusion to sevoflurane-remifentanil maintenance anesthesia resulted in decreased postoperative pain levels and opioid requirements after laparoscopic gynecologic procedures [28]. Nefopam is a relatively novel centrally acting, non-opioid analgesic with potential for opioid reduction effect. The mechanism of action is not yet well understood; however, it was suggested that inhibition of serotonin, dopamine, and norepinephrine reuptake may play a role along with NMDA antagonism. The drug acts at spinal and supraspinal sites. A placebo-controlled prospective study that compared effectiveness of low-dose intraoperative ketamine infusion to nefopam coadministration to standard remifentanil-based anesthetic regimen revealed a more profound morphine-sparing effect of the latter in the immediate postoperative period [29]. Both drugs demonstrated significantly reduced pain scores and opioid requirements compared to placebo. The drug is not currently approved for use in the USA.

Local and regional anesthesia are known to dramatically improve intraoperative and postoperative pain control. Central neuraxial approaches are excellent techniques administered as primary anesthetic mode or as adjuncts to general anesthesia. A review of epidural anesthesia in surgical practice concluded that this modality is associated with a significant decrease in incidence and degree of intraoperative physiologic perturbations, and facilitating hemodynamic stability [30]. Single-shot spinal, continuous epidural/spinal, or a combination of these techniques are all possible treatments, and preference should be made based on the specific patient's procedural characteristics. Contraindications and potential side effects should also be weighed against the benefits and decision made on an individual basis. Utilizations of a variety of peripheral nerve blocks for upper and lower limb surgery provide a handful of positive intraoperative and postoperative effects including less opioid consumption and better hemodynamic profile. Moreover, a recent study that use of peripheral nerve block results in reduction of incidence of postoperative delirium, likely secondary to decreased pain and reduction of potent parenteral anesthetic use [31]. This fact is especially advantageous in elderly patients, even when general anesthesia is employed as primary mode. Local anesthetic may be injected directly near the surgical site. It may help to reduce the somatic component of the pain; however the visceral element is left unaffected; thus it only should serve as an adjunct to multimodal analgesia regimen.

Intravenous (IV) acetaminophen is a unique part of multimodal anesthesia, as it is the only available non-opioid IV analgesic that has no boxed warning on the label and can be safely indicated for pediatric patients. There is ample evidence suggesting that direct antinociceptive effect of the IV formulation is not superior to oral form; however there are few differences in the overall clinical effect [32]. While there is an ongoing debate if IV acetaminophen has a role treating postoperative pain in patients who can tolerate oral intake, it was postulated that when administered parenterally, it may reach higher concentration in the cerebrospinal fluid [33]. IV route of administration offers possible benefit in terms of preventive effect as while given intraoperative prior or immediately after incision. One study demonstrated decrease in "rescue" opioid requirements, increased time to first requested analgesic, and lower incidence of postoperative nausea and vomiting (PONV) following cholecystectomy after preemptive administration of 1 g of IV acetaminophen [34]. More research is needed to provide further recommendation.

Ketorolac is one of the few available IV nonsteroidal anti-inflammatory drugs (NSAIDs) that has a role in the intraoperative pain management. Administration of the drug prior to emergence from general anesthesia results in synergistic antinociceptive effects in conjunction with opioid and other non-opioid medications. One study which looked at patients undergoing gynecologic laparoscopic procedures concluded that ketorolac given at the end of the surgery lead to reduced incidence of pain on awaking and need for rescue opioid use. Furthermore, it was associated with less severe pain and vomiting and faster discharge from PACU. Historically, there has been concern for the drug to increase hemorrhage risk, impede bone healing, and increase incidence in acute kidney injury especially in patients with decreased kidney function or dehydration. While there is a

clear theoretical risk of the abovementioned complications, several studies failed to confirm these statements [35–37]. It is prudent though to discuss the possible use of the drug with the surgical team and ensure patient is well hydrated prior to administration.

Anticonvulsants, including gabapentin and pregabalin, are often added to the multimodal analgesia. Gabapentin is known to be effective in treating neuropathic pain. Although it is an analog of gamma-aminobutyric acid (GABA), it is not active at $GABA_A$ or $GABA_B$ receptors, so the precise mechanism of action remains unknown. There is a theory that gabapentin acts on voltage-gated calcium channels in the spinal cord inhibiting release of neuromediators. These drugs are thought to interfere with the hyperexcitability of spinal cord dorsal horns, thus preventing central sensitization. Gabapentin is typically administered preemptively and prior to induction of anesthesia. Pregabalin has a more favorable pharmacokinetics and improved bioavailability compared to gabapentin. A study evaluating effectiveness of gabapentin for lumbar laminectomy given pre- or postoperatively demonstrated decrease in morphine requirements, vasodilator-stimulated phosphoprotein scores, and opioid-associated side effects [38]. Of note, authors stated that patients who received pregabalin reached discharge criteria 14 h earlier than their counterparts. Moreover, as single dose was compared to multiple dosing regimen throughout the perioperative period, there was no clinically significant benefit with repeated dosing. Among possible side effects, sedation, dizziness, and visual disturbances were the most common and occurred within the first 24 h. Further studies are needed to verify the target patient population and surgical procedures that would benefit the most from addition of pregabalin to multimodal anesthesia regimen.

Steroids are known for their multitude of effects with anti-inflammatory action being most clinically valued. In the scope of anesthesiologist practice, dexamethasone has been routinely used for postoperative nausea and vomiting prevention. Its potential antinociceptive effects were less researched until lately. Recent meta-analysis presented substantial data on the effect of intraoperative dexamethasone administration in the context of its possible antinociceptive properties. It was revealed that dexamethasone administered intraoperatively exerts opioid sparing [39, 40]. No major side effects were reported including wound infection or healing impairment. However, this fact needs further evaluation as not enough data was generated during open surgical procedures to make that statement universal. While preoperative administration of the drug provides even more marked pain relief, it is somewhat limited due to the well-known side effect of extreme perineal pain (50–70%), when drug is given fast in low volumes. While the precise pain-relieving mechanism of dexamethasone is yet unclear, it appears that it has to do with inhibition of peripheral phospholipase pathway which results in reduction of cyclooxygenase and lipoxygenase production [41].

The addition of Beta-blockers to opioids, has recently been investigated in the light of synergistic analgesic effect. Multiple studies showed that an intraoperative esmolol infusion provides better hemodynamic stability, lowers stress, reduces the risk of adverse cardiac events, and also significantly reduces postoperative pain and narcotic intake [42]. There are multiple theories as to how esmolol exerts its analgesic effect. Peripheral anti-inflammatory action along with intrinsic potential to abide noxious stimuli and decrease in catecholamine surge are to name a few. It has also been proposed that it is β-blockade-associated reduction in cardiac output and hepatic blood flow that slows metabolism of opioids [43]. Furthermore, it was proposed that intraoperative administration of esmolol may alter the permeability of fentanyl to blood-brain barrier and thus decreases fentanyl requirement [44].

A recent meta-analysis suggested that there is positive effect in reduction of postoperative pain with intraoperative systemic magnesium administration [45]. Opioid consumption was shown to be markedly decreased as well, and no complications associated with magnesium infusion were reported. Proposed mechanism derived from animal studies includes antagonism of NMDA receptors which alters duration and perception of pain [46].

Intraoperative pain management is a part of continuous process, and thus all phases of perioperative pain management should be consecutive and coordinated. Preventive and multimodal concepts are effective tools to provide comfortable intraoperative care and smooth transition to postoperative stage. Multiple protocols have been suggested for use by many high-tier academic

institutions tailored to specific surgical procedures. However, there is no one-fits-all model, and intraoperative pain management should be based on individual patient's characteristics. Central sensitization is the principal cause of uncontrolled postoperative pain and can result in significant distress and morbidity; hence efforts should be made to reduce its occurrence.

8.5 Postoperative Pain

Care of patients during the immediate postoperative period is one of the many responsibilities of the anesthesia provider. During this period, patients may present with a variety of complaints. One of the most common complaints is acute, postoperative pain. Over 80% of individuals that undergo a surgical procedure experience postoperative pain [47]. Inadequately controlled pain may lead to decreased quality of life, prolonged recovery times, and increased incidence of postsurgical complications [9].

Postoperative pain management begins before the operation. During the preoperative period, a thorough history and physical should be performed to properly assess the patient and plan for the management of postsurgical pain. It is important to address medical or drug history that may cause a deviation from a standard plan of care. Extensive recreational or analgesic drug usage can have a significant impact on the plan for pain management after surgery. For example, in a patient with history of opioid addiction currently in remission, the use of opioids in the treatment of postsurgical pain may trigger a relapse. If possible, the anesthesia provider should try to avoid opioids in this patient population.

The management of a patient's postoperative pain does not have to begin after the procedure. In reality, it is becoming increasingly common for pain management to begin even before the surgery is started. Management can be started utilizing a variety of medications and methods such as NSAIDs, peripheral nerve blocks, and epidurals. When analgesics are used prior to surgery, the goal is to block pain receptor activation or hinder the production and/or activation of pain neurotransmitters. In a meta-analysis of acute postoperative pain management, it was shown that people receiving local anesthetics and NSAIDs prior to surgery had less usage of pain medications postoperatively, even though pain scores were not decreased. Preoperative epidurals showed a decrease in both the use of analgesics and pain scores postoperatively [48].

8.6 Opioids

Although many methods of pain management exist, opioids remain the most used analgesics in the postoperative period. Opioids bind to receptors in the central nervous system and peripheral tissues to block the transmission of pain signals. They produce analgesia via mu (μ) opioid receptor agonist activity in the brain.

Opioids can be administered in a variety of ways including orally, transdermally, parenterally, neuraxially, and rectally. The most commonly used intravenous opioids are morphine, hydromorphone, and fentanyl (Table 8.1). Although opioids are the most commonly used analgesics postoperatively, they are not without side effects, the most significant of which is respiratory depression. Other common side effects include nausea, vomiting, and reduced bowel motility. Patients receiving chronic opioid therapy tend to become tolerant to many of the side effects over time. However, constipation and postoperative ileus caused by the decrease in bowel motility are complications that are still consistently seen in patients with a predominately opioid pain control regimen following surgery [49]. This has resulted in the development of peripheral opioid antagonists such as methylnaltrexone and alvimopan. These drugs selectively antagonize the peripheral opioid receptors, promoting a return of bowel function, while ignoring the central opioid receptors that are being acted upon for pain relief.

Opioids may be administered using a standard dosage every set number of hours or using a PCA (patient-controlled analgesic) pump. PCA pumps work by allowing the patient to self-administer a set dose of analgesic. The provider sets a maximum amount of analgesic that can be administered over a period of time. The pump can then be monitored and modified based upon how often the patient is self-administering medication. Studies show that PCA (patient-controlled analgesia) is valid as an alternative to conventional opioid administration in the postoperative period. Certain patient populations

Table 8.1 Graph showing common opioids used postsurgically, dosages, and facts

Opioid	Route	Dose	Miscellaneous
Morphine	IM	0.05–0.2 mg/kg	Excreted through the kidneys. May cause histamine release
	IV	0.03–0.15 mg/kg	
Hydromorphone (Dilaudid)	IM	0.02/0.04 mg/kg	No active metabolites. No histamine release
	IV	0.01–0.02 mg/kg	
Fentanyl	IV (Intraoperatively)	2–50 mcg/kg	100 times more potent than morphine
	IV (Postoperatively)	0.5–1.5 mcg/kg	
Sufentanil	IV (Intraoperatively)	0.25–20 mcg/kg	10 times more potent than fentanyl
Alfentanil	Intraoperatively:		Fastest onset of all opioids
	Loading	8–100 mcg/kg	
	Maintenance	0.5–3 mcg/kg/min	
Remifentanil	Intraoperatively:		Unique among the opioids in that it is metabolized by plasma esterases. Commonly used in patients with hepatic or kidney failure
	Loading	1.0 mcg/kg	
	Maintenance	0.5–20 mcg/kg/min	
	Postoperatively	0.05–0.3 mcg/kg/min	

need to be treated carefully when administering opioids, particularly obese and chronic pain patients. Because of their susceptibility to obstructive sleep apnea and possibility for an exacerbation of respiratory depression, providers are encouraged to limit the usage of opioids in obese patients. For these patients, a multimodal approach to analgesia starting before the surgical procedure is optimal. Placing an epidural prior to or soon after the surgery leads to a decrease in the need for opioids and thus gives the patient less of a chance of having complication that may be caused by some of the negative side effects of opioids, such as postoperative ileus [49].

8.7 Non-opioid Analgesia

Although opioids are the most commonly used drugs postoperatively, a variety of other drugs exist to treat postoperative pain. Drugs such as paracetamol, nonsteroidal anti-inflammatory drugs (NSAIDs), and local anesthetics work through different mechanisms and have different side effect profiles from opioids. This gives the provider the ability to adapt to specific situations and ultimately provide the patient with satisfactory pain control. Studies show that these drugs used with PCA morphine lead to a decrease in morphine usage and less chance of the deleterious effects of morphine usage in colorectal and obstetric operations [50, 51]. Ketorolac, an NSAID, has been shown by meta-analysis to decrease early pain at rest and overall opioid consumption when used as a single, 60 mg intramuscular dose during the perioperative period. Also, in a double-blinded, randomized trial of ketorolac vs placebo, it was shown that ketorolac is beneficial in reducing postoperative pain and narcotic usage after cesarean section.

Many nonsteroidal anti-inflammatory medications are cyclooxygenase (COX) inhibitors. Inhibition of COX hinders the key step in prostaglandin synthesis. Prostaglandins play a key role in the inflammatory process of the body. COX-1 receptors are widely distributed throughout the body (most importantly in the stomach and on platelets). COX-2 receptors are primarily produced in response to inflammation. Aspirin is an NSAID that irreversibly inhibits COX-1 through acetylation. Acetaminophen is an NSAID that is relatively selective for COX-2. There is a

significant risk of bleeding when giving patients increased doses of nonselective COX inhibitors due to inhibitory effects on prostaglandins that protect the stomach and promote blood clotting. These drugs should be avoided in patients with a history of stomach ulcers. Highly selective COX-2 inhibitors such as celecoxib have been developed to curtail these side effects. However, the general consensus is that COX-1 inhibitors are still preferred given the cardiovascular toxicity of the selective COX-2 inhibitors [52].

Other modalities exist as well for the treatment of postoperative pain such as epidural anesthesia, spinal anesthesia, peripheral nerve blocks, and local infiltration. Epidural and spinal anesthesia are frequently used in thoracic, abdominal, and pelvic surgery. During an epidural, a catheter is inserted into the epidural space, through which local anesthetics and/or opioids are administered. Epidural anesthesia may be performed in the cervical, lumbar, or sacral region and can range from a single-shot technique to the insertion of a catheter in which intermittent boluses or continuous infusions are administered. Spinal (intrathecal) administration of local anesthetic results in good postoperative analgesia for up to 24 h. Epidural and spinal anesthesia involve the same time commitment, but with spinal anesthesia skilled postoperative care is not required for maintenance of the catheter.

A transversus abdominis plane (TAP) block is a peripheral nerve block that can be used as an alternative to an epidural in patients that are having operation on the abdominal wall. A single shot of local anesthetic is administered into the plane between the internal oblique and transabdominal muscles. This plane encompasses an anatomical space that includes nerves that innervate the abdominal muscles and skin. The most common dosage is 20 mL of ropivacaine at 0.25%.

The injection of large amounts of local anesthetic (local infiltration) into the surgical field is also a technique used in a variety of procedures, mostly by colon and rectal surgeons. Limitations in the past to this analgesic approach were the short durations of action of the local anesthetics available. However, with formulations such as liposomal bupivacaine, providers are now able to provide postsurgical analgesia for up to 72 h using this technique. All of these methods work well as part of a multimodal approach to the management of postoperative pain.

8.8 Conclusion

Delivery of a surgical anesthetic can be performed in a variety of ways, including general anesthesia, regional anesthesia, neuraxial anesthesia, local anesthesia, or a combination of these techniques, depending on the suitability of the patient and the nature of the procedure [8]. As no single drug can be used as a "complete anesthetic," a balanced anesthetic technique, involving a variety of different techniques, is favored for these procedures [53]. As part of these balanced anesthetic techniques, one or more agents with analgesic properties will typically be utilized.

In this chapter, we have discussed the evaluation and treatment of pain in the preoperative, intraoperative, and postoperative period. We discussed the use of a variety of different agents that have been used for pain control, or as part of a multimodal pain control regimen. Regional and neuraxial techniques, local infiltration, opioids, acetaminophen, NSAIDs, ketamine, gabapentin, and other common anesthetic medications are often used effectively for pain control, either by themselves for pain control or as part of a balanced anesthetic. We also discussed the effect that adequate pain control can result in decreased use of hospital resources, faster recovery, and in some cases, decreased development of chronic pain.

Overall, analgesia is a cornerstone of an effective anesthetic, and the choice of analgesic agents can have both short- and long-term implications for the patient [1, 2, 6, 53].

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Regional Anesthesia/MAC

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_9

9.1 Introduction

As regional anesthesia, noninvasive surgeries, and short procedures with quick turnovers and faster recoveries become more popular, the use of monitored anesthesia care (MAC) increases. MAC generally provides increased patient satisfaction due to fewer adverse side effects than general anesthesia, and a pain-free, rapid surgical recovery when regional anesthesia is utilized along with it. These attributes make it perfect for ambulatory surgery centers, as patients are discharged home the same day. Ideally, MAC safely provides amnesia and analgesia while allowing the patient to spontaneously breathe and protect his airway during short simple procedures or longer cases done under regional anesthesia. Although amnesia and analgesia are achieved in most instances, there are instances where it is not due to complications associated with MAC anesthesia. Because the technique does not provide a specific level of sedation and can range from minimal sedation to deep sedation depending on what agents are used, oversedation can happen, which can lead to many adverse complications. These complications include but are not limited to hypotension, tachycardia, airway obstruction, and cardiorespiratory depression and/or failure. There are also secondary complications that are not necessarily due to the MAC anesthetic but are from the type and length of the procedure being done. Examples of these include local anesthetic systemic toxicity (LAST) due to a large amount of local anesthetic absorbed or injected into a blood vessel while it is being used to obtain regional anesthesia and an airway fire that may happen when electrocautery is used in the face while a patient is receiving supplemental oxygen.

Due to the delicate nature of MAC, it should only be utilized by experienced anesthesia providers who are trained in airway management. The provider needs to be aware of what types of patients will do well with MAC and what types will be more likely to have adverse complications. Choosing the correct patients for the technique is critical; therefore, a detailed history and physical exam for every patient is necessary. In general, ASA I and II patients with good airways are ideal candidates for MAC anesthesia. Extra consideration should be given to patients in the pediatric, geriatric, and morbidly obese populations as these patients are more likely to become oversedated from standard doses of medications. Patients with certain comorbidities such as pulmonary disease or obstructive sleep apnea also require special consideration as development of respiratory depression in this patient population can be detrimental. The airway exam is also very important as gauging the ease at which the airway can be obtained may help to determine whether a provider will choose to perform a case under MAC. Once a MAC technique is chosen, all standard ASA monitoring must be used, and the provider must be able to convert to general anesthesia immediately and secure the patient's airway. The provider also needs to be aware of the type of procedure being performed and what complications can arise when doing that procedure in conjunction with a MAC technique. This chapter will serve as a guide to anesthesia providers by defining MAC more broadly, discussing the agents most commonly used and their side effects, and discussing the most common procedures and complications to be aware of when using MAC.

9.2 Monitored Anesthesia Care

MAC is a type of anesthesia that consists of many of the same components as general anesthesia including amnesia, analgesia, sedation, and anxiolysis. MAC is administered by a qualified anesthesia provider and consists of pre-procedure, intraprocedure, and post-procedure anesthesia care. MAC is not a specific level of sedation but allows the anesthesiologist to change the level of sedation based on the patient's clinical and physiologic changes that occur during surgery. Sedation levels can vary from minimal, moderate, and deep sedation with deep sedation being the most common level during MAC. The provider must be able to convert to general anesthesia at any point during the surgical procedure if medically indicated. Analgesia is usually provided with local anesthetic. According to the ASA during monitored anesthesia care, the anesthesiologist provides:

» 1. Diagnosis and treatment of clinical problems that occur during the procedure
2. Support of vital functions
3. Administration of sedatives, analgesics, hypnotics, anesthetic agents or other medications necessary for patient safety

4. Psychological support and physical comfort and provision of other medical services as needed to complete the procedure safely [1]

MAC is often used interchangeably with conscious sedation, but the two are distinct. According to the American Society of Anesthesiologists (ASA), conscious sedation involves a physician supervising a medical provider or personally administering sedatives and analgesics to induce moderate sedation. The physician in this case must only possess the skills necessary to detect when moderate sedation converts to deep sedation and be able to reverse the deep sedation. The provider does not need to be trained in airway management. MAC on the other hand requires the provider to not only be trained in airway management but to also be able to utilize general anesthesia if need be. As a result, the anesthesia provider may use deeper sedation when required.

Monitored anesthesia care is becoming increasingly popular as it allows a quicker recovery from anesthesia compared with general anesthesia and is associated with decreased incidence of postoperative nausea and vomiting. MAC also causes less physiologic disturbances compared with general anesthesia and recent studies have shown increased patient satisfaction with MAC versus general anesthesia. With increasing concerns for OR efficiency and decreased hospitalization stays the quick recovery from anesthesia that is associated with MAC provides a safe and efficient alternative to general anesthesia. According to recent data MAC is the first choice in "10–30% of all surgical procedures" [2].

While monitored anesthesia care provides a quicker recovery from anesthesia, decreased postoperative nausea and vomiting, and less physiologic changes than seen with general anesthesia, MAC still has serious complications. A closed claims analysis was performed in 2006 and examined the ASA closed claims database to compare closed malpractice claims associated with general anesthesia with claims associated with monitored anesthesia care and regional anesthesia. The amount of monitored anesthesia claims was significantly less than general and even regional anesthesia, but the complications were similar.

Analysis [3]. The most common mechanism of injury in both MAC and general anesthesia was due to a respiratory event. Under monitored anesthesia care, these respiratory events were most likely due to inadequate oxygenation or ventilation. Cardiovascular events were also a significant portion of complications under MAC accounting for 14% of the injuries. These closed claims analysis concluded that "oversedation leading to respiratory depression" caused the highest incidence of injury in patients undergoing monitored anesthesia care. The anesthesia provider should use appropriate interoperative monitoring of patient's vitals and level of consciousness to prevent oversedation leading to respiratory depression. The closed claims analysis also concluded that "on-the-patient fires" was another leading complication in patient's undergoing MAC. Seventeen percent of injuries were due to cautery fires. The anesthesia provider should also be aware and avoid "the fire triad (oxidizer, fuel, and ignition source)" while administering MAC [3].

9.3 Patient Selection and Monitoring

Because converting to general anesthesia from deep sedation may occur due to the patient's inability to protect his airway or to adequately ventilate spontaneously, it is imperative that due diligence is done when choosing a patient as a candidate for MAC. One must make sure to communicate with surgical colleagues about the type of procedure and what is expected from the patient. One must also take into the account the projected level of sedation based on the procedure type and ensure that easy airway access would be always feasible. It cannot be stressed enough how important a thorough preoperative assessment including an anesthesia-directed history and physical exam is for the safety of the patient. As a matter of fact, it should be the same as it is in preparation for general anesthesia. There are several other unique features of MAC that should be addressed in the preoperative setting. Since patient cooperation is of paramount importance, mental status and ability to follow verbal commands should be preserved. Dementia, cognitive impairment, language barrier, agitation, and intoxication may compromise the patient's ability to communicate and require deeper level of sedation to allay anxiety and minimize movements, posing additional risks for airway compromise or

aspiration. Furthermore, though MAC may be a practical alternative to general anesthesia in high-risk patients with significant disease burden and decreased functional status, it is prudent to confirm that patient can tolerate prolonged supine or dependent position and remain immobile for the duration of the surgery. In patients with persistent cough, tremor, and marked orthopnea, MAC may not be ideal approach, especially if intricate microsurgical technique is involved and precision of surgical movements is imperative. The presence of certain underlying pathologies may have direct implications on the anesthetic choice and dosages to reduce the likelihood of conversation to general anesthesia. For instance, sedative drugs should be used judiciously in the elderly population or in patient with sleep apnea as the risks of respiratory and cardiovascular instability are higher [4]. Comprehensive airway evaluation should be routinely carried out as need for endotracheal intubation may arise, and if difficult airway is predicted, additional pertinent equipment should be readily available during the case. Recommendations regarding fasting guidelines and lab workup are no different from that for general anesthesia.

Application of MAC warrants not only vigilant cardiovascular and respiratory monitoring but also requires constant supervision of sedation level. As previously discussed, analysis of closed claimed files demonstrated the vast majority of adverse outcomes associated with MAC resulted from oversedation and subsequent respiratory depression leading to permanent brain damage or death [5]. Although every patient undergoing any type of anesthetic should have standard ASA monitors, pulse oximetry and capnography are instrumental in helping to detect hypoxemia. The precordial esophageal stethoscope is an optional modality that allows verification of adequate ventilation [6]. As for the level of sedation, several clinically relevant scales had been developed. Electroencephalography-based devices are available to supplement the subjective practitioner's judgment. The most widely known – the Observer's Assessment of Alertness/Sedation (OAA/S) Scale – was developed in the 1990s to evaluate the depth of sedation using midazolam. It, however, can be applied to other agents as well [7] (Fig. 9.1). Nonetheless, clinical validity of the scale has been recently questioned, and it is now mostly used for research purposes. Objective monitoring can be executed using electroencephalographic (EEG) or bispectral index (BIS) methods; however, a lot of controversy exists. In the early era of BIS use, several authors expressed significant interest in its implementation for MAC cases, and some studies showed relative effectiveness of BIS particularly during propofol-based sedation [9]. On the contrary, there is dearth of reliable evidence on other commonly used anesthetics. More recent studies argued its benefits, presenting conflicting data that indicated that, even with propofol, it is sometimes not possible

Level of responsiveness	Speech	Facial expression	Eyes	Score
Responds readily to name spoken in normal tone	Normal	Normal	Clear, No ptosis	5
Lethargic responses to name spoken in normal tone	Mild slowing or thickening	Mild relaxation	Glazed or mild ptosis (less than half the eye)	4
Responds only after name is called loudly and/or repeatedly	Slurring or prominent slowing	Marked relaxation (slack jaw)	Glazed and marked ptosis (half the eye or more)	3
Responds only after mild prodding or shaking	Few recognizable words			2
Does not respond to mild prodding or shaking				1

Fig. 9.1 Observer's Assessment of Alertness/Sedation (OAA/S) Scale [8]. (Copyright the Korean Society of Anesthesiologists, 2018. This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (▶ http://creativecommons.org/licenses/by-nc/4.0/), which permits unrestricted noncommercial use, distribution, and reproduction in any medium, provided the original work is properly cited)

to discriminate changes between light and deep sedation [10]. Another study revealed that auditory evoked potential index (AAI) is superior to BIS and can help differentiate slight fluctuations in consciousness [11]. Despite promising initial results, this approach requires additional hardware application and trained personnel that may significantly prolong OR time and increase cost, which contradicts the MAC concept. Up to date, no modality, other than close surveillance along with standard respiratory and cardiovascular monitoring, has shown proven clinical benefits and thus is not routinely recommended. In accordance with ASA guidelines, level of sedation is determined by patient's response to verbal, tactile, or painful stimuli. If patient is only responsive to painful stimuli, deep sedation ventilation may not be adequate and vigilant assessment is necessary. Anybody who is not responding to painful stimuli is considered under general anesthesia and requires definitive securing of the airways.

9.4 Systemic Sedatives and Analgesics

A variety of systemic analgesics and sedatives have a role in providing patient comfort under MAC. An ideal agent should have a fast onset, a wide therapeutic range, easy titratability, a short elimination half-life, and a favorable side effects profile. Particularly, it should be able to preserve spontaneous ventilation and maintain cardiovascular stability. A positive effect on postoperative nausea and vomiting (PONV) is also valued. Apart from pharmacological properties, it is essential that in the era of increasing healthcare expenses, efforts are made to maintain the balance of cost-effectiveness and patient safety. Thus, most clinically appropriate drug combinations should be advocated. In compliance with these principles, the patient's age, sex, underlying pathology, type and duration of anticipated procedure, and potential interactions between medications should be well thought out. Variety of drug delivery techniques are available allowing for optimal titratability. Bolus dosing is the easiest and fastest way of induction and facilitates sedation quickly with most of the currently used anesthetics. Blood and effect-site concentrations are however unpredictable, and the sedation levels might be fluctuant if bolus dosing is used for maintenance. On the contrary, various drug delivery systems, namely, target-controlled infusion, patient-controlled infusion, and variable rate infusion, provide a more reliable steady state of sedation and analgesia without peaks and drops. The latter helps to increase patient satisfaction level while abating potential side effects [12].

Various medications and their combinations have been extensively studied in the context of monitored anesthetic care. Satisfaction levels (physicians' and patients') along with incidence of side effects including respiratory depression are the major determinants of effectiveness and safety. Despite advantages of certain drugs over the others in the clinical context, there is paucity of substantial data to advocate for one-fits-all regimen.

9.4.1 Propofol

Propofol by itself or in combination with opioids has historically been the mainstay of monitored anesthesia care. It gained wide acceptance for predictable sedation level and short duration, fast onset and offset, significant antiemetic action, and satisfactory side effects profile. Propofol acts via GABA receptors potentiating inhibitory effects of the transmitter. It produces dose-dependent respiratory depression, myocardial depression, and vasodilation. At anesthetic doses, it yields sedation and consistent amnesia. Fast and clear cognitive recovery occurs shortly after discontinuation of the drug. It should be noted that no reliable amnesia can be achieved with low doses. Propofol is devoid of analgesic effects and therefore must be supplemented with analgesics if pain relief is needed.

9.4.2 Midazolam

Midazolam is a short-acting benzodiazepine acting via GABA receptor. It has anxiolytic and sedative properties, hence providing good comfort level implementing positive changes on perception of pain. Yet administration of midazolam may lead to unwanted prolonged psychomotor impairment. Additionally, synergism occurs in combination with opioids, enhancing the hypnotic effect and aggravating respiratory depression potential. A study revealed that a combination of midazolam and fentanyl (0.05 mg/ kg of midazolam

along with 2 μg/kg of fentanyl) put healthy volunteers at significant risk for apnea and hypoxemia [13]. One of the benefits of the combination and the reason why benzodiazepine/opioid regimen is supported by many clinicians is due to a fact that specific antagonists are available for both medications and the effects can be reversed.

9.4.3 Ketamine

Ketamine is an arylcyclohexylamine derivative and NMDA receptor antagonist. It provides good analgesia, amnesia, and cognitive disruption which is also referred to as dissociative anesthesia. It also preserves hemodynamic stability (except for the situations when patient is profoundly depleted of catecholamines) and spontaneous respirations. For these properties, ketamine is specifically valuable in MAC. Ketamine can be combined with propofol or midazolam to counteract their respiratory side effects and decreases the dose of both medications. Moreover, supplementing ketamine with midazolam reduces the likelihood of emergence delirium, specifically hallucinations, agitation, and postoperative dysphoria.

9.4.4 Dexmedetomidine

Dexmedetomidine is an alpha-2 adrenergic agonist that recently gained wide acceptance due to a constellation of positive effects, most importantly good hypnotic and mild analgesic properties along with minimal respiratory depression effects. Due to its propensity to cause hypotension and bradycardia, it may not be the ideal choice in elderly patients or for patients with structural heart pathology, rhythm disturbances, and hemodynamic instability [14]. Also, the onset/offset of the drug is prolonged compared to fast-acting GABA agonists, accounting for slow induction and delayed recovery. Hence, it may not be advantageous for quick ambulatory procedures when used as a sole anesthetic. Combination of dexmedetomidine with ketamine was proven to be a valuable tool in the pediatric population, precisely for magnetic resonance imaging cases [15]. It creates steady sedation and good analgesia with minimal risk of respiratory depression, which is critically important when immediate and direct access to the airways is not feasible.

9.4.5 Opioids

Opioids are commonly used during procedures under MAC and provide general analgesia if local analgesia is not sufficient alone. Fast-onset and short-acting drugs are preferred. Fentanyl is most commonly used. Other agents that are frequently utilized during MAC are afentanyl and remifentanil. Afentanyl may be given in frequent boluses and has a very fast onset. Remifentanil is suitable for continuous infusion due to its short context-sensitive half-life – especially when a continuous state of analgesia is required. However, remifentanil is notorious for causing respiratory depression even at low doses, so careful monitoring is critical.

9.4.6 The Adjuncts

There are a few other adjuncts that have been reportedly used as supplements to mainstay MAC regimen. Phenergan (promethazine) is currently used mostly for its anti-nausea properties; however it is also known for its mild sedative and hypnotic effects. It serves as an alternative to benzodiazepines for preoperative anxiolysis. A recent study compared the effectiveness of adding Phenergan to Fortwin (pentazocine) and midazolam combination. This mixture was found to be superior compared to ketamine + midazolam regimen in terms of hemodynamic stability, comfort, and surgeons' and patients' satisfaction [16]. Ketorolac is a nonsteroidal anti-inflammatory drug that has weak analgesic properties and can be considered as an alternative to opioids. The main advantage compared to opioids is the absence of respiratory side effects, pruritus and PONV; however oftentimes analgesic effect is not sufficient. Intravenous acetaminophen may potentially be added to the analgesic regimen and help provide pain-free experience for the patient. It has been extensively studied in regard to postoperative pain control and proven to decrease opioid consumption in the postoperative period; however more research is needed to describe its intraoperative effects.

The choice of sedatives and analgesics should be primarily driven by the required level of sedation, type of the procedure, and specific patient's characteristics. Knowledge of potential drug interaction and subsequent effects on respiration and hemodynamics is crucial, and emergency

equipment should always be available regardless of the case location in or outside of the operating room.

9.5 MAC Procedures

9.5.1 Ophthalmologic Procedures

Monitored anesthetic care (MAC) has become increasingly popular for vitreoretinal and cataract surgery compared to other anesthetic techniques. Topical anesthesia (TA) generally does not produce adequate analgesia for these procedures, whereas solely regional anesthesia (RA) poses serious albeit uncommon risks such as retrobulbar hemorrhage, globe rupture, and optic nerve injury. Consequently, MAC sedation is commonly used and has also been associated with increased patient-surgeon satisfaction with cataract surgery compared to other anesthetic techniques. Furthermore, patients undergoing cataract surgery with only TA have showed to have increased anxiety and discomfort when compared to MAC or TA combined with MAC.

Two common complications associated with ophthalmologic procedures are snoring and sneezing. Snoring has been proven to be a risk factor associated with head movement during vitreoretinal cases under MAC. It is increased by intraoperative propofol infusion. Avoidance of the use of propofol during the procedure can reduce the risk of head movement by reducing the level of sedation and thus the airway obstruction. Intraoperative sneezing is also associated with propofol usage for intravenous sedation combined with periocular local anesthesia. Risk factors for sneezing include male gender, history of photic sneezing, bilateral or upper eyelid infiltration, deep sedation, and concurrent administration of midazolam. The use of adjunct opioids, especially alfentanil, has found to be protective and has reduced the risk of sneezing. Additionally, avoidance of the use of midazolam as well as RA are protective.

9.5.2 Otolaryngologic Procedures

Tympanoplasty and percutaneous dilational tracheostomy are two otolaryngologic procedures that can be done under MAC. When done with dexmedetomidine, there were higher patient-surgeon satisfaction rates compared to use of midazolam-fentanyl combination. Dexmedetomidine decreases sympathetic outflow via the α2 agonist effect and continuous cardiovascular monitoring throughout the procedure is paramount. Additionally, due to decreased sympathetic outflow, there is reduced blood loss, resulting in improved visualization of the surgical field. The midazolam-fentanyl combination has been associated with increased risk of respiratory suppression and intraoperative hypotension, and continuous intraoperative cardiopulmonary monitoring is needed.

Complications are generally related to airway and pharmacologic adverse effects. Local anesthetic toxicity with these procedures is a possibility and is seen more commonly in the pediatric population. Care must be taken to ensure no accidental intravascular injection occurs as this can lead to neurologic and cardiovascular collapse. Airway complications may occur, and there may be a need to convert the procedure from a MAC to GA.

Anesthesia providers must also be extremely vigilant when doing MAC cases for head and neck surgeries due to the risk of on-patient fires. Most patients are given supplemental oxygen during MAC cases, and when combined with electrocautery, this supplemental oxygen can act as an oxidizer, while the electrocautery is the ignition source. The fuel can be represented by sponges, towels, or anything else in the surgical field. These three things, an oxidizer, fuel, and ignition source, represent the fire triad. Providers must communicate with the surgical team to minimize all components of the fire triad, i.e., lowering the FIO2 when cautery is needed.

9.5.3 Inguinal Herniorrhaphy

Inguinal herniorrhaphy (IH) can be performed under MAC with regional anesthesia. A traditional transversus abdominis plane (TAP) block or an iliohypogastric nerve block along with MAC has been shown to produce less postoperative pain, faster recovery times, and greater 24-h post-procedure satisfaction. This approach is also more cost-effective compared to GA and spinal anesthesia (SA), and it is ideal in an outpatient setting. In a small subset of patients, there exists

a need to convert to general anesthesia due to inadequate anesthesia. This may be due to an ineffective regional anesthetic technique or patient anxiety. Because preoperative education has been shown to decrease anxiety, all attempts should be made to educate and calm the patient prior to the surgery.

9.5.4 Cardiovascular Procedures

Endovascular aortic aneurysm repair (EVAAR), transcatheter aortic valve implantation (TAVI), and peripheral vascular procedures have all been performed under MAC, general anesthesia, and regional anesthesia as well. Patients who have undergone major vascular procedures with MAC compared to GA had adequate intraoperative anesthesia, less postoperative pain, shorter postoperative hospital stay, and reduced risk of respiratory complications. Due to the increased risk of cardiovascular complications that can occur with GA, MAC cases provide a greater safety profile than GA. Additionally, arteriovenous fistula under MAC with axillary block has shown to have increased 3-month patency rates for fistulae.

Major complications are related to the comorbidities of the patient and the anesthetic administered. Most patients undergoing vascular procedures have evidence of vascular pathology and are at increased risk for perioperative myocardial ischemia and stroke. These patients should be risk stratified and fully optimized preoperatively to prevent these complications. Additionally, side effects of local anesthetic administration such as neurotoxicity and cardiovascular collapse must be considered preoperatively as well. The use of local anesthetic agents that have a greater safety profile, such as ropivacaine, would be more appropriate for regional anesthesia than bupivacaine.

9.5.5 Interventional Pain

MAC is wide spread in the field of interventional pain. It is particularly useful in vertebroplasty and epidural steroid injections. MAC allows intraprocedural patient-surgeon communication while simultaneously allowing adequate analgesia and preservation of cardiopulmonary function. Communication is necessary in this field as surgeons require feedback from patients to prevent potential nerve damage. Epidural injection is an example of the type of procedure that may cause nerve damage if there is no communication. Epidural spinal steroid injections have increased risk of spinal cord damage. Needle contact with the cord is likely to elicit a strong paresthesia which can be impaired with the use of moderate or deep sedation which can alter the patient's perception of a needle-induced paresthesia. This then increases the likelihood of accidental injection of material directly into the cord which can produce a substantial neurologic injury. Needle penetration of the cord is not likely to produce widespread injury unless significant bleeding occurs. The risk is increased in patients with severe cervical spinal stenosis when epidural pressure is increased.

In fully conscious individuals, injection of small volumes of drug may produce significant discomfort or paresthesia, prompting the physician to limit the volume used. If sedation and analgesics blunt these sensations, larger volumes may be injected thus increasing the chance for injury. Electrical stimulation can be employed to minimize the chances of injury to adjacent nerves and stimulation and will produce both sensory and motor effects on nerve roots if the needle position is incorrect. While motor effects of stimulation are preserved, the sensory effects may be lost during moderate to deep sedation which can lead to neurological damage.

9.5.6 Ambulatory Procedures

Ambulatory practices have incorporated the use of MAC in outpatient gastroenterology and pulmonology suites. ERCP and colonoscopy have been increasingly performed under MAC due to decreased patient awareness, increased patient satisfaction, and reduced length of recovery. Bronchoscopy should allow the patient spontaneous ventilation while having the ability to protect their airway as well as blunt sympathetic response.

The use of dexmedetomidine, although it has a slow onset and offset, has been associated with lower incidence of oxygen desaturation and reduced incidence of oral suctioning due to preservation of respiratory drive. Ketamine has also been used as it allows preservation of airway

patency and respiratory function however can prove to increase difficulty of procedure as ketamine has been known to increase airway secretions. Use of glycopyrrolate may help in reducing such secretions.

Complications seen in the ambulatory setting include hypotension, hypertension, hypercapnia, and arrhythmias. These complications can be detrimental in patients who have a history of cardiopulmonary comorbidities as it can increase the risk of perioperative myocardial infarction, stroke, and postoperative respiratory failure. Control of blood pressure to within 20% of baseline can reduce these risks. Intraprocedural hypercapnia due to inadequate ventilation is also a concern. Due to their pulmonary pathology in patients undergoing bronchoscopy, these patients have an increased risk of respiratory compromise. Hypercapnia is common with moderate amounts of hypercapnia not linked to worse outcomes; however severe hypercapnia (PaCO2 > 100 mmHg) predisposes patients to increased risk of postoperative cardiac failure and increased extubation times and intraoperative stay. Intraprocedural blood gases can determine the presence of hypercapnia and the underlying cause to be corrected.

9.5.7 Neurosurgical Procedures

MAC has been commonly used for awake craniotomies as it allows patient and surgical team communication. It also allows for the maintenance of adequate cardiorespiratory function while also allowing intraoperative neuromonitoring. Commonly used combinations of drugs in these procedures are a combination of intravenous anesthetic and ultrashort-acting opioid such as propofol-remifentanil or sufentanil combinations. Recently, there has been an increased use of dexmedetomidine as it preserves respiratory function, reduces anesthetic requirements, and has neuroprotective properties.

Complications seen when using MAC for neurosurgical procedures include respiratory depression, reduced motor-evoked potentials (MEPs), and postoperative opioid hyperalgesia. Respiratory depression can be seen when both propofol and an opioid infusion are used. The combination has been proven to increase the risk for this complication. Continuous cardiopulmonary monitoring and diligent observation are required to identify and minimize the effects of respiratory depression. Conversion to general anesthesia may be necessary, and the provider should always be prepared to do so. Providers should also be aware of the possibility of reduced MEPs. Dexmedetomidine has been used in more modern times as an adjunct to propofol-/remifentanil-based TIVA for neurosurgical procedures. This has remained a controversial topic as some studies have shown a decrease in amplitude of the motor-evoked potential monitoring, if plasma levels of dexmedetomidine are greater than 0.4 ng/ml. However, other studies have shown no effect on MEP with dexmedetomidine. Careful monitoring of the administered dose of dexmedetomidine with adjustment if MEP is depressed should be done. Lastly, postoperative opioid hyperalgesia can be associated with prolonged use of intraoperative remifentanil. This along with opioid tolerance can predispose patients to respiratory compromise and increased analgesic requirements in the immediate postoperative period. Continued monitoring postoperatively while treating postop pain is necessary to prevent additional postop complications.

9.5.8 Pediatric Procedures

MAC sedation in combination with caudal blocks has become an increasing popular anesthetic technique particularly in pediatric urologic and general surgical cases. There is evidence to show that MAC procedures involving the use of regional anesthesia reduced the risk of early postoperative apnea in premature neonates when compared to GA. MAC anesthesia using propofol or dexmedetomidine has been shown to decrease the incidence of postoperative delirium and allows smoother emergence in this patient population compared to sevoflurane-based GA which is associated with 10–80% of emergence agitation. Administration of a caudal block generally targets the sacrococcygeal ligament in these patients. There exists a small risk of local anesthetic toxicity via accidental intravascular injection, leading to neurological deficits and cardiovascular collapse. Use of the appropriate anesthetic with a lower risk of toxicity should be considered.

9.6 Summary

Monitored anesthetic care procedures are frequently used among anesthesia providers due to the enhancement of minimally invasive procedures. It provides amnesia, analgesia, sedation, and anxiolysis. These are the same components as general anesthesia but with a faster recovery, a reduction in postoperative nausea and vomiting, intraprocedural patient-surgeon communication, and less physiological changes. MAC procedures, along with supplementation of local anesthetics, have gained popularity and are more favorable with patient satisfaction. In the pediatric population, MAC reduces the risk of postoperative apnea in the premature neonates and decreases the incidence of postoperative delirium allowing smoother emergence in the older children. Although the use of MAC procedures has its benefits, it also has its list of complications such as but not limited to deep sedation transitioning to general anesthesia where a protected airway is needed, hypoxemia from inadequate oxygenation or ventilation leading to respiratory compromise, side effects of the sedating drug used such as hypotension, local anesthetic systemic toxicity (LAST), and complications of the procedure such as cautery fires.

When choosing the best anesthetic sedative and analgesic combination, a thorough preanesthetic evaluation is needed, and the type of surgical procedure and level of sedation required, a knowledgeable anesthetic provider, and emergency equipment are prudent to yield a safe and uneventful case. The American Board of Anesthesiology (ASA) guidelines mandate a standard level of care with the use of intraoperative assessment of the patient's oxygenation, ventilation, circulation, and temperature. Poor oxygenation and ventilation will lead to hypercarbia, hypoxemia, and ultimately cardiovascular collapse. The anesthetic drugs such as dexmedetomidine, ketamine, propofol, and promethazine used for sedation have multiple side effects. Examples are hypotension, hypertension, and tachycardia, and if these are not treated promptly, cardiovascular collapse can take place. Vigilant monitoring is the key to minimizing complications. As instructed by the ASA guidelines, level of sedation is determined by a patient's response to verbal, tactile, or painful stimuli. If the sedation is deep as to where the patient cannot respond to painful stimulation, this level of sedation is considered general anesthesia and requires a protected airway.

Because regional anesthesia often accompanies MAC procedures, large amounts of local anesthetics are frequently used. Providers should be familiar with local anesthetic systemic toxicity and how to treat it. LAST can occur when local anesthetic is accidentally injected into a blood vessel or too much local anesthetic is absorbed into the vascular system. Symptoms can range from tinnitus and perioral numbness to tonic-clonic seizures and apnea and then eventually ventricular dysrhythmias and cardiac arrest. Treatments include airway support, low-dose epinephrine (10 mcg boluses), and lipid emulsion therapy. The intralipid emulsion should consist of 20% lipids and 1.5 ml/kg should be bolused followed by an infusion at a rate of 0.25 ml/kg/min. Airway supportive methods can range from a forward chin thrust with a nasal cannula to placement of a laryngeal mask airway or endotracheal tube.

In conclusion, although the MAC technique has its benefits, it can also present with grave complications if providers do not plan properly for their specific patient. Futhermore, it is imperative to understand the ramifications of the specific procedure taking place, and to monitor and diligently observe their patient throughout the procedure so that they may intervene promptly if necessary.

9.7 Review Questions

1. What is known as the fire triad?
   A. Oxidizer, fuel, ignition source
   B. Oxidizer, fuel, heat
   C. Fuel, heat, laser
   D. Ignition source, laser, O2

2. Which of the following is not a specific indication for choosing MAC over conscious sedation?
   A. Morbid obesity (BMI > 40)
   B. h/o sleep apnea or stridor
   C. Acutely agitated
   D. ASA P2 or greater

3. Which drug is an alpha-2 adrenergic agonist?
   A. Ketamine
   B. Dexmedetomidine
   C. Midazolam
   D. Phenergan

9.8 Answers

1. A – The fire triad is known as the oxidizer, fuel, and ignition source (Analysis, A.C.C. [3], Injury and Liability Associated with Monitored Anesthesia).

2. D – Include ASA P3 or greater, morbid obesity (BMI > 40), severe sleep apnea, inability to follow simple commands, spasticity/movement disorders, anticipated intolerance to standard sedatives, patients <12 years old and > 70 years old, pregnancy, h/o sleep apnea or stridor, oral/neck/jaw/facial abnormalities, and acutely agitated, uncooperative patients (Policy, M. C. [17]. Monitored Anesthesia Care).

3. B – Dexmedetomidine is an alpha-2 adrenergic agonist.

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Massive Perioperative Hemorrhage: Considerations in Clinical Management

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_10

10.1 Introduction

There is no universally accepted definition of massive hemorrhage. The British Committee for Standards in Haematology has consensus but arbitrary definition, "Bleeding which leads to a heart rate of more than 110 beats/min and/or systolic blood pressure less than 90 mmHg" [1]. Massive transfusion in an adult has commonly been defined as ten or more units of packed red blood cells (PRBC) in a 24-h period, which almost replaces one blood volume based on the total blood volume of a 70-kg male [2]. Massive transfusion can also be defined if one of the following conditions is satisfied: blood loss exceeding circulating blood volume within a 24-h period, blood loss of 50% of circulating blood volume within a 3-h period, blood loss exceeding 150 ml/min, and blood loss that necessitates plasma and platelet transfusion [3]. Hemorrhage is the main cause of death in major trauma patients surviving to the hospital admission [4]. In this review, we will discuss the risk factors for massive perioperative hemorrhage, clinical manifestations and evaluations, and various management strategies.

10.2 Etiology of Massive Perioperative Bleeding

Perioperative massive hemorrhage can be caused by various etiologies, as illustrated in Table 10.1.

10.2.1 Trauma

Major trauma is one of the leading causes of perioperative massive hemorrhage, and hemorrhage is the main cause of death following major trauma in patients surviving to hospital admission with the highest incidence in 1–3 h after admission [4]. Etiology of major trauma includes motor vehicle accidents, bullet injuries, blunt trauma injuries, fall from certain heights, glass injuries, blast injuries, etc. These traumatic injuries are potentially associated with major vascular laceration(s) or organ rupture (spleen injury) leading to extensive blood loss. Most of the patients expire on their way to hospital because of massive hemorrhage. So, hemorrhage/hemorrhagic shock is still the leading cause of death in all major traumatic injuries worldwide [4].

10.2.1.1 Surgical Procedures

1. Liver transplantation: In 1963, Starzl and colleagues performed the first liver transplantation procedure in human beings. The first five patients all died of bleeding complications. Liver transplantation has usually been associated with massive hemorrhage and requires considerable amount of blood transfusion. The etiologies of liver transplantation-associated bleeding can be multifactorial including preoperative (liver failure, cirrhosis, cholestasis, and splenomegaly), intraoperative (transection of the fragile collateral vessels, release of heparin-like factors from the allograft, coagulopathy), and postoperative (leaks at vascular suture lines, graft-versus-host disease, thrombocytopenia, coagulopathy, etc.) [5]. Intraoperative management-related issues such as massive volume load and subsequent hypothermia and hypocalcemia secondary to citrate toxicity can also significantly worsen the preoperative coagulopathy, thus further increasing the perioperative hemorrhage [6]. Excessive blood loss and large quantity

Table 10.1 Etiologies of massive perioperative bleeding

Major trauma	Surgical procedures	Coagulation abnormalities	Obstetric diseases
Major trauma	Liver transplantation	Acute traumatic coagulopathy	Placenta previa/accreta
	Cardiac/major vascular surgery	Clotting factor deficiencies	Embryonic emboli-associated DIC
	Major cancer surgery	Drug-induced acquired factor deficiency	
		An undiagnosed inherited bleeding disorder	
		Dilutional coagulopathy	

of blood transfusion during orthotopic liver transplantation are unfortunately associated with significantly decreased graft survival and dramatically increased episodes of sepsis and therefore prolonged ICU stay [6]. In principle, the degree of hemorrhage can be estimated based on the severity of preoperative liver disease and coagulation function, quality of the donor liver, recipient's overall clinical status, and surgical skills and experience of the transplantation team [7]. There is a strong correlation between MELD score and transfusion requirements in patients undergoing orthotopic liver transplantation. Higher MELD scores (>30) was found to be significantly associated with increased bleeding and transfusion requirements when compared to patients with lower MELD scores (<30) [8]. Massive bleeding can have multiple clinical consequences, as illustrated by ► Box 10.1.

2. Major cancer and spine surgery: Reconstructive and multilevel procedures like spine surgery and spine fusion procedures are potentially complicated by significant intraoperative blood loss and the need for allogeneic blood transfusion. The unique prone position (knee-chest) for spine surgery likely leads to increased intra-abdominal pressure which increases epidural venous pressure and consequently exacerbates intraoperative surgical bleeding. Raised intra-abdominal pressure is measured via a urinary bladder catheter [9]. The total blood loss is proportionate with the intra-abdominal pressure, also proportionate with patient's body mass index (BMI) [9]. In another study, the effects of prone versus jack-knife position on intra-abdominal pressure and intraoperative bleeding during lumbar disc herniation surgery were conducted, and intra-abdominal pressure came out to be significantly higher in prone position [10]. Certain anesthetic agents in spine and cancer surgeries play an important role in exacerbating intraoperative blood loss like sevoflurane results in significantly greater intraoperative blood loss than propofol [11]. Certain cancer surgeries also cause massive perioperative bleeding due to extensive intra-tumor blood vessel networks that lead to unpredictable internal bleeding during surgery. A case study is presented on metastatic prostate adenocarcinoma in which patient develops hyper-fibrinolysis leading to widespread ecchymosis and disseminated intravascular coagulation (DIC). Any surgical attempt to resect this type of cancer can potentially lead to massive perioperative hemorrhage and other complications [12].
3. Cardiac/major vascular surgery: In cardiac or major vascular surgeries, surgeons deal with main blood vessels like the aorta, coronaries, and femoral, tibial, brachial, or vertebral arteries. So, there are higher chances of intraoperative and postoperative hemorrhage leading to severe consequences.

Box 10.1 Consequences of Liver Disease on Coagulation

- Thrombocytopenia
- Accelerated or decreased fibrinolysis
- Qualitative defects in platelets function
- Predisposition to fibrinolysis

10.2.1.2 Coagulation Abnormalities

1. Acute traumatic coagulopathy: It could mainly be an iatrogenic or secondary coagulopathy, a condition in which various elements are thought to play a role, including consumption of clotting factors, hemodilution from large quantity of crystalloid infusion, acidosis, and hypothermia. The exact mechanism of coagulopathy is still unknown. One theory believes that actual injury causes release of certain tissue factors that lead to thrombin and fibrin generation and utilization leading to DIC [13]. Another theory describes that trauma-induced hypoperfusion and ischemia lead to release of activated protein C, which leads to consumption of plasminogen activator inhibitor, inhibition of the clotting cascade, systemic anticoagulation, and hyper-fibrinolysis [14]. A high fresh frozen plasma to RBCs ratio is the current treatment of choice for acute traumatic coagulopathy [15].

   Clotting factors deficiencies: Clotting factors deficiencies may be congenital or acquired. Congenital deficiency includes factor VIII deficiency called hemophilia A disease and deficiency of factor IX called hemophilia B. Another congenital bleeding disorder is von Willebrand's disease caused

by deficiency of von Willebrand factor (vWF). Acquired clotting factors deficiency also develops in selective individuals because of the autoantibodies affecting the activity or accelerating the clearance of clotting factors [16]. Such antibodies are usually directed against factor VIII and vWF. These acquired antibodies are basically IgG4 type targeting several epitopes of clotting factors [17].

An undiagnosed inherited bleeding disorder: Some individuals have congenital deficiency of coagulation factors like factor VIII and vWF. These patients do not have bleeding symptoms initially. If such patients are never being diagnosed with congenital coagulation factors deficiency and yet they present for any elective surgery or emergency trauma surgery, then bleeding is profuse and unpredictable [18]. Diagnosis is difficult in these patients unless some family members with some type of bleeding disorder or in some cases these patients are found to have large multimers of vWF [16]. Common bleeding sites are the skin, mucosa, and muscles. Hemarthrosis is rare. Recombinant factor VII and prothrombin complex concentrate are the first line of management.

2. Drug-induced acquired factor deficiency: Warfarin, an oral vitamin K antagonist, is used to prevent arterial and venous thromboembolism in variety of clinical conditions. It is one of the leading drugs causing emergency room visits for adverse drug reactions. Annually the frequency of bleeding complications associated with over-anticoagulation is 15% to 20%, with fatal bleeds accounting for as high as 1% to 3% [19]. Assessment of warfarin-induced anticoagulation is typically done using the international normalized ratio (INR). The INR levels and their management are summarized in Table 10.2. The authors recommend the use of 3-factor prothrombin complex concentrate (PCC) with vitamin K and a judicious amount of rVIIa as the treatment of choice for over-anticoagulation, although the risk of thromboembolism is still there. Selective serotonin receptor inhibitor (SSRI) is a group of antidepressant drugs most commonly used for depression all over the United States. Studies show that

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Table 10.2 Guidelines for the reversal of anticoagulation therapy [22]

INR	Clinical scenario	Management
<4.5	No bleeding	Hold warfarin until INR in therapeutic range
	Rapid reversal required	Hold warfarin Consider vitamin K 2.5 mg oral
4.5–10	No bleeding	Hold warfarin until INR in therapeutic range Consider vitamin K 2.5 mg oral
	Rapid reversal required	Hold warfarin Give vitamin K 2.5 mg oral or 1 mg IV infusion
>10	No bleeding	Hold warfarin until INR in therapeutic range Give vitamin K 2.5 mg oral or 1–2 mg IV infusion over 30 min, and repeat q24h as needed
	Rapid reversal required	Hold warfarin Give vitamin K 1–2 mg IV infusion over 30 min, and repeat q6–24 h as needed
Any INR	Serious or life-threatening bleeding	Hold warfarin Give vitamin K 10 mg IV infusion over 30 min Give 4 units FFP/plasma *Consider 4-factor PCC (Kcentra) (preferred for life-threatening bleeding)* *INR 1.5–3.9: 25 units/kg (maximum 2500 units)* *INR 4.0–6.0: 35 units/kg (maximum 3500 units)* *INR >6.0: 50 units/kg (maximum 5000 units)*

there is a risk of postoperative hemorrhage with SSRI use only when used along with NSAIDs or warfarin [20]. Cessation of SSRIs before surgery is still under investigation because cessation of SSRI before surgery may potentially precipitate a discontinuation syndrome, which may exacerbate depression and increase sensitivity to postoperative pain [21]. So, the internists, surgeons, and anesthesiologists should be aware of potential perioperative SSRI-associated bleeding risks.

3. Dilutional coagulopathy: Dilutional coagulopathy is defined as a coagulation abnormality due to "loss, consumption, or dilution of coagulation factors that occurs when blood is replaced with fluids that do not contain adequate coagulation factors" [23]. This hemostatic disturbance is further deteriorated by continuous fluid administration, acidosis, fibrinolysis, and hypothermia. It is a multifactorial change that affects thrombin generation, clot firmness, and fibrinolysis. Acquired fibrinogen deficiency is considered the leading cause of dilutional coagulopathy [24]. High molecular weight dextrans are also linked to severe disturbances of clot formation [25]. This impact on clot formation was significantly reduced by introducing new low molecular weight starches, but depending on the amount of fluid given, a marked impairment of hemostasis can still be observed. Rotation thromboelastometry is the test of choice to evaluate perioperative coagulation status. FFP transfusion 30 ml/kg is the treatment of choice for dilutional coagulopathy and in massive transfusion scenarios [26].

10.2.1.3 Obstetric Diseases

1. Placental anomalies: Definition of massive obstetric hemorrhage include a fall in hemoglobin concentration of >40 g/L or blood loss of >2500 mL or transfusion of > four units of RBCs [27]. Postpartum hemorrhage (PPH) means more than 500 mL blood loss from the genital tract within 24 h of birth. PPH is subdivided into minor (500–1000 mL), moderate (1000–2000 mL), and severe (>2000 mL) [2]. Common etiologies include uterine atony, placenta previa, placenta accreta, abruptio placenta, uterine rupture, or embryonic emboli associated DIC. In parturient, fibrinogen levels are 4–6 g/L, almost twice the level when compared to nonpregnant females. And the concurrent drop in protein C and S promotes prothrombotic state resulting in shorter PT and aPTT values. So, the combined results may come out normal in massive hemorrhage [28]. A retrospective study shows that there is no association between the method of placenta removal and postpartum blood loss in cesarean section deliveries. Placenta removal can occur spontaneously by massaging on the uterine fundus and applying gentle traction on the umbilical cord, or it can be removed manually by placing surgeon's dominant hand in the uterine cavity and removing the placenta by detaching it from the uterine wall [29].
2. Embryonic embolic event-associated DIC: Amniotic fluid embolism leading to DIC usually occurs at term or immediate postpartum. Amniotic fluid contains surfactant and various pro- and anti-anticoagulants. Surfactant, a lipoprotein produced by fetal lungs and present in increasing amounts in amniotic fluid with increasing gestational age, is structurally like tissue thromboplastin and possesses significant thromboplastic activity. It also contains cysteine protease that directly activates factor X, and it directly inhibits the platelets too [29]. Newborns may develop tachypnea and cyanosis. Patient shows signs of hypotension, brief generalized seizures, and profuse vaginal bleeding followed by unconsciousness. PT, aPTT, and bleeding time all are prolonged, and fibrinogen level falls drastically. Treatment strategy comprises of blood component replacement, including PRBC, FFP, platelets, cryoprecipitate, and possibly fibrinogen concentrate. Recombinant factor VIIa use is associated with increased mortality as compared to the patients who do not receive rFVIIa.

10.3 Clinical Manifestations

10.3.1 Vital Signs Changes

Perioperative massive bleeding is categorized as compensated, mild, moderate, and severe, as shown in ◘ Table 10.3.

Table 10.3 Vital sign changes in various severity of hemorrhage [30]

Stage	I (compensated)	II (mild)	III (moderate)	IV (severe)
Blood loss	<15% 750–1000 ml	15–<30% 1000–1500 ml	30–<40% 1500–2000 ml	>40% 2000 ml or more
Blood pressure	Normal Vasoconstriction redistributes blood flow, slight rise in diastolic BP seen	Orthostatic changes in BP Vasoconstriction intensifies in noncritical organs (skin, muscles, and gut)	Markedly decreased SBP <90 mmHg vasoconstriction decreases perfusion to vital organs like the liver, spleen, and kidneys	Profoundly decreased SBP <80 mmHg decreased perfusion affects the brain and heart
Respiration	Normal	Rate mildly increased	Moderate tachypnea	Marked tachypnea, respiratory collapse
Heart rate	Normal (<100 bpm)	Tachypnea (>100 bpm)	Tachycardia (120 bpm)	Tachycardia (140 bpm)
Urinary output	>30 ml	20–30 ml/h	<20 ml/h	Anuria
Capillary refill	Normal <2 s	>2 s Clammy skin	>3 s Cool, pale skin	>3 s Cold mottled skin
Mental status	Normal or slightly anxious	Mildly anxious or irritated	Confused and agitated	Obtunded

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10.3.2 Vital Organ Perfusion-Related Presentations

All ASA members and consultants strongly agree to the monitoring of vital organ's perfusion using standard ASA monitors (Table 10.4) (Fig. 10.1).

Table 10.4 Perfusion monitoring parameters

Organs	Perfusion monitoring parameters
Heart	Blood pressure, heart rate, oxygen saturation, EKG, and echocardiography
Brain	Cerebral oximetry and NIRS
Kidneys	Urine output and arterial blood gas analysis

10.4 Evaluation and Diagnostic Checklist

10.4.1 Prothrombin Time and Activated Partial Thromboplastin Time

PT is used to test factor VII (extrinsic factor pathway). aPTT measures the integrity of intrinsic system (factor VIII, IX, XI, XII). Using the cutoff value of international normalized ratio of more than 1.5 times normal, PT demonstrates a sensitivity of 88% and a specificity of 88% in detecting at least one non-hemostatic coagulation factor level after trauma, whereas aPTT (more than 1.5 times normal) demonstrates a sensitivity of only 50% and a specificity of 100% because factor VIII is often increased as an acute phase reactant in trauma and surgical patients [31]. The limitations of PT and aPTT are summarized in ▶ Box 10.2.

Thromboelastography (TEG) and Thromboelastometry (ROTEM) Since PT/aPTT tests are usually performed in central/core laboratories of the hospital, there is substantial time delay in getting the results. So TEG/ROTEM can be performed as a point-of-care hemostasis monitoring test. Both tests evaluate the speed and strength of clot formation as well as clot stability; both help to evaluate hemophilia, fibrinogen deficiency, factor XIII deficiency, and fibrinolytic state [33]. Reference ranges can vary from institution to institution. Clinical results of both tests can be similar, but the two results are not interchangeable [34]. Systemic fibrinolysis is suspected when clot breakdown is observed within 1 hour [35].

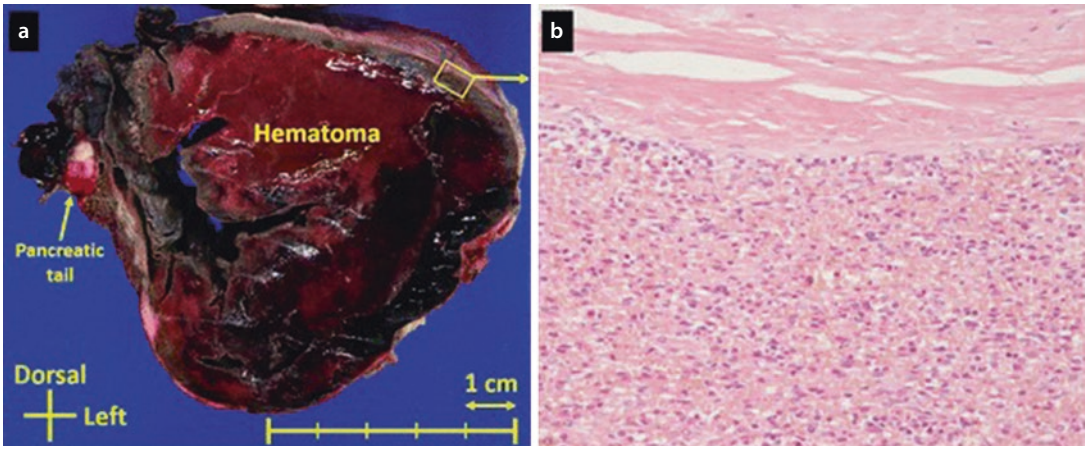

Fig. 10.1 **a** The excised specimen was grossly 9cm in diameter, had a giant hematoma surrounded by gray hrad parenchyma witha smooth capsule. **b** The specimen microscopically showed normal splenic tissue with a firm capsule [60]

Box 10.2 Limitations of PT/aPTT [32]

- PT and aPTT do not provide any clue about in vivo interaction of platelets with coagulation factors.
- PT and aPTT remain prolonged even if thrombin generation is improved because of antithrombin or protein C deficiency.
- PT/aPTT does not tell about the overall stability of a hemostatic thrombus because both tests are terminated at very low thrombin levels and before fibrin is polymerized.

10.4.2 Electrolytes Alterations

Serum calcium: Since massive hemorrhage is accompanied with massive blood and blood products replacement, electrolyte alterations are common consequences particularly serum calcium levels as it plays an important role in coagulation cascade and has an inotropic effect on cardiac myocytes. RBCs are stored in citrate, a calcium-chelating agent. So, massive transfusion leads to potentially severe hypocalcemia [36].

Serum magnesium: Citrate also binds magnesium like calcium, so patient may develop hypomagnesemia resulting into certain fatal cardiac manifestations as well.

Serum potassium: Hypokalemia or hyperkalemia may also occur because of release of stress hormones or reentry of potassium ions into transfused RBCs or higher potassium concentration in stored RBCs [37].

Table 10.5 Advantages/disadvantages of POC testing [39]

Advantages of POC testing	Disadvantages of POC testing
Only a small volume (1–5 ml) of blood is needed for testing	No single POC coagulation test covers the functioning of the entire hemostatic system
Rapid availability of results	Hypo- and hyperthermia affect the results
Lab transportation of blood sample is no longer necessary	Total cost of POC exceeds that of conventional coagulation testing
Can be carried out without specialized training	Pre-existing coagulopathies can alter the results

10.4.3 Point-of-Care Testing

It includes basic electrolytes, serum glucose level, lactate measurement, arterial blood gas analysis, and Hb/Hct ratio. Timely measurement of these parameters facilitates assessment of occurrence and severity of any disturbance and helps its management accordingly. Currently POC testing is usually suggested in most of trauma patients who have significant injuries but not enough to activate a massive transfusion protocol (MTP) [38]. The advantages and disadvantages of POC are summarized in Table 10.5.

10.5 Anesthetic Management of Massive Perioperative Hemorrhage

Anesthetic management strategies of massive perioperative hemorrhage are summarized in Table 10.6.

10.5.1 Non-pharmacologic Management

10.5.1.1 Transfusion

Blood products transfusion is generally considered for massive perioperative hemorrhage [40], except in those patients with unique religious believe such as Jehovah's Witness which prohibits any blood product infusion (▶ Box 10.3).

Table 10.6 Management strategies of massive perioperative bleeding

Management of massive perioperative hemorrhage	
Non-pharmacologic	**Pharmacologic**
Transfusion	Desmopressin
Temperature management	Tranexamic acid
Patient positioning	Aminocaproic acid
Acid-base balance	Aprotinin
Damage control resuscitation	Vasopressors
Other non-pharmacologic measures	

Box 10.3 Currently Available Blood Products for Massive Perioperative Hemorrhage

Therapeutic agents generally considered for massive perioperative hemorrhage:

- RBCs
- Fibrinogen
- Fresh frozen plasma (FFP)
- Cryoprecipitate
- Albumin
- Prothrombin complex concentrates
- Recombinant factor VII

Packed Red Blood Cells (RBCs)

For many decades, the decision to transfuse RBCs has been based upon the "10/30 rule" that means transfusion was used to maintain a blood hemoglobin concentration above 10 g/dl (100 g/L) and a hematocrit above 30% [41]. These guidelines were revised by the National Institutes of Health Consensus Conference in 1988 and many times afterward. Basically, there is no universally accepted single criterion for RBC transfusion. It varies with patient's clinical status and oxygen delivery needs and from institution to institution.

Oxygen delivery = cardiac output × arterial oxygen content

In healthy subjects, oxygen delivery is increased by increasing cardiac output, but in critically ill patients, oxygen delivery becomes more dependent on arterial oxygen content [42]. So, the higher hematocrit, the more oxygen will be delivered to tissues. Following is the blood transfusion guidelines for hemodynamically stable patients without active bleeding (Table 10.7).

For patients with massive bleeding or hemodynamically unstable, blood transfusion should be guided by the ability to achieve hemostasis and the rate of bleeding, rather than by the hemoglobin level alone. Therefore, the decision of transfusion

Table 10.7 Blood transfusion guidelines [41]

Hemoglobin Level	Comments
<6 g/dl	Transfusion recommended except in exceptional circumstances
6–7 g/dl	Transfusion generally likely to be indicated
7–8 g/dl	Transfusion may be appropriate in patients undergoing orthopedic surgery or cardiac surgery
8–10 g/dl	Transfusion generally not indicated but should be considered for some populations such as those with symptomatic anemia, ongoing bleeding, acute coronary syndrome with ischemia, and hematology/oncology patients with severe thrombocytopenia who are at risk of bleeding
>10 g/dl	Transfusion generally not indicated except in exceptional circumstances

in acutely hemorrhaging patients cannot rely on thresholds. Another concern is whether administration of fresher blood improves clinical outcome or not. One study demonstrated that fresher blood did not improve clinical outcomes as compared to stored standard-issue blood [43]. Without any doubt, RBC transfusion during surgical hemorrhage can potentially improve outcome and even be lifesaving in bleeding patients. However, it is challenging we may not be able to completely delineate the relative contributions of hemodynamic instability, systemic inflammatory reaction, and the transfusion-related side effects to the adverse clinical outcomes associated with surgical blood loss [44].

Fibrinogen

Fibrinogen provides a matrix and mesh network essential for clot strength, thus an important therapeutic product for bleeding control in perioperative settings. Following massive hemorrhage, hypofibrinogenemia occurs because of hemodilution from volume replacement and consumption by clotformation. So, the clot strength is evaluated by thromboelastography, and fibrinogen is administered along with other clotting factors to control perioperative bleeding [45]. Four fibrinogen precipitates are currently available and used all over. It is important to note that high fibrinogen levels can lead to high thrombin generation and ultimately thromboembolic events. Also of note, fibrinogen concentrate must be reconstituted by adding water and agitating for several minutes and has a somewhat limited shelf-life. To raise the serum fibrinogen level by of 1 g/L, 60 mg/kg of fibrinogen administration is required [46] (Table 10.8).

Table 10.8 Suggested bleeding management with focus on fibrinogen repletion strategy [46]

Suggested bleeding management with focus on fibrinogen repletion strategy		
1	Fibrinogen level is <1.5–2 g/l	Fibrinogen concentrates 25–50 mg/l Cryoprecipitate 8–10 units
2	Platelets are <100,000/mm	Platelet concentrate 8–10 units
3	INR >1.7 OR hypovolemia	FFP 20–30 ml/kg

Plasma

Plasma is extensively transfused in surgical and trauma patients, but research shows there is no benefit for most of the clinical conditions except trauma [47]. Some studies showed that the risks of excessive plasma transfusion might outweigh the benefits, hence proving to be harmful [48]. Plasma has three different preparations as illustrated in ▶ Box 10.4.

FFP contains all the components in donor plasma, including albumin and immunoglobulins and procoagulant, anticoagulant, and antifibrinolytic factors. If thawed, FFP is kept at 1–6 °C for 5 days, and such plasma can be used in acute emergencies for massive transfusion. There are some safety concerns as well with this FFP use: first being the transfer of viral infection that can be reduced in the future with use of viral-free plasma products [49] and second being fluid overload and multiple organ failures because a large volume of FFP is required to meet required serum coagulation factors level [50]. It should be kept in mind that these plasma preparations are never a good source of fibrinogen as fibrinogen concentration can vary 1–3 g/l. A large volume of plasma is required to replenish required fibrinogen level that can lead to volume overload instead [51]. The ideal choice for fibrinogen replacement is fibrinogen precipitate or cryoprecipitate.

Cryoprecipitate

Cryoprecipitate contains factor VIII, fibrinogen, fibronectin, von Willebrand factor (vWF), and factor XIII used widely for congenital and acquired coagulopathies. In 2007, the first version of the European guidelines on the management of bleeding after major trauma recommended treatment with fibrinogen concentrate or cryoprecipitate if significant bleeding is accompanied by a plasma fibrinogen level <1 g/L; updates to these guidelines were in 2010 [52]. Generally, 1 unit of cryoprecipitate per 10 kg of body weight will increase the fibrinogen level by about 0.5 g/L. The target threshold of 1.0 g/L has been pushed up to 1.5 g/L in many

Box 10.4 Types of Plasma Preparations

Different plasma preparations
- Fresh frozen plasma (FFP)
- Plasma frozen within 24 h of collection
- Thawed plasma (used within 5 days of initial thaw)

institutions (2.5 g/L in obstetric hemorrhage) [53]. The following are indicationsfor three recommendations of cryoprecipitate use: congenital fibrinogen deficiency, bleeding patients with von Willebrand's disease, and the correction of microvascular bleeding in massively transfused patients with fibrinogen concentrations less than 80–100 mg/dl [54, 55]. In a randomized controlled trial, efficacy of FFP infusion was compared with cryoprecipitate supplement; the result suggested FFP were more efficacious, and FFP produced a significantly greater improvement in INR and activated partial thromboplastin time (aPPT) and resulted in less exposure to blood products than cryoprecipitate [56].

Albumin

During surgery, circulation is usually supported by crystalloids or colloid as a temporizing measure when there is an impending need for blood transfusion. Colloids such as albumin and hydroxylethyl starch (HES) are advantageous since they may remain in the intravascular compartment longer than crystalloid [57]. A meta-analysis found increased perioperative bleeding and need for transfusion with the use of albumin compared to administration of hydroxyethyl starch. Albumin may reduce the platelets activation and release of inflammatory mediators. Another randomized controlled trial compared the effect of albumin administration and Ringers' lactate (LR) during a major surgery and found similar blood loss in the two groups of patients yet increased need for transfusion of blood in the albumin-treated group [58]. A randomized clinical trial studied the impact of albumin on coagulation competence and hemorrhage during a major surgery. Resultsshowed that the perioperative use of 5% albumin compared to LR to support the circulation during cystectomy reduces the postoperative volume surplus but affects coagulation competence and has no impact on postoperative complications or hospital stay [59].

Prothrombin Complex Concentrates (PCC)

Prothrombin complex concentrate (PCC) is a term to describe pharmacological products that contain lyophilized, human plasma-derived vitamin K-dependent factors II, II, X, and X and various amounts of proteins C and S. PCC is administered at bedside irrespective of blood group and usually given to patients using oral anticoagulants [61]. It is also effective for warfarin reversal or deficiency of vitamin K in patients requiring urgent surgery, i.e., within 6 h. Generally, it is not recommended for massive transfusion and coagulopathy associated with liver dysfunction. Patients with heparin-induced thrombocytopenia (HIT) are the absolute contraindication [62]. FDA has approved PCC use only in warfarin-related bleeding because only vitamin K-dependent factors are affected in it, while perioperative coagulopathy involves deficiency of multiple coagulation defects like thrombocytopenia, hypofibrinogenemia, and hyper-fibrinolysis [63]. There is a risk of thromboembolic events with use of these PCC as well, first reported many years ago. In 1990s many activated factors were removed from PCC to improve its safety. In today's PCC, factor II called prothrombin is identified as the main culprit causing thrombogenicity. That's why it is recommended that PCC should be labelled according to prothrombin content as compare to Factor IX [63]. Three retrospective clinical studies have shown that although PCC alone can attenuate bleeding, it is more effective when used combined with FFP [45, 64]. In another study in a rabbit model of hemostasis, four-factor prothrombin complex concentrate administration significantly decreased edoxaban (oral anticoagulant)-associated hemorrhage, and edoxaban-induced factor Xa inhibition and anticoagulant effect have been shown to be similar in rabbits and humans [64].

Recombinant Factor VIIa

Recombinant activated factor VIIa is approved in Europe for the management of hemophilia A or B with inhibitors, acquired hemophilia, inherited factor VII deficiency, and Glanzmann thrombasthenia with antibodies to glycoprotein IIb/IIIa and/or human leucocyte antigens and refractoriness to platelet transfusion. It is also recommended in massive perioperative hemorrhage in those patients who do not have already existing coagulopathy. It is effective in reversing the coagulopathy but is associated with widespread arterial thrombosis too. So, recombinantfactor VIIa is not the priority until the last option [64].

10.5.2 Massive Blood Transfusion Protocol

While most institutions have developed their own massive transfusion protocol (MTP) involving multidisciplinary committee, the common

theme of all such protocols is determining specific triggers for activation of MTP, transfusion end targets, and the logistics of blood product and adjunct availability [65]. A sample MTP is shown in ► Box 10.5.

Generally, MTP is activated after replacement of total blood volume in 24 h needing ≥10 units of packed RBCs, replacement of >4 units of packed RBCs in 1 h with the anticipation of continuous need for blood products, or replacement of 50% of the total blood volume within 3 h and blood loss of up to 1.5 ml/kg/min for more than 20 min. In children, this is activated after transfusion of 4–10 units [68]. MTPs may have a predefined ratio of RBCs, FFP/cryoprecipitate, and platelet units in each pack (e.g., 1:1:1 or 2:1:1 ratio) for transfusion [69]. It is recommended to use the following MTP checklist.

Box 10.5 Sample Massive Transfusion Protocol from the National Blood Authority [66, 67]

Massive transfusion protocol (MTP) checklist:

- Is raising the patient's legs possible? (Avoid head-up position.)
- Inform transfusion medicine doctor "on call" that the MTP has been activated.
- Call for help (e.g., anesthesia clinical assistant [ACA] or second anesthesiologist), or assign a nurse or ACA to check blood products and do charting.
- Start arterial catheter after large-bore intravenous access has been established at two sites (14–16G peripheral intravenous lines preferred; consider large-bore sheath introducer or dialysis-type catheter).
- Is cell salvaging an option? Call the perfusionist "on call."
- Send baseline blood work (type and screen, CBC, INR, fibrinogen, electrolytes/biochemistry).
- Has systemic anticoagulation been reversed?
- Is salvage surgery (i.e., packing and revisiting later) an option?
- Ask the surgeon: "Should we call a vascular surgeon or other assistance for you?"
- Fluid/blood warmer (rapid infuser set up?).
- Forced air heater or other warming device (if <37 °C).
- Should calcium administration be considered?
- Consider intravenous tranexamic acid (15–30 mg·kg^{-1}).
- Consider NaHCO3 or THAM for a pH <7.2.
- Change blood filter every four transfusions if possible (and change the 3-L reservoir every 4 h).

MTP can lead to some complications such as acid-base disturbances, electrolyte abnormalities, and hypothermia, in addition to acute trauma coagulopathy, which are reviewed in the table below.

10.5.2.1 Temperature

Hypothermia is associated with significant coagulopathy. Hypothermia is defined as 35 °C or below since enzyme denaturalization occurs at this temperature [70]. The following are the effects of low temperature on coagulation, as shown in ► Box 10.6.

10.5.2.2 Patient Positioning

Performing a straight leg raise or exaggerated lithotomy position has been shown to increase cardiac output and to increase coronary and cerebral perfusion pressure, respectively, for between 5 and 10 min. In case of sudden severe blood loss when leg raising or exaggerated lithotomy position is not possible, then 5 degrees of Trendelenburg position or keeping the patient in a level position is recommended [71].

10.5.2.3 Acid-Base Balance

Maintenance of acid-base balance is critical in massive perioperative hemorrhage. In trauma patients, acidosis is usually induced by tissue hypoperfusion leading to anaerobic respiration and lactic acid production. This metabolic acidosis impairs almost all components of coagulation. At pH <7.4, platelets change their shape and structure. Impaired thrombin generation due to reduced activity of coagulation factor complexes on the cell surface is a major cause of coagulopathic bleeding. Furthermore, acidosis leads to increased degradation of fibrinogen which further aggravates the coagulopathy. Therefore, maintaining a delicate acid-base balance in a massive perioperative hemorrhage is mandatory for the anesthesiologists.

Box 10.6 Effects of Hypothermia on Coagulation [66]

- Increase in fibrinolysis
- Reduced synthesis of coagulation factors
- Activation of clotting cascade is slowed down
- Direct inhibition of platelets through sequestration

10.5.2.4 Damage Control Resuscitation

This concept was first proposed in the mid-2000s as an alternative approach to manage the hemorrhagic shock. Damage control resuscitation components are shown in ► Box 10.7 [72, 73].

10.5.2.5 Other Non-pharmacologic Management

Other non-pharmacologic measures are outlined in ► Box 10.8.

1. *Piggyback technique*: Instead of two end-to-end anastomoses in the classic technique, piggyback involves anastomosing the donor retrohepatic vena cava directly to the recipient inferior vena cava to help patient better tolerate the hypovolemic state [74].
2. *Low CVP level*: A CVP of less than 5 mmHg is required to reduce intraoperative bleeding. However, there are the risks associated with maintaining a low CVP including cardiovascular instability and air embolism [75].
3. *Intraoperative blood salvage technique*: Autologous blood transfusion and intraoperative blood salvage are useful techniques for the special patient population like Jehovah's Witnesses and patients with rare blood types, undergoing surgery with high risk of intraoperative blood loss and transfusion. Cell salvage may be used in obstetric, cardiac, vascular, orthopedic, pediatric, and oncologic surgeries. Cell salvage with the use of leukocyte-depleting filters removes nearly all cancer cells. Randomized trials suggest that the use of intraoperative cell salvage (ICS) with LDFs results in no difference in long-term survival or tumor recurrence. Nevertheless, the use of cell salvage techniques in cancer surgery remains controversial [76].
4. *Intraoperative normovolemic hemodilution*: In this technique, whole blood is withdrawn from a patient by venesection and is replaced by other isotonic fluids. This blood is then re-transfused intraoperatively and postoperatively as required. This preserves the integrity of RBCs and clotting factors [74].

Box 10.7 Components of Damage Control Resuscitation

- Rapid control of surgical bleeding
- Early and increased use of red blood cells, plasma, and platelets in a 1:1:1 ratio
- Hypotensive resuscitation strategies
- Prevention and treatment of hypothermia, hypocalcemia, and acidosis
- Limitation of excessive crystalloid use

Box 10.8 Other Non-pharmacologic Measures

- Piggyback technique
- Low central venous pressure
- Intraoperative cell salvage
- Intraoperative normovolemic hemodilution

10.5.3 Pharmacologic Management

1. *Desmopressin*: Desmopressin enhances platelet activation and thrombus formation and thus restores hemostasis perioperatively. It does not change whole blood thromboelasticity and coagulation times. Adverse effects may include transient hypotension or tachycardia due to endothelial release of nitric oxide potentially induced by desmopressin [77].
2. *Tranexamic acid*: The use of tranexamic acid in massive postpartum hemorrhage seems to be promising. A randomized, multicenter clinical trial enrolled 20,000 obstetric patients and showed that tranexamic acid reduces death due to bleeding in women with postpartum hemorrhage with no adverse effects. Tranexamic acid should be given as soon as the onset of bleeding to achieve the maximal benefits. Patients in tranexamic acid group were administered 1 g tranexamic acid intravenously, while patients in control group received normal saline [78]. Another study was conducted in pediatric patients undergoing scoliosis surgery in 2005. The benefits of tranexamic acid in controlling perioperative bleeding were investigated. Intraoperative blood loss was 41% lower in patients receiving tranexamic acid (1230 +/− 535 ml) compared with the placebo group (2085 +/−1188 ml, $P < 0.01$) [79]. Tranexamic acid has also been documented to safely reduce the need for blood transfusion in surgery

and improve important health and economic implications in high-, middle-, and low-income countries [80].

3. *ε-Aminocaproic acid*: Meta-analysis of placebo-controlled randomized clinical trials indicate that ε-aminocaproic acid administered before and/or during a procedure is effective in reducing total blood loss and the total number of patients transfused in major orthopedic, cardiac, or liver surgery. Aminocaproic acid administration also lowers the requirement of blood transfusion perioperatively as demonstrated by randomized clinical trials in knee replacement surgery [81]. The 2015 American Society of Anesthesiologists' (ASA) guidelines on perioperative blood loss management suggest the intraoperative antifibrinolytic therapy in the perioperative setting to decrease blood loss and blood product transfusions in major cardiac, liver, and orthopedic surgery [82]. The dosing of ε-aminocaproic acid varies considerably in the literature; commonly reported is a loading dose ranging from 25 to 150 mg/kg followed by a maintenance dose of 12.5 mg–30 mg/kg/h [83]. Side effects include seizures and renal dysfunction. Being a structural analogue of neurotransmitter: GABA, ε-aminocaproic acid has lower seizure complications as compared to tranexamic acid [84].
4. *Aprotinin*: It is a small peptide extracted from bovine tissues which belongs to the SERPINS family. It can neutralize a variety of peptides like trypsin, plasmin, and tissue and plasma kallikrein. Due to its antiplasmin activity obtained at low concentrations, aprotinin is often used as an antifibrinolytic agent perioperatively. Aprotinin also inhibits thrombin-induced platelet activation by unknown mechanisms. Aprotinin was discontinued due to potential increase in long-term mortality in coronary artery bypass surgery patients. There are ongoing investigations attempting to bring it back to clinical utilization in selective groups of patients.
5. *Vasopressors*: Certain vasopressors are of clinical benefits in reducing hemorrhage associated with liver transplantation. The use of low-dose vasopressin (0.04 U/min) infusion during the dissection phase of liver transplantation was associated with reduced blood loss when compared with control group in a retrospective nonrandomized study of 110 patients[85].

10.6 Conclusions

This chapter highlights a very important topic in the field of anesthesia practice. Managing the massive perioperative bleeding is a very challenging task, both for surgeons and anesthesiologists. We discussed the possible etiologies of massive perioperative hemorrhage including trauma, major cardiothoracic, spine surgery, liver transplantation, obstetric complications, and several congenital coagulation anomalies. Incidence and mortality of perioperative hemorrhage varies with different causes. The most common cause is major trauma. The clinical presentation of massive hemorrhage depends upon the severity and rate of blood loss. Amniotic fluid embolism-induced disseminated intravascular coagulation has a very high mortality rate that should be addressed very seriously by both obstetricians and anesthesiologists. Prothrombin time, activated partial prothrombin time, and international normalized ratio were the traditional laboratory tests used for diagnostic purposes for many decades, while TEG and ROTEX revolutionized the diagnostic techniques for hemostasis by providing results quickly and accurately, which helps clinical management of patient in massive hemorrhage tremendously. Serum electrolytes also provide very useful information which helps in management decisions. Treatment strategies can be non-pharmacological measures including massive blood and blood product transfusion, surgical hemostasis, and maintenance of normothermia and electrolyte and acid-base balance. And pharmacologic management includes desmopressin, antifibrinolytic agents, and some vasopressors.

10.7 Review Questions

? 1. What point-of-care techniques can you use to measure fibrinogen in the surgical bleeding patient?

? 2. What are the sensitive electrolyte alterations in massive perioperative hemorrhage in trauma?

3. What is the ideal transfusion option for patients already using oral anticoagulants?

4. What is the treatment of choice for dilutional coagulopathy?

5. What is the relationship between MELD score and blood transfusion in a patient of liver transplantation?

6. What is piggyback technique?

10.8 Answers

1. Thromboelastometry (ROTEM; TEM International, Munich, Germany) and thromboelastography (TEG; Haemonetics Corp., Braintree, MA) are increasingly used as point-of-care devices in perioperative settings.

2. Hypocalcemia and hypokalemia are two sensitive electrolytes disturbances seen in massive perioperative hemorrhage due to trauma.

3. Prothrombin complex concentrate (PCC) is the ideal transfusion option for patients already on warfarin therapy.

4. FFP transfusion 30 ml/kg is the treatment of choice for dilutional coagulopathy and in massive transfusion scenarios.

5. High MELD scores (>30) was found to be significantly associated with increased bleeding and transfusion requirements compared to patients with low MELD scores (<30).

6. Piggyback technique involves anastomosing the donor retrohepatic vena cava directly to the recipient inferior vena cava to make patient better tolerate the hypovolemic state in liver transplantation.

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Cardiovascular System Damaging Events

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_11

11.1 Complications, Cardiac Arrest, and Local Anesthetic Toxicity

All surgical procedures performed with the use of anesthesia carry a certain amount of risk, regardless of the anesthetic technique used. Of course, it must also be recognized that an attempt to perform almost any surgical procedure without prior administration of anesthesia would carry even greater risks, and very few (if any) humans would agree to have a surgical procedure performed upon themselves without administration of anesthesia. In particular, the risks of major cardiac events occurring in the perioperative period are quite common; however these risks can be mitigated or even prevented if appropriate perioperative care is performed.

Prior to any surgical procedure requiring administration of anesthetic agents, a thorough preoperative history and physical are necessary to evaluate risk of adverse cardiac (or other) events and to obtain medically indicated tests prior to the procedure. This evaluation of the patient's history and review of indicated laboratory or other preoperative tests are done to reduce, or eliminate, the patient's risks. This applies especially when the patient comes to surgery with a consideration of baseline cardiac risks. Considering that patient safety is of paramount importance, a detailed anesthetic plan may then be formulated so as to reduce the chances of an untoward event occurring in the perioperative period.

This chapter deals with the identification and management of the major types of adverse cardiac events that may occur in the perioperative period and includes strategies to reduce the chance for them to occur. It is intended to also provide the reader with information that pertains to an anesthetic plan which reduces the risk of such events.

11.2 Hypertension

11.2.1 Preoperative Hypertension

Preoperative evaluation of patients begins with a detailed history and physical. The patient should be questioned about whether or not the underlying medical conditions are well controlled, the patient's current medication regimen, and the patient's compliance to the medication regimen. A pre-procedure review of the patient's medication regimen is vital since chronically, hypertensive patients generally tend to be on a strict regimen of medications. It is imperative that the clinician be aware of the medications which need to be continued in the perioperative period. Most antihypertensive medications are continued in the preoperative period except angiotensin-converting enzyme inhibitors (ACEI). These medications need to be held pre-procedurally on the morning of the surgery, as their use is associated with intraoperative hypotension [4].

Beta-blockers (β-blockers) are commonly a mainstay of therapies for patients with a history of congestive heart failure and myocardial infarction. The 2008 POISE study of 8351 patients from 190 hospitals across 23 countries "with, or at risk of, atherosclerotic disease" examined a composite of cardiovascular death, nonfatal myocardial infarction, and nonfatal cardiac arrest in patients newly started on extended-release metoprolol succinate in the immediate perioperative period. Of note however, patients were excluded from the POISE study if they had already been receiving beta-blocker therapy or had a prior adverse reaction to therapy with beta-blocking drugs or had any other contraindication to their use. This study included only patients started on metoprolol within 2–4 h prior to the surgical procedure or within 6 h after completion of the surgical procedure. While this study found greater than 80% of patients in both the study and control groups had atherosclerotic cardiovascular disease, fewer patients in the study group experienced nonfatal myocardial infarctions, and this difference became obvious within a few days following surgery. This study found both risks and benefits associated with perioperative initiation of beta-blocker therapy. While the metoprolol group had fewer nonfatal myocardial infarctions, there were actually more cardiovascular and non-cardiovascular deaths, nonfatal cardiac arrests, fatal and nonfatal strokes, congestive heart failure, clinically significant hypotension, and clinically significant bradycardia in the group of surgical patients newly treated with metoprolol in the perioperative period for this study [3].

A report from the American College of Cardiology/American Heart Association Task Force on Practice Guidelines, published in 2014 in *Circulation*, further examined this study and others, then came to the conclusion that periopera-

tive beta blockade started within 1 day or less before non-cardiac surgery prevents nonfatal MI but increases the risk of stroke, death, hypotension, and bradycardia. This report also stated that there was insufficient data to determine risks or benefits if beta-blocker therapy was started 2 or more days prior to surgery. This seemed to highlight the benefit of *continuing* beta-blockers in the perioperative period in those patients who have chronically used beta-blockers, as their use was shown to reduce the incidence of perioperative MI and stroke [8]. Conversely, it discouraged *initiation* of beta-blocker treatment in the perioperative period as this appears to increase the risk for perioperative hypotension, MI, and stroke [3, 8]

There is also a need to determine whether hypertension associated with tachycardia is due to a secondary cause such as anemia or renal failure. This is important because it may warrant obtaining tests such as a complete blood count and a complete metabolic panel to determine the severity of disease as well as to determine the baseline function of the patient [2].

Social history of the patient also contributes to preoperative evaluation concerns, as smoking, obesity, lack of exercise, and/or history of drug use are modifiable causes of hypertension. Controlling these factors preoperatively may also help in optimization of the patient [2].

Causes of elevated BP that should be ruled out in the perioperative setting include:

- Pain
- Anxiety
- Hypoxemia
- Hypervolemia

Patients with preoperative blood pressures of ≤180/110 mmHg may proceed with surgery (unless there is evidence of end-organ damage). Evidence of end-organ damage in patients with such blood pressures is defined as hypertensive emergency which mandates the need for medical management to prevent worsening of sequelae [2].

11.2.2 Intraoperative Hypertension

Intraoperative hypertension (IH) can be caused by increased sympathetic stimulation from tracheal intubation as well as response to pain. IH from tracheal intubation can be treated with lidocaine, fentanyl, and esmolol [5]. Increased sympathetic response to pain can be treated with intraoperative opioids as well as antihypertensive medications such as beta-blockers, nitrates, calcium channel blockers, and rapid-acting Angiotensin Converting Enzyme Inhibitors (ACEI) [5]. Nitroglycerin, nitroprusside, and milrinone can be used to control IH during cardiac surgery. Heart rate should also be considered when treating IH as an increased heart rate may increase myocardial oxygen demand in these patients and predispose to ischemia [5].

11.2.3 Postoperative Hypertension

Common causes of postoperative hypertension are pain, hypercarbia, hypoxemia, and emergence from general anesthesia. Patients should be monitored in the PACU to ensure all vital signs return to within normal limits [5]. Postoperative Hypertension can be treated with beta-blockers, α2-agonists and also clevidipine; the ideal regimen should be rapid acting, inexpensive, safe, and convenient [5].

If treatment of reversible causes of hypertension, as well as antihypertensive administration, do not lower the blood pressure to an acceptable blood pressure, the patient should be admitted to inpatient unit or ICU ward for further monitoring [5].

11.3 Hypotension

11.3.1 Preoperative Assessment

Since many factors contribute to baseline blood pressure for any individual, positional changes, medical comorbidities, and potentially a host of other factors influence an individual's blood pressure. Changes from baseline should lead one to assess the patient for causes of hypotension. As mentioned before, ACEI should be discontinued prior to the procedure to prevent intraoperative hypotension.

11.3.2 History and Physical Examination

A thorough history and physical exam prior to any procedure is key. Prior to the procedure, the patients may not have had any fluid intake for approximately 8 h; this predisposes the patient to intravascular volume depletion [2]. This is felt to

be a common cause of preoperative hypotension and exacerbation of hypotension at the moment of anesthesia induction. Although currently there is no clinically useful method to reliably and accurately determine a patient's intravascular volume, a reliable method to make this determination is needed. Currently the best estimate of preoperative intravascular fluid depletion is achieved by considering the fluid deficit from duration of NPO status, based on the patient's body mass, added to recognized sensible losses related to acute preoperative blood loss, emesis, diuresis, and diarrhea [2].

11.3.3 Intraoperative Hypotension

11.3.3.1 Etiology

Intraoperative hypotension (IOH) appears to be a common phenomenon, but an exact definition of specific parameters to diagnose intraoperative hypotension is somewhat elusive. Rather than a specific systolic, mean, or diastolic blood pressure value as a clear definition of intraoperative hypotension, general consensus is that a decrease in systolic blood pressure greater than 20% below the individual patient's baseline value is often chosen to define perioperative hypotension. Although the incidence of postoperative stroke appears to be uncommon and is felt to be primarily due to an embolic phenomenon, there is some evidence that the duration of hypotension during a surgical procedure influences the risk of a postoperative finding of an ischemic stroke [1]. In a case-controlled study within a retrospective cohort of 48,241 patients undergoing general anesthesia, Bijker et al. found evidence suggesting that the duration of intraoperative hypotension, defined as changes up to a 30% reduction in a patient's mean arterial blood pressure from baseline values, correlated with increasingly greater risks of postoperative stroke within the first 24 h up till 10 days later in patients undergoing non-cardiovascular, non-neurologic surgery [1].

Procedures of longer duration may lead to increased fluid losses resulting in IOH unless appropriate fluid resuscitation is performed. If IOH persists, it can disturb organ perfusion and lead to ischemic damage to end organs. Even short episodes of intraoperative hypotension with mean arterial pressure <55 mmHg are associated with increased risk of acute kidney injury and myocardial infarction following non-cardiac surgery [1, 5]. Studies have shown an association between short episodes of IOH (MAP < 55 mmHg) and perioperative myocardial infarction, acute kidney injury (AKI), and cerebrovascular accident (CVA) as well as a higher mortality rate in both cardiac and non-cardiac surgery [1, 6–8].

11.3.3.2 Treatment

Hypotension may be due to hypovolemia due to blood loss or inadequate fluid resuscitation and can be treated with a fluid bolus as well as common intraoperative vasopressors such as phenylephrine and ephedrine. The clinician must be wary of pneumothorax especially in patients undergoing laparoscopy as intraoperative pneumothorax can produce a sudden hypotension with asystole or pulseless electrical activity [2].

11.3.4 Postoperative Hypotension

11.3.4.1 Etiology

Mild postoperative hypotension is commonly observed in the post-anesthesia care unit (PACU) but usually does not require intensive treatment. Significant hypotension is often defined as a decrease of SBP of at least 20% below the individual patient's baseline and usually requires treatment [2]. Causes of significant postoperative hypotension are generally hypovolemia, left ventricular dysfunction, and arterial vasodilation (which is usually related to prolonged infusion of anesthetic agents); hypovolemia is by far the most common cause of hypotension in the post-anesthesia care unit [2, 5].

11.3.4.2 Hypovolemia

Hypovolemia can be divided into absolute hypovolemia or relative hypovolemia. Absolute hypovolemia may be due to fluid sequestration by tissues, wound drainage, or hemorrhage. Relative hypovolemia may occur due to vasodilatory effects from local anesthetics, venodilators, and alpha-adrenergic blockade. Hypotension may also occur from sepsis or from anaphylactic reactions to medications. In these situations, a combination of vasodilation and hypovolemia secondary to fluid loss is generally present [2].

Hypotension which occurs due to a tension pneumothorax or cardiac tamponade generally results from impairment of blood return to the

right heart. A new onset of left ventricular dysfunction in a previously healthy patient undergoing a surgical procedure is a less common cause of postoperative hypotension. When it does occur, it is generally seen in patients with underlying coronary artery disease, valvular heart disease, or congestive heart failure. This etiology of left ventricular dysfunction can be precipitated by fluid overload, myocardial ischemia, increases in afterload, and arrhythmias. Venous pooling of blood in peripheral tissues is a more likely etiology of a sudden onset of hypotension and reduced cardiac output [2].

11.3.4.3 Treatment

Mild hypotension is a common side effect following anesthesia administration, as many anesthetic agents produce vasodilation. Significant hypotension, defined as 20–30% reduction of blood pressure below the patient's baseline level, usually requires correction, and the treatment is based on the ability to assess intravascular volume [2]. A fluid bolus of 250–500 cc of crystalloid or a 100–250 cc bolus of a colloid may be used in most situations as a test of a hypovolemic etiology and also acts as a therapeutic maneuver concurrently. An increased blood pressure in response to this fluid administration generally confirms hypovolemia as the etiology. With severe hypotension, a vasopressor or inotrope may be necessary to increase arterial blood pressure until the intravascular volume deficit is corrected [2].

One must monitor for signs of cardiac dysfunction in patients with a history of heart disease or cardiac risk factors [2]. Failure of a patient to respond to initial measures attempting to correct hypovolemia should prompt evaluation of cardiac function via echocardiography or invasive monitoring. Manipulation of preload, cardiac contractility, and afterload may be necessary to correct the apparent hypovolemia in these patients [2].

When examination of the hypotensive postoperative patient also reveals unilateral breath sounds and tachycardia, the diagnosis of tension pneumothorax should be high on the list of differential diagnoses. Deviation of the trachea, away from the side of the tension pneumothorax, helps confirm the presence of a severe tension pneumothorax. If symptoms suggesting a tension pneumothorax are found, this should be treated rapidly and aggressively with immediate decompression via pleural aspiration and chest tube placement, even before radiographic confirmation. Severe hemodynamic compromise is likely to follow rapidly if a tension pneumothorax is left untreated while attempting to obtain confirmatory studies [2].

Previously, rapidly obtaining a chest X-ray to confirm or rule out pneumothorax was considered an important step in the management of this diagnosis. Currently, a rapid ultrasound exam of the thorax searching for the "lung sliding sign" is now recommended and can often be performed more quickly in the immediate postoperative setting. If found to be present, tension pneumothorax needs to be treated.

Another consideration for the hypotensive post-op patient is to search for Beck's triad (muffled heart sounds, increased jugular venous distention, and hypotension with increased pulse pressure) which suggests cardiac tamponade, especially in patients following chest trauma or those who are immediately post cardiothoracic procedure [2].

11.4 Sinus Tachycardia

During the preoperative period, sinus tachycardia might result from anxiety, pain, hypovolemia, or withdrawal of beta-blockers. Intraoperatively sinus tachycardia may be due to pain from surgical stimulation, light anesthesia, hypovolemia, hypotension, or administration of sympathomimetic agents. In the postoperative period, postsurgical pain or hypovolemia may cause sinus tachycardia [9, 11].

Depending on the cause, administration of opioids, crystalloids, or anesthetic agents might help relieve sinus tachycardia. If tachycardia is still persistent after the above measures, then administration of short-acting beta blocker like esmolol might help to reduce heart rate [10, 12].

Sinus tachycardia in patients with co-existing coronary artery disease might be detrimental since it will increase the oxygen demand/supply ratio within cardiac muscle. Hence it is crucial to maintain heart rate within normal limits in such patients.

If the tachycardia remains persistent, then a cardiologist should be consulted to evaluate the patient, especially to rule out underlying tachyarrhythmia that might progress to fatal arrhythmias.

11.5 Chest Pain (Angina, MI)

Patients with significant coronary heart disease may demonstrate ischemia of cardiac musculature which manifests clinically as chest pain or angina. Unless it is considered that the patient with symptoms consistent with angina or chest pain must go to surgery emergently, any patient with these symptoms should be first evaluated via a left heart catheterization by a cardiologist to check the extent of coronary lesions.

If it is an emergency surgery and the patient exhibits symptoms of ongoing angina, then administration of sublingual nitroglycerine is recommended to relieve the symptoms. During the surgical procedure, myocardial oxygen supply and demand ratio should be kept normal as possible. This may be achieved by keeping the heart rate and blood pressure as close to patient's preoperative baseline. During the intraoperative period, a continuous infusion of nitroglycerin may be started to decrease the preload as well as dilate the coronary vessels.

Intraoperatively, transesophageal echocardiography is useful to monitor cardiac wall motion abnormalities. If needed, infusions of inotropic agents and vasopressors such as epinephrine, norepinephrine, dobutamine, milrinone, etc. may be initiated to support cardiac function. Placement of a central line is often useful to deliver these inotropic agents and vasopressors. Placement of a pulmonary artery catheter might also be necessary to monitor pulmonary artery pressures.

Postoperatively the patient should be admitted to a cardiac ICU for recovery [9, 10].

11.6 Cardiac Arrest

Cardiac arrest during the perioperative period may result from various causes. Hypoxia, hypovolemia, hypothermia, hypokalemia, hyperkalemia, acidosis, tension pneumothorax, cardiac tamponade, pulmonary thrombosis, or coronary thrombosis are often the etiology.

An absolute or relative hypovolemia may result from acute surgical blood loss, but may also occur during induction with anesthetic agents due to the sudden onset of vasodilation effects upon administration of these medications. Hyperkalemia from succinylcholine administration may also be a cause for myocardial dysfunction. Acidosis may occur secondary to sepsis, bowel infarction, or other etiologies.

Tension pneumothorax may result from a spontaneous rupture of emphysematous bullae or from an iatrogenic etiology during placement of a subclavian vein catheter. The risk of a vascular air embolus, resulting in sudden, otherwise unexplained, cardiac collapse, is also present while placing a central venous catheter.

Embolic phenomena may also be the etiology of sudden cardiac arrest. Pulmonary emboli may result from a pre-existing deep vein thrombosis. Coronary thrombosis may result from a sudden dislodgement of an atherosclerotic plaque.

Standard CPR guidelines should be followed while resuscitating a patient with cardiac arrest. Any reversible causes such as hypoxia, hypothermia, hyperkalemia, hypotension, acidosis, tension pneumothorax, or cardiac tamponade should be corrected immediately in the operating room. Treatment of pulmonary emboli includes embolectomy, fibrinolytic therapy, or anticoagulant therapy. Treatment of coronary thrombus includes angioplasty, stent placement, or emergency coronary bypass surgery [11, 13].

11.7 Local Anesthesia, Cardiotoxicity, and Other Comorbidities

Some degree of temporary cardiovascular depression and some mild decrease in blood pressure are expected to occur each day, as the heart rate slows when a person goes into the state of natural sleep. Likewise, in anesthesia practice, some degree of cardiac depression is expected to occur from the use of anesthetic agents which provide progressively deeper states of sedation and general anesthesia. Additionally, some degree of cardiac depression may be pre-existing in a patient who presents for a surgical procedure due to cardiotoxicity from medications the patient is using prior to administration of any anesthetic agent.

The greatest concern of severe cardiac depression and cardiac toxicity from administration of an anesthetic agent (instead of just a mild sleep-related cardiovascular depression) is due to the inadvertent intravascular administration or absorption of bupivacaine. With proper administration, bupivacaine provides a long-lasting block

of sensory and motor nerves, as well as potentially blocking autonomic nerves in the area covered by the block when used in regional anesthesia. An inadvertent intravascular administration of bupivacaine usually results in severe, life-threatening cardiovascular complications and severe depression of the central nervous system which is often accompanied with transient seizure activity. Cardiovascular collapse from accidental intravascular injection of a regional anesthetic is a rare but often catastrophic complication. Why does this happen? How is it that anesthetics administered around a nerve or bundle of nerves provide desirable results, but if too much of the otherwise proper dose is administered intravascularly, toxicity rapidly occurs, and reversal of those effects is traditionally felt to be exceedingly difficult?

Administration of toxic doses of local anesthetics increases disruptions of cellular mechanisms, thus interfering with inotropic function, pathways that regulate Na^+, K^+, and Cl^- ion flow, modulation of the autonomic nervous system, and enzymatic processes for adenosine triphosphate formation. This mechanism is the desirable result when the drug is administered around a nerve bundle but undesirable when it affects the cardiovascular system. Standard, prolonged resuscitation efforts are not always successful in the event of local anesthetic cardiotoxicity. Traditionally, the cardiovascular collapse associated with an intravascular injection of bupivacaine was felt to be lethal in most cases, unless a large dose of heparin could be immediately administered for anticoagulation and the patient could be connected to a cardiac bypass circuit and pump for a few hours to allow the intravascularly injected bupivacaine to be metabolized and eliminated from the body.

Although different amounts of bupivacaine, levobupivacaine, and ropivacaine can be administered intravascularly before cardiovascular toxicity results, all are potentially lethal with accidental overdose. Likewise, even "safer" local anesthetics with a shorter duration of action, such as lidocaine or procaine, also may affect the cardiac conduction system if administered in large enough intravenous doses, especially if rapidly administered. In fact, these short-acting local anesthetics are intentionally administered intravascularly in some situations, such as to assist in management of arrhythmias. Local anesthetic agents all function by preventing the conduction of nerve impulses primarily by inhibition of voltage-gated Na^+ channels in nerve cell membranes. Their time to onset, duration of action, and adverse effects are all drug-specific, though they share similar characteristics [14, 15].

With the chance discovery that intravenous lipid emulsion administration may improve the chance of successful resuscitation, recommendations now include assuring that lipid emulsion is immediately available in every location where regional anesthetic administration occurs. Initially, recommendations were to have 500 cc of 20% lipid emulsion available whenever an injection was done for a regional anesthetic block. There have also been reports of successful initial resuscitation, but with the cardiac dysfunction returning within the following 60 min. More recent recommendations are that 1000 cc of this 20% lipid emulsion should be readily available, so that a repeated rapid administration may be done if needed.

As suggested at the beginning of this discussion, a patient presenting for surgery may already have some degree of cardiovascular depression as a "pre-existing condition" from other medical conditions such as a tumor either compressing vascular structures or secreting vasoactive compounds. Alternatively, that "pre-existing condition" may be from cardiovascular effects from other medications and treatments used in the management of those problems. Plans for anesthesia management in this situation include consideration of the direct effects of the tumor, toxic effects of the chemotherapy and radiation therapy, drug-drug interactions with chemotherapeutic agents, specifics of the surgical procedure, pain syndromes, and psychological status of the patient, especially if the patient is a child.

Cancer therapy agents, such as chemotherapies and cytotoxic drugs, may present uncommon but significant complications of cancer treatment. Radiation (X-ray) therapy to the chest may cause direct cardiac damage. This is found at a higher rate in children, especially when the child is younger at the time of diagnosis. The use of higher cumulative radiation doses, female gender, trisomy 21, and black race have all been associated with greater cardiac damage from radiation therapy in the child [16, 17].

Some of the most widely used and most successful anticancer drugs are doxorubicin and other anthracyclines. But it is well recognized that use of these drugs is associated with a cumulative, dose-dependent cardiotoxicity which may be expected to occur in >20% of patients treated

with them. Unfortunately, the pathogenesis is not completely elucidated. CHF (congestive heart failure) develops in a dose-dependent manner in patients treated with this class of drugs. The risks of CHF increase with higher cumulative doses, particularly when the cumulative dose exceeds 500 mg/m^2 in adults and 300 mg/m^2 in pediatric patients. The cardiotoxic effects of anthracyclines may be enhanced by other treatments, including radiation or trastuzumab (brand name Herceptin, among others). Anthracyclines may also lower the threshold for developing cardiac damage associated with aging or comorbid conditions, such as hypertension and diabetes mellitus.

Other classes of anticancer drugs that are also known to be associated with cardiotoxicity include fluorouracil, monoclonal antibodies, protein kinase inhibitors, and alkylating agents. Examples of many of these drugs include cyclophosphamide, ifosfamide, cisplatin, carmustine, busulfan, chlormethine, and mitomycin.

Fluorouracil (5-FU) toxicity may appear as underlying coronary artery disease or coronary artery spasm. The monoclonal antibody, trastuzumab, is known to potentiate cardiotoxicity when used concurrently or sequentially with an anthracycline. Severe CHF may develop in patients treated with Gleevec (imatinib mesylate), apparently related to mitochondrial damage in myocardial cells.

In addition to chemotherapeutic agents however, local anesthetics are not the only anesthesia agents that may cause cardiac problems. Essentially all inhalational anesthetics cause some degree of cardiovascular depression, which in most cases is transient and resolves shortly following completion of the anesthetic agent use. Ketamine however may present a different set of concerns, as the increased production of catecholamines associated with its use may cause oxidative damage to myocardium. Following administration of ketamine, experimental animals have demonstrated elevation of parameters associated with oxidative and myocardial damage. Despite this concern, ketamine has shown it is an important, and relatively safe anesthetic agent when used appropriately [16]. Administration of disulfiram, a drug with antioxidant properties, has been shown in rats to prevent elevation of parameters indicating oxidative and myocardial damage. Will this develop into a practical therapy for human use? The answer is not yet known [19, 20].

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Airway and Respiratory System Damaging Events

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_12

12.1 Introduction

Over the years, the practice of anesthesia continues to improve in both safety, efficacy, and quality; but there are certain airway and respiratory events that could lead to serious complications in the perioperative period. These complications can translate into excess healthcare costs in the form of patient morbidity and mortality, extended or unplanned hospitalizations, medication administration, etc. The goal of this chapter is to help the providers gain a better understanding of the airway and respiratory issues that can occur in the perioperative period so that the provider can identify the patients and/or procedures that are most at risk. Secondly, this chapter serves to highlight these airway and respiratory issues that can occur so that the provider may be more prepared to treat and in some cases prevent such complications from occurring. Airway and respiratory complications leading to litigation are a small proportion of all claims against anesthetists but are associated with notably high rates of death and brain damage, high rates of "less than appropriate care," and high costs [1]. Postoperative pulmonary complications are a major part of any surgery, and when compared to cardiac complications, there have been similar rates of morbidity and mortality and prolonged hospital stays [2]. Preoperative preparation should aim to prevent morbidity associated with these events, and intraoperative strategies could help lessen associated morbidity and mortality. Even though there is not a clear consensus on what constitutes a pulmonary complication, these adverse effects can hopefully be mitigated.

12.2 Airway Complications in PACU

The anesthesia recovery unit can be riddled with ventilatory issues and respiratory complications that include, but are not limited to, hypoxemia (hemoglobin oxygen concentrations less than 90%), hypoventilation (respiratory rate <8 breaths per minute or a partial pressure of CO2 > 50 mmHg), and airway obstruction (stridor, laryngospasm, bronchospasm). Providers may be required to intervene with noninvasive (BiPAP, oral and nasal airway) and invasive airways (endotracheal tube or supraglottic airway) and pharmacologic rescue (reversal for neuromuscular blockade and opioid/benzodiazepine antagonism) [3].

Hypoxemia in the PACU can present as altered mental status, tachypnea, dyspnea, and tachycardia. It may easily be confused as emergence delirium, agitation, "sundowning" seen mainly in the elderly, or even new-onset psychosis [4]. With prolonged hypoxemic duration and worsening respiratory distress, the patient's primary and secondary respiratory muscles fatigue. Due to the imbalance of myocardial oxygen consumption and demand, ischemia occurs, followed by arrhythmias and eventual respiratory and cardiac arrest [5].

On induction of general anesthesia, atelectasis develops rapidly in the majority of adult patients from pulmonary shunt [6], alveolar hypoventilation [7], and V/Q inequalities [8, 9]. Relaxation of the diaphragm allows abdominal pressures to be transferred into the thoracic cavity resulting in compression of the lung [10]. Alveolar hypoventilation results in hypercapnia from insufficient ventilation as a result of opioids, hypnotics, residual neuromuscular blockade, or metabolic disturbances [11]. V/Q mismatch results from changes in the thoracic rib cage dynamics [12] and rostral diaphragmatic movements [13, 14]. While these compile the majority of hypoxemic events in the PACU, it is, however, important to regard the nature of the surgery and its impact on ventilatory mechanics, vascular compression, and persistent action of anesthetic drugs [15]. Despite having received seemingly appropriate neuromuscular blockade reversal, patients may continue to exhibit persistent residual paralysis from short- and intermediate-acting neuromuscular blockade in the PACU [16].

Key to the management of PACU patients is a keen awareness of the surgical type. The largest known patient and/or procedure factor that contributes to respiratory complications postoperatively parallels the proximity of the surgery to the diaphragm [17]. The more approximate the incision site is in the diaphragm, the higher the risk of respiratory complications (see Table 12.1).

Treating hypoxemia in the PACU is generally done by providing supplemental oxygen. The goal of O2 therapy is to maintain partial pressure of oxygen (PaO2) of ≥60 mmHg which correlates to an oxygen saturation (SaO2) of 90% [18]. By titrating in careful quantities of FiO2, you can improve alveolar hypoventilation; however, if FiO2 gets too high, it may knock out hypoxic

Table 12.1 Risk factors for respiratory complication and level of evidence

Level of evidence	Patient related	Procedure related	Lab tests
Good	ASA class >/= 2	Thoracic surgery	Albumin level < 35 g/L
	Cardiac failure	Abdominal surgery	
	Advanced age	Upper abdominal surgery	
	Functional dependence	Head neck surgery	
	COPD	General anesthesia	
		Aortic aneurysm repair	
		Neurosurgery	
		Prolonged surgery	
		Vascular surgery	
		Emergency surgery	
Fair	Impaired sensorium	Perioperative transfusion	Chest radiography BUN > 7.5 mmol/L (>20mg/dL)
	Cigarette use		
	ETOH use		
	Weight loss		
	Abnormal findings on CXR		

pulmonary vasoconstriction and hypoxic ventilatory drive needed in patients that require an elevated partial pressure of CO2 (COPD) [18] and will increase dead space. While supplemental oxygen will ameliorate diffusion impairments and provide increased oxygen extraction, with V/Q mismatch, an elevation in the partial pressure of O2 (PaO2) can wash out alveolar nitrogen and can shift a lung area of low V/Q mismatch into a true shunt secondary to alveolar collapse [4]. Treatment for improving V/Q mismatch includes bronchodilators for COPD and asthma and PEEP for acute lung injury and pulmonary edema [4]. The application of noninvasive ventilation (NIV), like CPAP, can be used to recruit more alveoli from in those with hypoxemia from atelectasis. By providing positive pressure, the work of breathing decreases, and pulmonary compliance can improve [4]. However, NIV may be inappropriate for some patients, particularly those that are *status post* gastric or esophageal surgery [19]. Relative contraindications to NIV are those at high risk for aspiration, altered mental status, refractory hypoxemia, hemodynamic instability, and arrhythmias and those who cannot have a nasal or facial mask from head or neck surgeries [20]. Ultimately, careful consideration of hypoxic causes and oxygen delivery mechanisms needs to be weighed prior to providing appropriate oxygen therapy and titration in the PACU for hypoxemic patients.

12.3 Children

The highest incidence of morbidity and mortality has been proven to be the extremes of age [21, 22], and this section will focus on the lower extremes of age. In comparison to older children, it has also been agreed that incidence of adverse events is higher in infants [15, 21, 23–26]. Respiratory events occur with higher frequency in younger children particularly those involved with ENT surgery versus other surgical sites [27, 28]. The higher incidence is said to be from narrow infant airway anatomy and higher incidence of respiratory tract infections [29, 30] in younger children.

Of the adverse events, the most common are incidents related to the respiratory tract [23, 27, 31, 32]. Airway management in children can vary

greatly and include, but is not limited to, nasal cannula, mask ventilation, supraglottic airways, and endotracheal intubation. The risk of respiratory complications increases with intubation [27], particularly in those with new onset or recent upper respiratory tract infections [33]. Interestingly, the risk of perioperative respiratory events is lower when endotracheal intubation is done with neuromuscular relaxants; furthermore, this risk decreases 8% with each increasing year of age [28]. In recent years, muscle relaxants have been shied away due to the frequency of allergic reactions observed under general anesthesia [34].

Adverse events or respiratory complications include laryngospasm, which is total airway obstruction and usually unresponsive to maneuvers for soft tissue obstruction. Airway obstruction is thought to be associated with redundant, soft airway tissue where partial airway obstruction occurs (snoring) (Table 12.2). This can be relieved by providing jaw thrust, positive pressure, or oral airway. Bronchospasm is when the bronchial smooth muscle contracts erratically causing expiratory wheezing, hypercapnia, and oxygen desaturation. Often the capnography reading will have steeper slope, and there will be elevated peak airway pressures. Oxygen desaturation can be seen when the SpO2 dips below <95% [28].

Table 12.2 Factors identified as being predictive of respiratory complications/adverse events

Good evidence	Not supported
Age of child (<6 years old)	Asthma[a]
Respiratory infections	Bronchial hyperreactivity[b]
ENT surgery	Allergies
Tracheal intubation *without* muscle relaxant	Induction technique (IV vs inhalation)
Passive smoke exposure	Provider experience in intubating
LMA (more mechanical failure)	Patient's sex
Anesthetic care by *non-pediatric*-trained anesthesiologist (twice as likely if anesthesiologist is a resident)	Type of intubation (orotracheal or nasotracheal intubation)
	Cuffed endotracheal tube
	Duration of surgery

Refs. [28, 35, 36]
[a]Study included only children with controlled asthma
[b]Study included only children with no acute symptoms of bronchial hyperreactivity

Box 12.1 Cuffed Endotracheal Tube Benefits [44]

- Reliable, sealed airway requiring less tube exchanges
- Avoids repeat oral-airway manipulation by laryngoscopy
- Decreases fresh gas flows
- Constant minute ventilation
- Precise respiratory and capnography monitoring
- Prevention of aspiration
- Decreases OR pollution with volatile anesthetics and N20
- At cuffed pressure less than or equal to 20 cm H20, there is no increased incidence of postextubation stridor vs uncuffed ETT

Alarming postmortem studies showed 45% of intubated children who had died showed at least some degree of airway trauma [37]. The most common cause of laryngotracheal injury associated with intubation is using an endotracheal tube that is too large [38]. While the debate of cuffed versus uncuffed endotracheal tubes remains controversial, if a child is intubated for surgery, the literature shows that cuffed endotracheal tubes can and should be considered [39–43] (▶ Box 12.1).

12.4 Legal Issues

Despite years of systematic training, quality improvement initiatives, checklists, and equipment upgrades and enhancements, the truth is anesthesia and its procedures do not come without risks. While it may be impossible to attribute the actual numbers of adverse events caused by, or at least in part by, anesthesia, it is worthwhile to consider the implications of what providers do on a daily basis and how complications negatively impact patient lives and even cause irreparable harm. Despite suffering harm from complications, it is still a vast minority that point the litigious finger in filing a claim against anesthetic

providers. The other side of that coin indicates that the compensation rates, if those harmed actively pursued claims, could rise dramatically [45]. Although a small sample size in Denmark, Hove et al. showed that from 1996 to 2002, 374 patients were awarded in total eight million euros as financial compensation for harm caused by anesthetic procedures. Their study was remarkable in that only 0.2% of patients receiving anesthesia may develop complications that leads to financial compensation [46].

The most common adverse outcomes are related to medication errors [47, 48]; however, since most of errors are negligible and often times unreported, they are poorly represented in studies. According to the American Society of Anesthesia Closed Claims Project (ASACCP), adverse outcomes from respiratory events are the largest class of injury. In 1990 Caplan et al. determined that 34% of all claims were related to respiratory events and 85% involved in either death or permanent brain damage as severe outcomes, 76% demonstrated substandard care, and 72% were considered preventable with improved monitoring [49]. Additionally, they determined that most (72%) respiratory claims received a median payment of $200,000. Respiratory events were classified as inadequate ventilation (38%), esophageal intubation (18%), and difficult intubation (17%) [49]. Aspiration made up 3% and occurred mainly during induction prior to endotracheal intubation. Interestingly, half of the aspiration claims were during emergency surgery [49]. Interestingly, during 1 study of 222 claims, 35% of the medicolegal claims demonstrated that the providers had previously claims against them [50].

In 1990, the ASA Airway Task Force made recommendations, and Peterson et al. (2005) indicate a reduction in death and brain damage only upon induction (35% vs 62%) and not at other times [51]. Cheney et al. reported (1975–2000) a drop in respiratory claims and brain damage; however, the downward trend did not delineate a clear causality by improved monitoring [52, 53]. Perhaps new training or safety measures are responsible; however, since the advent of pulse oximetry and capnography, providers are able to detect cyanosis [54–56] earlier and esophageal intubation with reliability. Even though providing these additional monitors may provide some benefit to patient safety, closed claim research [57] grandstands that monitors are only as effective as the provider using them. Larson et al. (2009) cautioned that in 28% of their respiratory claims, pulse oximetry and/or capnography was not applied, observed, or interpreted correctly and resulted in catastrophic respiratory events [57].

We are akin to witness advancements in technology regarding anesthesia equipment, volatile anesthetics, enhanced monitoring techniques, provider training, patient safety education, surgical techniques, and perioperative risk and optimization assessments. While these may depreciate the risks with anesthesia, it is undoubtedly up to the provider to demonstrate constant and consistent vigilance, adherence to standard of care practices, and anticipation of issues and potential problems.

12.5 Risk Factors

There are numerous risk factors for airway and respiratory issues in the perioperative period. These risk factors can generally be broken down into three categories (Table 12.3). Due to the lack of uniform consensus on the definition of adverse respiratory events, there is not an absolute way to determine the frequency of adverse respiratory events in the perioperative period. Respiratory complications are more frequently seen in pediatric anesthesia cases. Studies have shown that children with an upper respiratory infection are more at risk of respiratory complications including but not limited to laryngospasm and bronchospasm during the procedure. For some of these cases, this could lead to the need for prolonged postoperative stay for monitoring, supplemental oxygen, and bronchodilation medications. The choice and airway management has also been shown to have an effect on the incidence of respiratory complications during the case. Bordet et al. looked at the rate of airway complications in pediatric patients comparing face mask, laryngeal mask airway (LMA), or tracheal intubation with a tube. They found that the incidence of airway issues was highest in those patients receiving LMA at 10.2% vs 4.7% for face mask and 7.4% for a tracheal tube. Airway issues in this study were defined as any laryngospasm, bronchospasm, laryngeal edema, aspiration, desaturation less than 90%, failure to intubate, air leak or ventilation problem, breath holding, and others. They

Table 12.3 Risk factors for adverse respiratory events in the operating room [59]

Surgical factors	Patient factors	Anesthesia factors
Emergency procedures Abrupt surgical stimulation ENT procedure Dental procedures Respiratory procedure Secretions in airway Blood in airway	Upper respiratory infection within the last 2 weeks Premature infants Young age Smoking exposure Current asthma and/or recurrent symptoms Nightly dry cough Eczema Sleep apnea Obesity Cystic fibrosis Allergies Respiratory sickness Airway malformations NPO violation	Inhalational induction Premedication with midazolam Use of desflurane for maintenance of anesthesia Administration of neuromuscular blocker Less experienced anesthesia personnel and postanesthesia care recovery staff High patient-to-staff ratio in the PACU Mixed population hospital (children and adults) Topical lidocaine on vocal cords

also revealed three independent risk factors for airway complications were presence of a respiratory infection, age less than 6 years old, and the use of LMA [1].

The type of surgery that patients are having also plays a role in the development of respiratory complications in the perioperative period. Prior studies have shown that the rate of pulmonary complications in abdominal surgeries can be as high as 30% [58]. Patients who undergo abdominal and thoracic surgery have been shown to have lower vital capacity and forced residual capacity postoperatively. These changes lead to ventilation-perfusion mismatches that can eventually result in hypoxemia. Laparoscopic surgeries have also been shown to reduce lung volumes and forced residual capacity by up to 50% which can also lead to ventilation-perfusion deficits that can cause hypoxia. It can take up to 2 weeks for these lung changes to return back to normal baseline values.

Anesthetic technique can have an impact on postoperative pulmonary function. There is no clear evidence for the use of one type of anesthetic technique over another in reducing the amount of perioperative pulmonary complications. There are certain effects that each anesthetic produces that can affect the pulmonary function of a patient. In general, regional anesthesia confers the benefit of allowing the patient to maintain spontaneous respiration without the need to instrument the airway. The sensation of pain can impair a patient's ability to take deep breaths and cough; this type of lung restriction could lead to atelectasis and in turn hypoxia. Studies suggest that there is a reduction in perioperative pulmonary complications in high-risk patient that receives epidural with local anesthetics, but the lack of consensus on definition of postoperative pulmonary complications makes it difficult to show any advantage [58].

General anesthesia generally has various effects on the pulmonary system that could cause a decline in pulmonary function. Premedication with benzodiazepines has not been shown to reduce the occurrence of laryngospasm or bronchospasm, and it is associated with a 1.8-fold increase in the overall incidence of perioperative respiratory adverse events [59]. Inhaled anesthetics decrease the tidal volume with spontaneous respiration, functional residual capacity decreases, and atelectasis can form in dependent portions of the lung leading to ventilation-perfusion mismatching. Even small concentrations of volatile anesthetics can blunt the ventilator response to hypoxia and hypercarbia by suppressing peripheral chemoreceptors; this could potentially lead to postoperative pulmonary complications as well. Neuromuscular blocking agents have been shown to produce cephalad displacement of the diaphragm leading to mechanical depression of the dependent parts of the lung causing atelectasis [60]. Neuromuscular blocking agents such as rocuronium can be used to decrease the incidence of laryngospasm at the time of endotracheal intubation, but the patients still tend to have a higher incidence of laryngospasm in the postoperative period [61, 62]. The general take home should be that neuromuscular blocking agents should be used in cases where muscle relaxation is neces-

sary. Studies seem to indicate that due to a decrease in the occurrence of adverse perioperative respiratory events, IV induction may be more desirable when compared to inhalational induction with volatile anesthetics [61, 63, 64].

Patient factors also play a role in the development of postoperative pulmonary complications. The knowledge of these factors beforehand can help the provider identify patients at high risk and lessen the incidence and effect of postoperative pulmonary complications. Patient risk factors that have a higher incidence of postoperative pulmonary complication include cigarette smoking, underlying chronic respiratory disease, emergency surgery, anesthetic time of 180 min or more, and advanced age [65].

Table 12.4 Stratification of obesity in adults [67]

Stratification of risks for adults based on body mass index (BMI)		
BMI	**Classification**	**Stratification of coexisting diseases**
Less than 18	Underweight	Low
18–25	Normal	Normal
Greater than 25	Overweight	Moderate to severely increased (increases with increasing BMI)

12.6 Obesity

The incidence of obesity in the United States and other developed nations is rapidly growing. Obesity is often defined as condition of abnormal or excessive accumulation of adipose tissue, to the extent health may be impaired [66]. Obese individuals not only differ in the amount of fat that they store, but they also differ in the regional distribution of fat within the body. It is the accumulations of abdominal adipose tissue that is the greatest risk factor for the development of disease versus the amount of adipose tissue present [67]. Body mass index (BMI) is what is generally used to classify the level of overweight and obesity. The definition of obesity varies somewhat, but it is generally defined as a body mass index greater than or equal to 30 mg/kg^2. Table 12.4 is generally what is used by the WHO to classify the level of overweight and obesity.

Obesity is increasing worldwide, and the reasons for the increasing incidence of obesity are multifold, but obesity presents certain challenges in the airway and respiratory system for patients undergoing anesthesia. The incidence of obesity is increasing worldwide necessitating the importance of recognizing the issues that obesity presents for the airway and respiratory system.

12.6.1 Airway Changes with Obesity

Although obesity is not a definitive risk factor for a difficult airway, it can present challenges in airway management. There are studies that have shown a significant yet weak correlation between BMI and the difficulty of a provider to obtain the airway. Failure in managing the airway is the most important cause of mortality in patients undergoing general anesthesia. About 50–75% of cardiac arrests during general anesthesia are because of difficult intubations [68]. The etiologies of difficult intubations vary and are related to the distribution of adipose tissue throughout the body including the airway. In addition to obese individuals seeming to have a more difficult airway, obesity also seems to be a risk factor for difficult mask ventilation. Kheterpal S et al. looked at the attempts of mask ventilation of over 22,000 patients and concluded that a BMI of 30 or more was an independent risk factor for the combination of difficult mask ventilation and difficult intubation [69]. Neck circumference has also been shown to correlate with BMI for both genders and has been used recently to classify individuals as overweight or obese [69]. Neck circumference correlates positively with changes in the systolic and diastolic pressure and other components of the metabolic syndrome and is considered as an index of upper body obesity [70] (Fig. 12.1) (Table 12.5).

12.6.2 Respiratory Changes with Obesity

Obesity causes marked changes on the respiratory system. Obesity affects many respiratory physiological parameters, including compliance, resistance, lung volumes, spirometric measures,

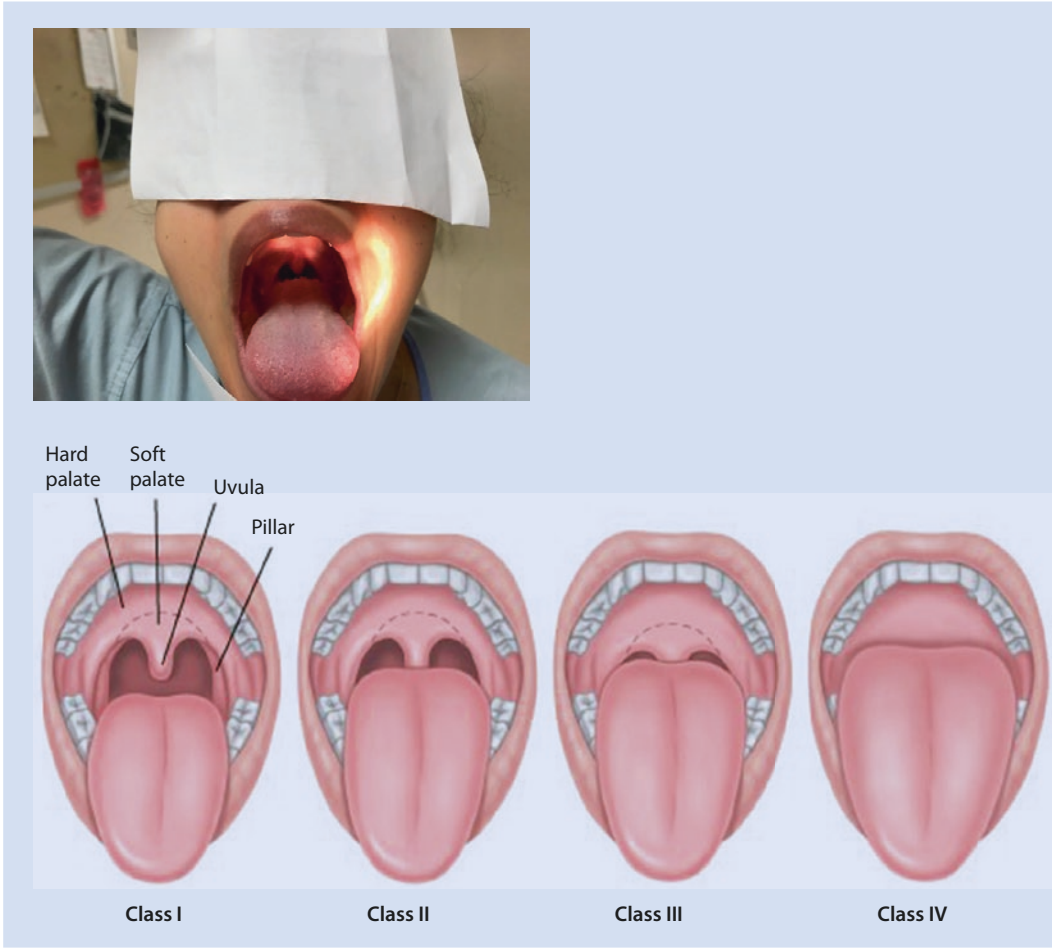

Fig. 12.1 Example of Mallampati class I airway

Table 12.5 Mallampati classification scoring system

Mallampati score	Structures visualized
Class I	Soft palate, hard palate, tonsillar pillars, full uvula, fauces
Class II	Soft palate, hard palate, full uvula, fauces
Class III	Soft palate, hard palate, base of uvula
Class IV	Hard palate

bronchial hyperreactivity, upper airway mechanical function, neuromuscular strength, diffusing capacity, and gas exchange. These, in turn, may affect the work of breathing, ventilatory drive, and exercise capacity and lead to sleep-breathing abnormalities [71]. Obesity, particularly severe central obesity, affects respiratory physiology both at rest and during exercise. Reductions in expiratory reserve volume, functional residual capacity, respiratory system compliance, and impaired respiratory system mechanics produce a restrictive ventilatory defect. The obese patient also has significantly increased oxygen consumption (VO2) and CO2 production (VCO2) and an impaired ventilatory system [72]. After being anesthetized and paralyzed, VO2 declined by 16% in obese individuals compared with <1% in lean individuals. Many factors may contribute to increased WOB in obese individuals, including impaired respiratory mechanics, upper airway mechanics, neuromuscular strength, gas exchange, neurohormonal influences, and

ventilatory drive [71]. The most common and consistent pulmonary function test abnormality seen in obese individuals is a reduction in functional residual capacity (FRC) and expiratory reserve volume [73]. Because breathing occurs at low FRC and in the less compliant portion of the pressure-volume curve, increased effort is needed to overcome respiratory system elasticity. Thus, obese individuals need to do more respiratory work to maintain appropriate levels of ventilation [72]. Many aspects of respiratory function worsen in the supine position and during sleep in obese subjects, especially during the rapid eye movement stage of sleep [74]. Sleep-disordered breathing is very common in the obese patient with obstructive sleep apnea (OSA) and obesity-related respiratory failure being more common [75]. It has been estimated that about 50% of patients with a BMI greater than 40 have symptoms of obstructive sleep apnea (OSA). Obstructive sleep apnea is defined as complete or partial closure of the upper airway which can result in hypercapnia, oxygen desaturation, and sleep fragmentation [76]. OSA is associated with a higher rate of postoperative respiratory failure, cardiac events, and ICU admission [77].

12.7 Airway Fires

Patients undergoing surgery are at risk for airway fires. In the past it was attributed mainly to flammable anesthetic agents, but currently airway fires are most likely associated with laser surgery and the use of electrocautery during head and neck surgeries. The incidence of operating room and airway fires has declined over the last century due to decreased use of flammable anesthetic agents and their replacement with less or nonflammable anesthetic agents. Approximately 700 fires are reported each year with more than 500 near misses or unreported cases. Despite the knowledge of risk factors and how to prevent fire, surgical fires continue to occur. Each year in US hospitals, about 650 cases are reported, according to the Food and Drug Administration with 3 to 4 times near misses and unreported events. In closed claim database, the cautery fires causing burns increased from 11% to 44% from 1994 to 2003; majority of them were attributed to airway and facial plastic surgeries. Although it is not a common complication to occur, it does have grave consequences. Prevention of such a rare but fatal complication is essential. Hence, a thorough knowledge of the predisposing risk factors, components, preventive measures, and management of airway fire is crucial for an anesthesia provider. Anesthesia providers have direct control over the method of administration and oxygen concentration. Communication between all the members involved in patient care is the key to successfully manage an airway fire [78].

12.8 Components

The three elements involved in airway fire or what constitutes the fire triad are the fuel, an oxidizing agent, and the ignition or the heat source. The fuel sources that have the ability to catch fire could be the endotracheal tubes, drapes, alcohol-based preps, dry sponges and swabs, gauze, gowns, foam padding, clothing, mattresses, plastic supplies, body hair, silicone or palliative airway stents, and vaporized adipose tissue. The oxidizing agents are oxygen, nitrous oxide, and air. The sources of heat or ignition may be laser, cautery, hot light bulb, fiber-optic light or cables, warming devices, frayed cords, high-speed burrs, static electricity, and defibrillators [79] (Fig. 12.2).

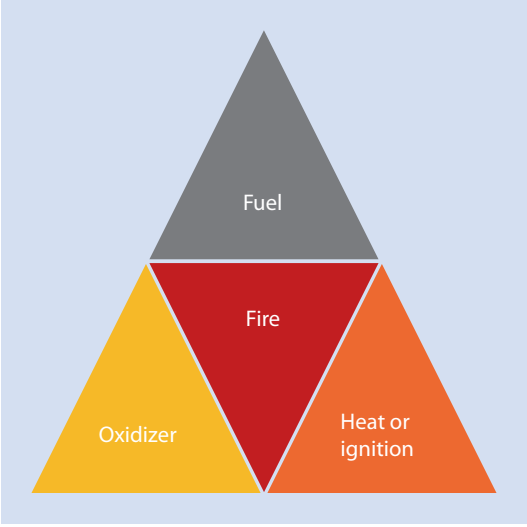

Fig. 12.2 Fire triad

12.9 Predisposing Risk Factors for Airway Fire

Some of the predisposing risk factors are the type of surgery, surgical site, use of ignition source, and need for use of oxidizing agents such oxygen supplementation during surgery.

The types of surgeries that pose the most risk for airway fires are head and neck surgeries or surgeries above T5 level, ENT procedures such as tonsillectomies, adenoidectomies, tracheostomies, skin or plastic surgeries, cataract or eye surgeries, burr hole surgeries, rigid bronchoscopies with airway stent placement, tracheal dilation and granulation tissue removal, and airway debulking procedures [78].

Electrosurgical units or cautery and lasers are frequently used to coagulate or cut tissue and in bipolar mode. The cutting mode of electrocautery is more hazardous as it generates more heat than the coagulation mode. The bipolar electrocautery or argon plasma coagulation used at low voltage with short burst period has the least risk of causing fire ignition and is recommended as a safer option. This poses a great risk during airway surgeries in an oxygen-rich environment. This kind of oxygen-rich environment may occur when the oxygen can leak around tracheal cuff or concentrate heavily under the drapes in an open source of oxygen such as nasal cannula or mask especially when higher concentrations of oxygen are used (>40%). Some of the ignition tests conducted on polyvinyl chloride ETT showed that even after moving the ETT away from the cautery still ignited the ETT whenever oxygen concentration was increased.

A mixture of oxygen and nitrous oxide is frequently used to ventilate and anesthetize patients, respectively. These highly combustible gases require a very low level of heat source to ignite. Also the oxygen-rich environment may lower the temperatures at which fuel sources such as drapes and endotracheal tube can catch fire easily than at room air. Tissue especially fatty tissue when heated by an ignition source may turn into gas and burn if mixed with high concentration of oxygen [79].

12.10 Preventive Measures

As with any potential hazard, awareness is the first step to prevention. Airway fires are significant risk in the OR, but with awareness and preventive measures, they can be easily avoided. ASA guidelines for prevention of operating room fires include proper education of all anesthesia providers for fire safety specifically for OR fires. Before each surgical case, the OR team should determine if a case is at high risk for surgical fires. If a high-risk situation exists, the team should decide on a plan and roles for preventing and managing a fire. Communication between nursing staff, anesthesiologist, and surgeon is critical.

Cuffed endotracheal tubes (ETTs) are strongly recommended as they are more advantageous over uncuffed ETTs. The ETT cuff may serve as a barrier and prevent leaking of oxygen from the trachea and accumulating around the operative site. It is very essential to check the integrity of cuff before use. ASA guidelines for laser procedures recommend that a laser-resistant tracheal tube should be used. The tracheal cuff of the laser tube should be filled with saline and colored with an indicator dye such as methylene blue.

When an ignition source is in use such as a cautery or laser, it is preferred to lower the inspired oxygen concentration below <40% while maintaining patient's oxygen saturation within normal range. Oxygen with air mixture or oxygen with helium mixture has been recommended. Red rubber catheters or other materials should not be used to sheathe the probes. The heat from the active electrode may ignite the rubber even in the air.

During procedures such as tonsillectomies, commercially available electrosurgical electrode probes that are insulated should be used to prevent burns in the oral cavity. Avoid usage of red rubber catheters as sheath for the probes as it can ignite easily.

The use of wet gauze or sponges can help decrease oxygen concentration in the oropharyngeal area by catching leaking oxygen or nitrous oxide. Also scavenging around the surgical site with separate suction may help reduce the chances of creating an oxygen-rich environment.

In some studies the use of LMA for adenotonsillectomies has been suggested to reduce airway fire but is debatable as the risk of aspiration can increase ("Practice Advisory for the Prevention and Management of Operating Room Fires," 2008) (▶ Box 12.2).

Box 12.2 Readily Available Operating Room Fire Equipment That Needs to Be Readily Available

- Several sterile saline containers
- A carbon dioxide fire extinguisher
- Rigid bronchoscope blades and rigid fiber-optic laryngoscope
- Replacement endotracheal tube, face masks
- Replacement breathing circuits
- Replacement sponges and drapes

12.11 Management

Early recognition is the key to successful treatment. Some of the signs of airway fire are visualization of smoke or spark with a loud pop, and in some cases gray dust may be seen. Dyspnea and hypoxemia may develop quickly depending on the severity of the burn and patient's underlying physical health status.

The sequelae of airway fire are airway edema, inflammation, mucosal necrosis, presence of soot, and charring in the airways on bronchoscopy exam. Damage of ciliary transport function and failure to clear casts in the bronchi may lead to debris or pseudomembrane formation and obstruction of the bronchi. The bronchial obstruction could further lead to atelectasis and pneumonia.

In the management of airway fire, the most important thing to do is to eliminate the fire and protect the patient. It is necessary to halt the procedure, remove the object on fire, and immediately cut off the oxygen source.

Immediate extubation versus maintaining the ETT is debatable. General ASA guideline says immediate extubation during any airway fire is appropriate as the thermal injury may continue or worsen if the burning ETT is kept in place. The debate arises in patients with difficult airways where maintaining the ETT may be considered after assessing the risk vs benefits. The decision to keep or remove ETT may depend on the case at hand.

Depending upon the anesthesia provider's assessment on control of airway, steps should be taken to extinguish the airway fire by disconnecting the oxygen supply immediately with or without extubation. Next step is to remove the cautery from the fire site and spray saline and wash the area. Flooding the area with carbon dioxide has also shown to be of help in preventing the spread of airway fires induced by cautery.

Maintaining oxygenation, ventilation, and stabilization of hemodynamic status should be the goals of therapy for smoke inhalation injury. If necessary, immediate reintubation and ventilation with self-ventilating bag at room air may be used. Inhaled bronchodilators and racemic epinephrine help reduce bronchospasm and stridor, respectively. Anticholinergic drugs may be used to prevent excessive secretions. Humidification helps relieve excessive drying of the airway and mucous plugging. Even though antibiotics and corticosteroids do not improve morbidity and mortality, they may not be routinely used in patient with smoke inhalation, but they should be considered, in case of secondary infection and airway edema. These patients may have to be observed in intensive care units until they are stable [79].

In severe burn injury cases, repeat bronchoscopy with protected brushings and washings every 3–5 days may be necessary. Fiber-optic or rigid bronchoscopy may need to be performed to remove granulation tissue and exudate in case of extensive burns. Some patients may need tracheostomy temporarily to allow for the healing of the burnt tissue. Most patients with mild to moderate injury make good recovery without complications. In rare cases of severe burns, if the condition of the patient does not improve in regard to oxygenation and ventilation, then the patient may need lung transplantation.

In summary, the OR team should determine high-risk cases and be at high alert during the procedure. Awareness is the key to avoidance of fire. The OR team should have a plan and decide on the roles in preventing and managing fire. In successful management of a fire, communication and multidisciplinary approach between the anesthesiologist, a surgeon, and the nursing staff is crucial [79].

12.12 Airway Trauma

Trauma to the airway is a well-recognized complication of anesthesia. Most airway injuries are associated with difficult intubation and are a significant source of morbidity and mortality

among patients and a source of liability for anesthesiologists. The frequent sites of airway injury were the larynx (33%), pharynx (19%), and esophagus (18%) according to the closed claims. Approximately 6% of closed claim database were due to airway injury coming only after other complications such as death (32%), spinal cord or peripheral nerve damage (16%), and brain damage (12%) [80].

12.13 Types of Airway Injuries

Damage to the nose, temporomandibular joint (TMJ), larynx, trachea, pharynx, or esophagus constitutes airway injury. Coming to laryngeal injuries, most of them were mostly associated with non-difficult intubations. Arytenoid dislocation, vocal cord paralysis, hematoma, and granuloma formation were some of the laryngeal injuries that were noticed. Hoarseness was one of the common symptoms of laryngeal injury.

Unlike most laryngeal injuries, pharyngeal injuries were associated with difficult intubation. Laceration and contusion, localized infection, and perforation were most common pharyngeal injuries. Sore throat was a frequent symptom. Pharyngeal injuries could be severe enough leading to mediastinitis and death.

Among esophageal injuries perforation of the esophagus was common. Similar to pharyngeal injuries as mentioned above, these were associated with difficult intubation as well. Female gender and age greater than 60 years were the other risk factors for this type of injury. Patients with esophageal perforation have poor outcome as it is a serious complication.

Another type of injury associated with difficult intubation, female gender, and age greater than 60 years is pharyngoesophageal injuries. These patients developed subcutaneous emphysema and pneumothorax in the immediate postoperative period. Delay in diagnosis was associated significantly with the development of the late infectious sequelae such as mediastinitis or mediastinal abscess, retropharyngeal abscess, or pneumonia in two thirds of the patients.

Tracheal injuries occurred due to tracheal perforation, surgical tracheostomy, and infection. The chances of injury were high when the tracheotomies were performed for the purpose of emergency airway management associated with difficult intubation. The other indications for tracheostomy were development of subglottic or tracheal stenosis as a consequence of tracheal intubation. Patients with tracheal perforation developed subcutaneous emphysema, pneumothorax, and pneumomediastinum. Chest X-ray helped in making the diagnosis when clinical signs were not obvious.

Temporomandibular joint (TMJ) injuries such as pain and dislocation were associated with routine tracheal intubation and accounted for about 10% of airway trauma claims. Preexisting TMJ disease is a risk factor.

12.14 Risk Factors

Most of the abovementioned airway traumas are due to difficult airway encounters. Difficult airway could be due to many factors including but not limited to obesity and cervical arthritis to mention a few. With the presence of preexisting conditions such as poor dentition, TMJ disease increases the incidence of dental and TMJ injuries, respectively. Females less than 60 years of age, prolonged intubation, excessive inflation of the endotracheal cuff, excessive movement of the ETT, procedures such as emergency surgical tracheostomies, emergent nonoperating room intubations, improper head positioning, poor muscle relaxation, application of a high cricoid pressure, long-term indwelling naso- or orogastric tube, transesophageal echocardiogram (TEE) probes, airway tools such as oral and nasal airways, endotracheal tubes, laryngeal mask airways, laryngoscope blades, bougies, a rigid or flexible stylet with or without exposure of the tip, and the rigid bevel of an endotracheal tube are some of the risk factors for trauma to the airway.

12.15 Prevention

A good history, physical exam, anticipation, and thorough preparation with backup plan are vital for prevention. It is important to do a good preoperative assessment and know about previous anesthetic or difficult intubation history and previous head and neck surgeries. A thorough airway exam

including the dental exam is essential with proper documentation. Anesthesia consent should include all the injuries that are possible in the oral cavity such as dental, laryngeal, pharyngeal, and esophageal injuries. The airway management and need for reintubation, or tracheostomy especially in suspected difficult airway cases, should be discussed with the patient. Next, communication with the surgical team about airway management is also very crucial. In patients with history or anticipated difficult airway undergoing elective procedure, it is important to have a discussion with the surgical team about the airway management plan and if necessary to schedule a case when there is help such as on a weekday or regular work hours for patient's safety. It is important to have the necessary airway equipment readily available such as different-sized laryngoscope blades, ETTs, oral/nasal airways, video-assisted laryngoscope, fiber-optic scopes, bougie, and laryngeal mask airway. The knowledge of ASA difficult airway algorithm and proper way to use the airway equipment is also as crucial as having them.

12.16 Management

Anticipation, rapid detection, and treatment are the key to successful management of a complication. Most of the airway complications are minor and are temporary or self-limiting as most patients recover completely without permanent disability. If difficult airway was encountered, having a high index of suspicion for a complication is important. These patients must be observed and watched for development of signs and symptoms of potential airway complications. Survival after major complications has been reported to be improved by early diagnosis and initiation of treatment.

Prompt diagnosis of pharyngoesophageal perforation may be difficult as early symptoms of perforation are absent or relatively nonspecific and include sore throat, deep cervical pain, chest pain, and cough. If it progresses to subcutaneous emphysema, pneumomediastinum, or a pneumothorax, then hypoxia, cyanosis, or change in vital signs occurs.

After a difficult intubation, surgeons should be notified and alerted about the possibility of a complication. This warns them to be under high vigilance as they are directly in continued patient care postoperatively. In cases where there is a delay in diagnosis, late infectious sequelae such as deep cervical or retropharyngeal abscess, mediastinitis, or pneumonia may occur and increase the risk of morbidity and mortality. These patients may present with symptoms of fever, dysphagia, and dyspnea. Overall mortality after esophageal perforation is reported to be as high as 25%, even with rapid diagnosis and treatment. The treatment consists of limitation of oral intake, antibiotic administration, surgical closure, and drainage.

A high index of suspicion by the anesthesiologist and the surgeon may reduce the risk of severe complications [80].

12.17 Conclusions

The incidence of airway and respiratory complications will never be nil. The use of pulse oximetry and capnography has reduced a large number of airway complications perioperatively. Even with utmost care by the anesthesiologists and use of advanced monitors, they continue to happen.

The causes are multifactorial and depend on various factors including but not limited to patient's physical health status, technical errors, type of procedure, anesthetic type, obesity, age of the patient, misjudgments, lack of adequate experience in infrequent complications, and use of high-risk fire-causing equipment as mentioned in this chapter. Most complications are minor and recover completely. Unfortunately some complications are severe and fatal, leading to patient morbidity and mortality. They also increase the cost and may have legal implications. It is hence important to have adequate knowledge of the perioperative airway complications that could occur, their prevention, and management. Prior discussions, plans, and communication among all the OR personnel are the key to avoidance and management of a complication if it were to happen. Having protocols in place for rare, but serious complications such as airway fires or operating room fires is very helpful. Conducting fire drills helps better understand and manage the situation. Multidisciplinary approach is the best approach for a successful management of a complication.

12.18 Review Questions

1. Which of the following respiratory parameters increases in obese individuals compared to lean individuals?
   A. Tidal volume
   B. Functional residual volume
   C. Oxygen consumption
   D. Upper airway respiratory tone

2. Which of the following anesthetics has the *least* risk of perioperative adverse events?
   A. General anesthesia without the use of paralytics for cerebral aneurysm clipping
   B. Administration of rocuronium for laparoscopic cholecystectomy
   C. Premedication of an anxious patient for endoscopic sinus surgery
   D. Supraclavicular block placement and administration of IV Tylenol for AV fistula in the left arm

3. Which of the following occurs after induction of general anesthesia?
   A. Pulmonary shunting occurs
   B. Alveolar hypoventilation
   C. Ventilation-perfusion mismatching
   D. All of the above

12.19 Answers

1. C
2. D
3. D

- **Websites**

► https://www.apsf.org/wp-content/uploads/collateral/posters/ORFirePrevFlyer_8.5x11_doublesided.pdf

► http://anesthesiology.pubs.asahq.org/data/Journals/JASA/931053/6FF1.png

American Society of Anesthesiologists, operating room fire algorithm

1. (Lee et al., 2012)
2. (Mehta et al., 2013)
3. ("Practice Advisory for the Prevention and Management of Operating Room Fires," 2008)
4. ("The Anesthesia Patient Safety Foundation (APSF) announces the availability of the 18-minute educational Video: Prevention and Management of Operating Room Fires - Anesthesia Patient Safety Foundation," n.d.)
5. (Akhtar et al., 2016)
6. (Karen B. Domino, M.D., M.P.H.; Karen L. Posner, Ph.D.; Robert A. Caplan, M.D.; Frederick W. Cheney, n.d.)
7. (American Society of Anesthesiologists., Posner, Caplan, & Cheney, 1999)

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Burns in the Operating Room

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_13

13.1 Introduction

In 2017 the World Health Organization [1] stated, "A burn is an injury to the skin or other organic tissue primarily caused by heat or due to radiation, radioactivity, electricity, friction or contact with chemicals." The operating room has many of these sources commonly present. Burn injury occurs from *fire* or other *thermal* sources, stray *electrical* current from monitors and equipment, and contact with *chemicals*. This chapter will look at these four common sources of burn injury in the operating or procedure room and consider risk assessment and prevention. Friction from positioning and movement during surgery is yet another cause of burns not covered.

13.2 Fire

The ECRI Institute (formerly the Emergency Care Research Institute) is a not-for-profit organization that researches approaches to improve patient safety. In 2009 ECRI [2] estimated that 550–650 surgical fires occur each year in the United States. Operating room fires can occur inside the body, on the skin, or in the environment around the patient in the operating room. The result of an operating room fire ranges from no injury to minor or major burns and even to patient death although that is extremely rare. Operating room fires are dramatic events that can produce catastrophic injury, but with persistent, effective teamwork, they are also preventable. The first step to take in the prevention of operating room fires is to recognize that there is a risk. The next step is to take consistent and definitive action to mitigate the risk factors to prevent a fire. Finally if a fire does occur, appropriate steps must be followed to minimize injury. Every member of the operating room team is responsible for patient safety and thus the prevention and response to operating room fires.

» Operating room fires are dramatic events that can produce catastrophic injury, but with persistent, effective teamwork they are also preventable.

13.2.1 The Fire Triad

There are three elements required for a fire to occur often called the "fire triad." The fire triad consists of *fuel*, an *oxidizing agent*, and an *ignition source*. All three of these elements are commonly present in a typical operating room, although they may not be easily recognized as potential dangers. Fire prevention requires us to remove at least one of the triad elements. Cooperation and constant vigilance of the entire operative team is needed so that the elements of the fire triad are not being brought together.

13.2.1.1 Fuel

There are multiple sources for fuel present during most surgical procedures (Table 13.1). A commonly available fuel is the alcohol in alcohol-based surgical skin preparation solutions. Surgical drapes, towels and sponges, patient clothing and sheets and blankets, hair, ointment, and dressings can also all serve as fuel. Every plastic part of the

Table 13.1 Fuel sources

Organic solvent solutions	NIBP cuff
Alcohol-based prep solutions	Anesthesia mask
Surgical drapes and towels	Breathing circuit
Surgical gauze and dressings	Endotracheal tube
Surgical gloves, gowns, mask, cap, shoe covers	Laryngeal mask airway
	Oxygen tubing, mask, cannula
Petroleum-based ointment	Oral and nasal airways
Adhesive	NG tube
Patient gown and clothing	IV tubing
Sheets and blankets	Tape
Hair	Paperwork
GI tract gas	Packaging materials

anesthesia circuit, the endotracheal tube, and oxygen cannulas, masks, and tubing can be a fuel source as well as paperwork, charts, and books. Just about everything in the operating room except the tile walls and the metal door knob will ultimately burn.

13.2.1.2 Oxidizer

The second element of the fire triad is an oxidizing agent. In the operating room, oxidizers include room air, oxygen, and nitrous oxide. Higher oxygen concentrations increase the chance of ignition and burning. Nitrous oxide by itself is not flammable, but when it is heated in an existing fire, it will release additional oxygen and so supports combustion even more readily than just oxygen.

» Nitrous oxide by itself is not flammable, but when it is heated in an existing fire it will release additional oxygen and so supports combustion even more readily than just oxygen.

13.2.1.3 Ignition

The most common sources of ignition in the operating room are the many different styles of electrosurgery units (ESU) used to cut and coagulate tissue. Other ignition sources include electrocautery, lasers, defibrillator pads, fiber-optic lights and sources, surgical power drills, burs and saws, electrical arcs from a fault, and static electricity (Table 13.2).

Table 13.2 Ignition sources

Electrosurgical units (ESU)	Surgical drills, burs, and saws
Electrocautery units (ECU)	Defibrillator pads
Lasers	Static electricity
Fiber-optic lights	Electrical faults
Operating room lights	

13.3 Prevention of Fire

The easiest way to avoid an operating room fire would be to eliminate all items in one of the three arms of the fire triad. Unfortunately, that is not very feasible. All of the examples mentioned above have crucial specific jobs in the care of the surgical patient and are not easily eliminated. However, operating room teams can work to avoid bringing items from the three triad elements together at the same time and same place which is what creates the conditions for a fire to start. This is a recurring, multi-step process that the team must perform for each and every surgical procedure to prevent a problem that may seem remote and unlikely and one that many of us have never seen. Many organizations such as the American Society of Anesthesiologists (ASA), the Anesthesia Patient Safety Foundation (APSF), the Association of periOperative Registered Nurses (AORN), the ECRI Institute, and the Food and Drug Administration (FDA) have all made efforts to produce educational materials to assist organizations in developing an environment of safety when it comes to operating room fires and have developed checklists and practice parameters to assist in fire prevention. We will address the recommendations as they relate to the three elements of the surgical fire triad.

13.3.1 Fuel

The variety of items that can serve as fuel in a fire in the operating room are so plentiful that it is hard to imagine completely eliminating fuel to solve the problem. Instead the entire operating room team needs to be educated to recognize the fuels for what they are and to limit the risk to the patient.

13.3.1.1 Alcohol Prep Solutions

The American Society of Anesthesiologists (ASA) Operating Room Fires Closed Claims Analysis [3] cited alcohol prep solutions as the fuel in 12% of all cases resulting in claims. Alcohol-containing prep solutions are inexpensive and highly effective for decreasing surgical site infection, so they currently play an extremely valuable role in the care of our patients and not likely to go away anytime

soon. But liquid alcohol creates vapors that can be the fuel for a fire and so is potentially very dangerous. After the liquid alcohol has fully dried and the vapors have dispersed, there is no fuel available from alcohol to support a fire. Thus, allowing alcohol to fully dry before draping is just one step in a process for safely using alcohol-based skin preps while keeping the risk of fire low. The appropriate timing may be variable depending on the type or amount of solution used and the characteristics of the patient and the location of the prep. Although 3 min is the amount of time that is commonly used, visual inspection of the area should be performed prior to draping the operating field confirming that there is no residual liquid.

The FDA became involved in surgical fire prevention in 2015 because they regulate skin prep solutions [4] and several of these substances can serve as fuel for a fire. In 2007, recognizing the risk of alcohol-based skin prep and OR fires, the Centers for Medicare and Medicaid Services (CMS) issued a memorandum [5] that required implementation of fire risk measures whenever alcohol-containing skin preparations are used. One step to decreasing the fire risk of alcohol-containing skin prep solutions is to control the amount of alcohol used in the skin prepping process. Both the FDA and CMS recommend the use of the applicator provided by the manufacturer rather than open use of the solution out of a bottle. The applicators can still lead to pooling of the solution on the patient and on the surgical bed, or the solution can soak linens, patient clothing, or even hair. This should be avoided as the pooled alcohol or alcohol-soaked material will evaporate and the vapor can then ignite. The use of towels around the prepped area to absorb excess solution that are then safely discarded prior to final sterile draping is a safe practice that can reduce the risk of fire by removing one source of fuel.

CMS now requires that hospitals and surgery centers that utilize alcohol-based skin prep establish policies and procedures to reduce the risk of fire. In the 2007 memorandum, CMS made several recommendations for the proper handling of alcohol-containing prep solutions which are summarized in ► Box 13.1. All members of the operating room team should be cognizant of the risk and participate in making sure prep solutions are dry before surgical drapes are applied. CMS requires that verification of the above precautions takes place prior to initiating the surgical procedure such as with the use of a standardized time-out and checklist. All operating room sites should adhere to these precautions, create documented policies and procedures to ensure adherence to the precautions, and then document the use of the safety measures in the patient's record. In summary, one can limit the risk of alcohol becoming a fuel in a fire in the operating room by using appropriate technique and application, limiting pooling of alcohol, and allowing adequate drying time.

Box 13.1 Safety Recommendations for Prep Solutions

- Use controlled dose applicators
- Follow manufacturer instructions for application
- Use sterile towels to catch runoff and remove when finished
- Avoid pooling of prep
- Do not allow prep to soak hair, sheets, or clothing
- Ensure prep is dry before drapes are applied
- Allow vapor to disperse

13.3.1.2 Surgical Drapes and Gowns

Surgical drapes are also a common fuel source. From 1990 to 2006, 81% of operating room surgical fires were fueled by surgical drapes [6]. Culp et al. [7] reviewed the Consumer Product Safety Commission's (CPSC) flammability of garment testing protocol known as the Standard for Flammability of Clothing Textiles (SFCT), which measures the burn time of material samples [7]. They modified the testing to include various concentrations of oxygen as might be present near a patient receiving supplemental oxygen. Currently only surgical gowns are required to undergo flammability testing. Not surprisingly, they concluded that in oxygen-enriched environments, the time to ignition of surgical drapes and sponges was decreased and that as the oxygen concentration increased, the risk of a surface flash fire also increased. They demonstrated that in 50–100% oxygen environments, surgical drapes, sponges, and gowns would all be considered Class III fabric, which means they would be unacceptably flammable as consumer wear. They concluded that physician anesthesiologists and other operating team members should make informed decisions on the material choices to decrease the likelihood of surgical fires.

13.3.1.3 Other Fuels

There are other fuels present in the operating room [8]. Just about anything made of plastic can serve as a fuel including nasal and oral airways, anesthesia masks, endotracheal tubes, laryngeal mask airways, nasal cannulas, and face masks. In addition to surgical drapes, gowns, and sponges being potential fuel, bed linens, patient clothing and gowns, gauze, towels, and dressings can similarly serve as a fuel source especially if saturated with flammable liquids. Ointments, makeup, and hair are other potential fuel sources. Petroleum-based ointment can readily burn.

» Ointments, makeup, and hair are other potential fuel sources.

13.3.2 Oxidizer

While a fire can start in the presence of the 21% oxygen in room air, increasing oxygen concentration increases the risk of ignition and combustion. Also, the time for ignition of a fire decreases with increasing oxygen concentration [7, 9]. The seemingly innocuous MAC procedure with supplemental oxygen delivered via an open system such as a nasal cannula can be particularly dangerous because vigilance regarding fire may be very low. Nasal cannula oxygen at high flow rates can produce surprisingly high concentrations, especially if it is allowed to pocket under the drapes [10]. Another particularly dangerous situation is oxygen channeling through the drapes if the edges of the drapes are not tightly adhered to the skin. A wrinkle in the edge of the drape can allow a tunnel to form and allow oxygen to move or accumulate and cause a fire away from where the oxygen is being delivered. Forced air ventilation or suction scavenging of excess oxygen under the drapes may be helpful in decreasing the oxygen concentration available to start a fire. Oxygen and nitrous oxide use are almost always under the direction and control of the anesthesia team. To decrease the risk of fire, delivery of supplemental oxygen by open systems such as nasal cannula or face mask should be avoided. If patients require a higher concentration of oxygen, especially in procedures above the clavicle, consideration should be given to inducing general anesthesia and utilizing an endotracheal tube or laryngeal mask airway to minimize increased ambient oxygen concentration. Fires during MAC cases increased from 6% of MAC claims during 1985–1989 to 31% of MAC claims from 2000 to 2009 [3].

» To decrease the risk of fire, delivery of supplemental oxygen by open systems such as nasal cannula or face mask should be avoided.

13.3.3 Heat and Ignition

13.3.3.1 Electrosurgery

Electrosurgery units (ESU) are by far the most commonly reported ignition source for surgical fires (e.g., "Bovie™," Bovie Medical Corporation, Purchase, NY, and others). Diathermy is the general process of creating heat in tissue with high-frequency electrical current, essentially radio waves. The terms electrosurgery and electrocautery are often incorrectly interchanged. An electrosurgical unit uses AC electricity at high frequency from an active electrode (e.g., the handpiece of a "Bovie™") to deliver the energy to the tissue for cutting, coagulating, and destroying. There are numerous brands with proprietary methods to accomplish similar goals. A true electrocautery device uses DC electricity to heat up the tip of the device until it glows red, and then that is applied to the tissue to cause coagulation. All of these devices can be a source of ignition in a fire. Current ASA Closed Claims Analysis on Operating Room Fires showed that electrosurgery was involved in 90% of fire claims [3]. ESUs are used in 80% or more of all surgical procedures [11]. According to Mehta et al., and ASA closed claims data, claims for ESU-induced fires during MAC increased dramatically, representing almost a third of claims related to MAC in the 2000s.

13.3.3.2 Surgical Drills, Burs, and Saws

During operation surgical power drills, burs, and saws may produce enough heat from internal friction or friction of the cutting surface against the tissue to serve as an ignition source. A surgical bur is a spinning grinder with metal teeth. During an operation it can spit off sparks of hot material that have landed on hair or other fuels and started

a fire. It may be advisable to drip saline on the cutting surfaces and/or the tissue during use to cool the surfaces as well as to limit activation time of the device.

13.3.3.3 Lasers

Medical lasers are another source of ignition in the operating room. The ability of a laser to focus a lot of energy on a small area makes them useful in surgery but also potentially dangerous. Lasers focused on dry materials such as the surgical drape, towels, or gauze can cause an ignition. Of particular concern is the use of laser devices in the airway which puts the high-energy beam in very close proximity of both a fuel and oxidizer source, the endotracheal tube, and any oxygen in and around the endotracheal tube, even room air. This will be addressed later in the section on airway fires. ▶ Box 13.2 outlines common laser safety precautions.

Box 13.2 Laser Safety Recommendations

- Appropriate staff education and frequent updates
- Establish specific laser safety policies and procedures
- Specific laser credentialing of physicians
- Check equipment and cables for damage
- Have equipment tested frequently with documentation
- Only the operator should trigger the device
- Minimize active laser time
- Use standby mode when laser is not in use
- For airway lasers use laser-resistant airway devices
- Eye protection for staff and patient

13.3.3.4 Fiber-Optic Lights, Cables, and Light Sources

Fiber-optic light sources are very common in surgery both as headlights and as the source for lighting for endoscopic procedures. The heat generated at the tip of the light source and at any of the metal connectors can cause ignition. As a result, fiber-optic lights and connectors should never be rested on surgical drapes, towels, or sponges because they could be hot enough to start a fire or burn the patient's skin.

13.4 Operating Room Preparation

13.4.1 Personnel, Process, and Teamwork

Prevention of surgical fires is critical; these events should all be preventable. Knowledge of the risk of fire by the entire operating room team is paramount. Education must take place, but to be truly effective, fire drills should be conducted on a regular basis including operating room and patient fires specifically. Operative teams should be educated, conduct drills, debrief, and correct errors in the process through continued education.

The first step in operating room fire prevention is recognition of the risks described in the previous sections. Every surgical procedure is preceded by a time-out, and every time-out should be accompanied with a surgical fire risk assessment.

» Prevention of surgical fires is critical; these events should all be preventable.

13.4.2 Flammable Solutions

AORN has produced a Fire Risk Assessment Tool [12] to assist the operating room team in recognition of the risk of surgical fire and to enhance communication in the operating room regarding fire risk and treatment. The risk of surgical fire is identified in five areas which address the presence of components of the fire triad. The first section addresses the use of alcohol-based prep solutions or other flammable solutions preoperatively. If they are used, prevention techniques such as avoiding pooling and adequate drying time should be adhered to. This should be confirmed before an ignition source is introduced to the same area.

13.4.3 Anatomic Location

The second question section relates to the anatomical location of the procedure. In particular, it should be ascertained if the procedure will be above the xiphoid process or in the oropharynx. If

it is, an adhesive drape should be used and the hair and skin protected. When supplemental oxygen is required, it should be minimized, or it should be delivered through a closed system such as an endotracheal tube or LMA. Airway fires and precautions will be discussed later in this chapter as they have some unique dangers and precautions.

13.4.4 Oxygen and Nitrous Oxide

The third section of the AORN checklist asks about the use of oxygen and nitrous oxide. If those oxidizers are in use, drapes should be placed in a manner to allow adequate forced air ventilation to disperse high concentrations of oxygen or flammable vapors like evaporating alcohol skin prep. The lowest possible concentration and flow of oxygen is always advised. Providers should consider using forced air or suction to scavenge excess oxygen from under drapes. If the surgical procedure is above the xiphoid, oxygen should be turned off for at least a minute and the area ventilated with room air before the ESU is used. This requires good communication between the operating team and the anesthesia team. The time-out procedure should also allow for recognition of the fire risk and should include a reminder discussion on the importance of communication between team members when an ignition source is used.

13.4.5 Electrosurgical Units, Lasers, and Fiber Optics

The fourth section is concerned with the correct use of the ESU and other devices. Ideally, only the person holding the ESU electrode should trigger the device via the handheld or the foot pedal to prevent unintentional arcing. The operator of the ESU should communicate with the anesthesia team when the ESU will be used, especially in MAC cases and high-risk procedures. ESU should not be used to enter the bowel or trachea. Current used should always be the minimum current required to be effective so that there is not excessive arcing and possible flame formation at the tip. Whenever the ESU electrode instrument is not in use, it should be placed in the plastic holder and not laid on the patient or drape, and the active electrode tip of the ESU should always be in view before it is triggered by the user so that there is not inadvertent arcing to an unintended area that might contain enough fuel and oxidizer to start a fire. The tip should also remain clean. If coagulated tissue builds up on the tip of the device, the tissue itself may burn and flame, and then that may ignite other materials. ESU and fiber-optic light cords and cables should be dry and free of coils and knots. The cables and connectors of a fiber-optic light can become very hot and may serve as a source of ignition. Cables should be inspected frequently for damage, and the light source should be in standby mode when not in use.

To reduce the fire risk, a bipolar electrode should always be considered as there has never been a fire reported related to the use of bipolar electrosurgical units, possibly due to lower energy being used and less chance of an arc occurring [13].

» If coagulated tissue builds up on the tip of the device the tissue itself may burn and flame and then that may ignite other materials.

Laser safety is similar in that the cords should be free of coils, moisture, and breaks and that only the operator should trigger the laser. The laser should be placed in standby mode when not in use, and the working end should be protected by placing on a moist drape or towel and away from flammable materials or the patient's skin.

13.4.6 Fire Contributors

The fifth and final section of the AORN checklist covers other fire contributors that may be present during a procedure. This includes defibrillator pads, drill bits, and burs.

Defibrillator pads should be appropriately sized and applied completely without any wrinkles to the patient's skin. The skin should be dry and free of lotion, and only approved conducting gel should be used. When defibrillator pads must be used to cardiovert or defibrillate a patient, the lowest current acceptable should be used, and the operating room team should always be prepared

for a spark and ignition. In the operating room, very often these pads are out of the field and under the drapes, requiring even more vigilance to drying the area of prep solutions and minimizing oxidizers under the drapes.

The five sections of the AORN checklist help the operating team assess the risk for surgical fire and improve communication and recognition of risk among the team. In the simplest terms, the questions should be asked and a yes or no answer should be given. If "yes" the risks should be discussed, and prevention preparation should be made including preparations to respond to a fire. Vigilance must be maintained for unusual sounds and smells as they may be the first sign of an invisible ignition. Once a procedure is identified as a high-risk for fire, appropriate precautions should be followed as outlined in ▶ Box 13.3.

» The five sections of the AORN checklist help the operating team assess the risk for surgical fire and improve communication and recognition of risk amongst the team.

Box 13.3 High Fire Risk Procedure Precautions

- Appropriate staff education and frequent updates
- Risk assessment during time-out procedure and throughout
- Identify roles of OR team members in a fire
- Allow prep solutions to dry
- Do not allow pockets or channels to form in drapes that would allow oxygen to accumulate
- Minimize oxygen supplementation or consider closed system
- Turn off oxygen and allow oxygen concentration to decrease prior to ESU activation
- Communicate prior to ESU activation
- Minimize current and ESU activation time; consider bipolar
- Keep gauze and sponges moist
- Have designated saline or water readily available on the field
- Frequent open communication among the OR team
- Constant vigilance and preparedness to act
- Follow all standard institutional and OR fire precautions

13.4.7 Silverstein Fire Risk Assessment Tool

Another simple risk assessment tool is the Silverstein Fire Risk Assessment Tool, developed by Kenneth Silverstein, M.D., a physician anesthesiologist and Chief Clinical Officer at Christiana Care Health System in Delaware [14]. This easy-to-use tool consists of these three questions, each scored 0 for NO and 1 for YES. Will open oxygen source such as a nasal cannula or mask be used? Will a laser or electrocautery unit be used? Is the procedure at or above the level of the xiphoid process? A low fire risk procedure is a score of 0 or 1. Intermediate fire risk is a score of 2. High fire risk scores 3.

Silverstein Fire Risk Assessment Tool

Will open oxygen source such as a nasal cannula or mask be used?

Will a laser or electrocautery unit be used?

Is the procedure at or above the level of the xiphoid process?

Low fire risk procedure is a score of 0 or 1.

Intermediate fire risk is a score of 2.

High fire risk scores 3.

The APSF has developed a simple and useful algorithm (◘ Fig. 13.1) that can be followed once a procedure is designated as a high-risk procedure [15].

13.5 Management of Operating Room Fires

13.5.1 General Action Plan

Despite excellent planning, training, and proper preventative measures, you and your patient may be faced with a fire. The fire may be in or on the patient, or it may be nearby in the same room or down the hall. Well-established institutional policies and procedures should be in place and followed to prevent patient injury. Typically this would include very general memorizable action plans like R.A.C.E. for Rescue, Alert, Contain, Extinguish or Evacuate and fire extinguisher usage P.A.S.S. for Pull the pin, Aim low, Squeeze the handle, Sweep the discharge nozzle.

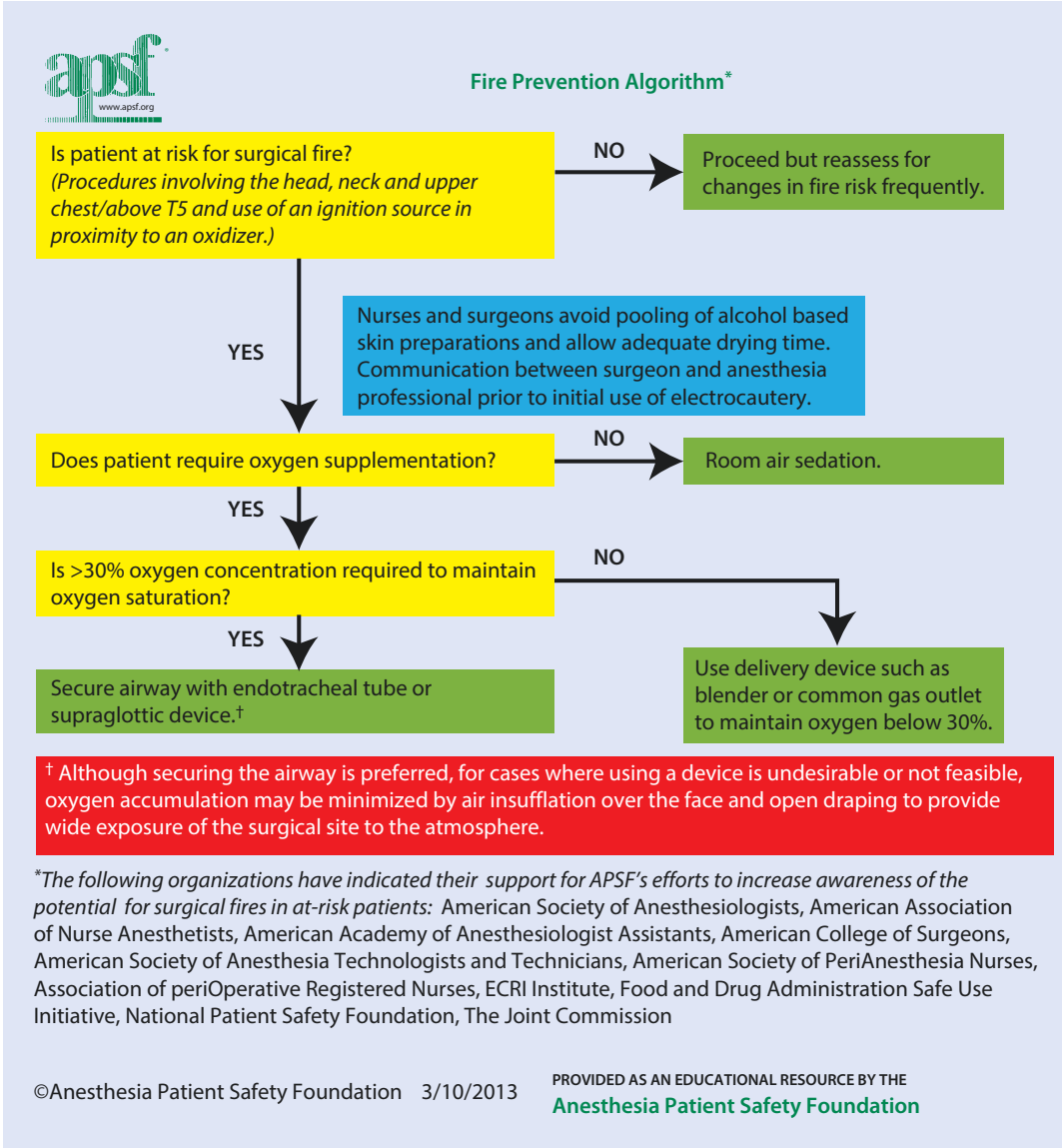

Fig. 13.1 APSF fire prevention algorithm, used with permission from APSF

Fire Action Plan

R: *Rescue*
A: *Alarm or alert*
C: *Contain or confine*
E: *Extinguish or evacuate*

There should be a system to alert others of the fire such as "code reds" or activating a fire alarm pull station. Fire should be contained by closing off doors as appropriate, shutting off fresh gas flow, and removing potential fuel and oxidizers from the area. The next step would be extinguishing the flames using approved methods appropriate for the type of fire. The facility should again have a well-defined procedure for this, which should be known to all staff throughout the facility and drilled frequently.

Fire Extinguisher Use

P: *Pull the pin*
A: *Aim low*
S: *Squeeze the lever*
S: *Sweep the fire*

13.5.2 Specific Next Actions to Take

The ASA has produced an effective algorithm for operating room fires depicted in Fig. 13.2 [8]. If any signs of fire like smells, sounds, or visual cues present themselves, then it is better to speak up and act. The first step is to halt the procedure and alert the rest of the operating room team. If no fire is present, the procedure may be continued if investigation of the cause is completed and fire is not present.

If a fire is present, stop the flow of airway gases. Any burning materials should be immediately removed from the patient and extinguished using saline or water. If the fire is in the airway, stop the flow of gases and remove the endotracheal tube immediately. In an airway or intracavitary fire, flood the site with saline or water. If fire persists a carbon dioxide fire extinguisher can be used on the materials and the patient. Recently ignited materials should be isolated until completely extinguished so that the fire is not fed.

If after these first actions the fire continues, the general fire alarm should be sounded, and standard hospital protocols should be followed. This includes rescuing the patient from the fire area, containing the fire by shutting off gas supply to the room and shutting the door, and evacuating as needed. Continued efforts to contain or manage the fire should be undertaken by those members of the team separate from those charged with caring for the patient.

After the fire is extinguished, the patient should be examined thoroughly for any injury. Treatment should begin with assessment of patient injuries, which may not be readily apparent immediately, especially in the airway. Inhalational injury secondary to smoke and fumes as well as exposure to burning products in an airway fire may occur. Fire and smoke injuries may take some time to evolve in the airway. Burned skin should be treated immediately to limit injury and to prevent infection. Depending on the extent of injury, consideration should be given to transferring a patient to a burn center after stabilization. Great care should be taken in removing burning items so that a secondary fire does not occur in the operating room around the patient. There should be a call for help to obtain additional caregivers and members of the team as necessary to contain and extinguish the fire allowing other members of the team to care for the patient.

Standard fire drills and precautions do not cover the unique nature of operating room fires. Specific education, drills, and simulations for OR fires should be focused on fire risk assessment, prevention, and management. Fire drills should be conducted with all members of the operating room team at specific time intervals to assure awareness of the risk and management. A simple drill can easily imprint on the providers important information regarding the location of extinguishers, fresh gas shutoff valves, and emergency exits in the operating room suites. These locations may not always be obvious, and searching for them in a time of disaster is not conducive to a good outcome. Drills can also help the facility to recognize potentially dangerous situations or lack of safety equipment in a safe, controlled setting rather than during an actual catastrophe. Operating room fire drills should be complementary to facility fire drills and procedures.

After a fire, there should be an open discussion with the patient and the family with the risk management team of the facility if available. The events should be discussed without assessing blame. The status of the patient and the plans for care should be discussed. Speculation on why the event happened should be avoided in the early stages. The time for that discussion can come later. The incident should be reported to the quality assurance personnel, and a root cause analysis should be undertaken. This will allow the team to evaluate the predisposing factors and what could have been done differently and hopefully decrease the chance of a similar event. Equipment should be quarantined and disposables saved if possible to assist in the investigation of causes.

13.6 Airway Fires

Airway fire prevention and treatment require special reinforcement and consideration. Airway procedures are the perfect storm bringing an oxygen-enriched environment in the respiratory tree in close proximity to the ignition source of the ESU or laser with the endotracheal tube serving as the fuel. These rare but potentially catastrophic events can be prevented with appropriate caution and preparation. If an airway fire does occur, the treatment must be rapid and appropriate to minimize patient injury. ▶ Box 13.4 outlines the precautions that should be taken in cases that may result in an airway fire.

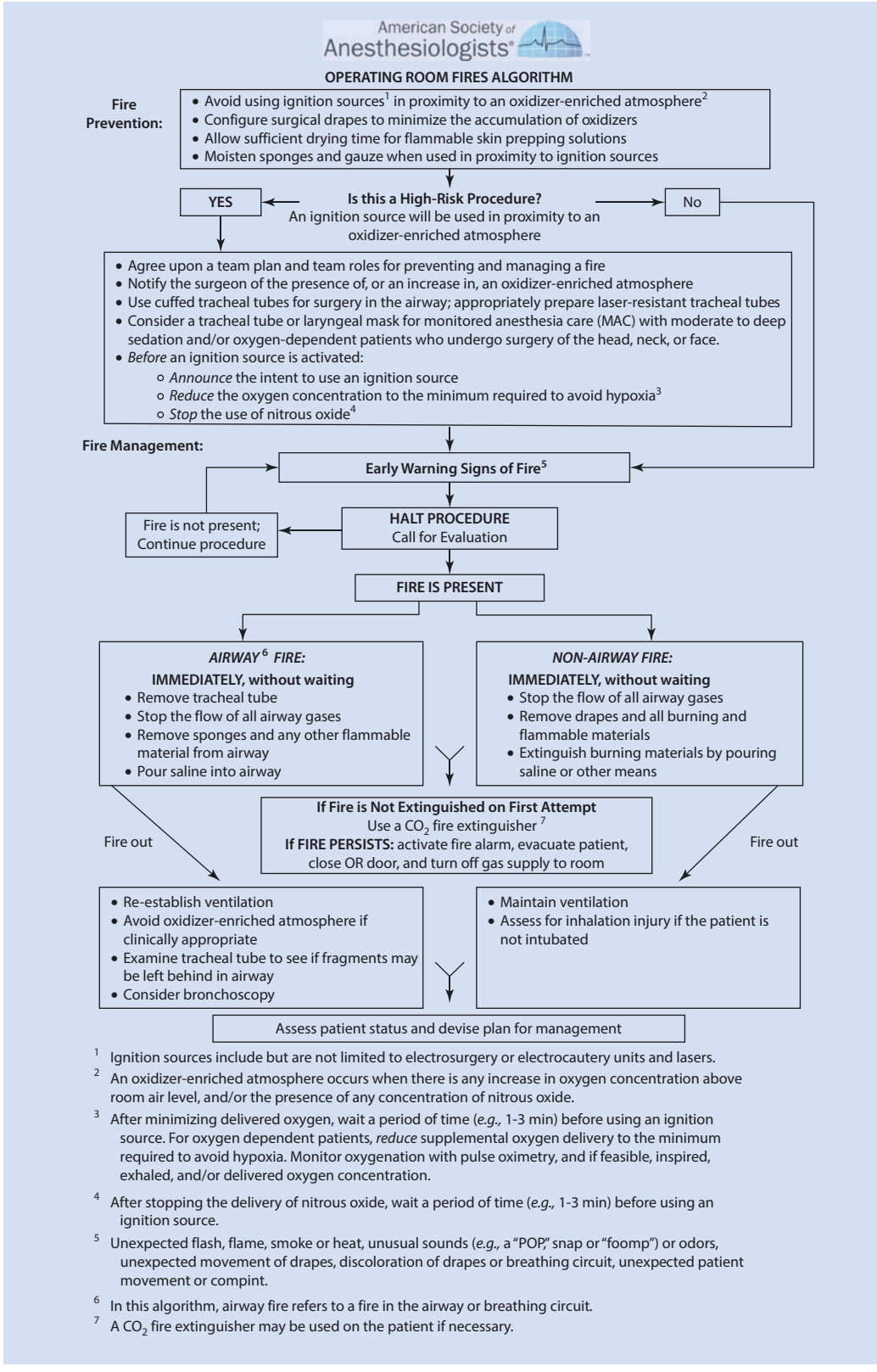

Fig. 13.2 ASA operating room fire algorithm, used with permission

Box 13.4 Airway Fire Precautions

- Recognition of risk
- Follow standard fire precautions with recognition of high risk
- Minimize oxygen concentration
- Communicate before activation of ESU or laser
- Never use ESU to enter the airway
- Use laser-resistant endotracheal tubes when applicable
- Fill endotracheal tube cuff with tinted saline for laser cases
- Be prepared to emergently turn off fresh gases and remove the endotracheal tube
- Additional airway equipment available
- Saline or water available and designated on the field or table
- Vigilance and a rehearsed plan of action if a fire occurs

13.6.1 Preparation

Preparation for a case that could lead to an airway fire includes all of the previously mentioned general fire prevention education, skills, strategies, communication, equipment, and practiced teamwork plus some additional items which should be immediately available:

- Saline or water in a basin with soaked gauze sponges on the field to extinguish a fire
- Backup airway equipment such as endotracheal tubes and an anesthesia mask if a burned airway device must be removed
- An anesthesia machine that can deliver air to deliver a lower FiO2 anesthetic
- Even greater attention to the sparing and "fire safe" use of the ESU

Adding a laser to an airway procedure brings an even higher energy ignition source than an ESU. Typical PVC endotracheal tubes readily ignite producing thick black toxic smoke and are generally avoided. Laser "safe" tubes made of alternate materials or covered with metal foil or other coatings to reduce flammability can be easily purchased. Purpose-made metal foil tape can be wrapped around a regular endotracheal tube to lessen the vulnerability of the tube to a laser's heat. Flexible metal endotracheal tubes are available. The cuff(s) of all of these tubes should be filled with saline, often tinted with methylene blue for easier leak detection, to reduce the risk of a laser strike on the cuff. Alternatively the endotracheal tube may be repeatedly placed and removed by the surgeon performing using the laser during periods of apnea.

» Airway procedures are the perfect storm bringing an oxygen enriched environment in the respiratory tree in close proximity to the ignition source of the ESU or laser with the endotracheal tube serving as the fuel.

13.6.2 Prevention

Tracheostomy and tonsillectomy are two typical airway procedures. If the cuffed endotracheal tube works perfectly, oxygen should not escape during a tonsillectomy. But during a tracheostomy, the risk of fire goes up even more because the surgeon intentionally enters the potentially oxygen-enriched tracheal lumen. Even small holes in the airway can produce a jet of oxygen-enriched gas igniting a fire. ESU should not be used to enter the trachea to limit the chance of ignition within the trachea. Decrease the FiO2 to 21% but at least less than 30% if possible, and realize that it may take several minutes for the FiO2 in the trachea to decrease adequately. Good communication with the surgeon is necessary.

Lasering vocal cord lesions is definitely a high fire risk case. Jet ventilation has been advocated to reduce the fire risk by reducing the fuel of the endotracheal tube in the airway. Unfortunately, airway fires can still occur with jet ventilation. Wegrzynowicz et al. [16] published a case report where jet ventilation was used for a patient having a vocal cord papillomata removed [16]. All fire precautions were taken including having the entirety of the patient's head covered in saline-saturated OR towels to prevent laser injury and fire. An inadvertent laser strike caused second-degree burns as two fingers of a surgeon's glove flamed bright blue and orange. A muffled roar was heard as this flaming gas was entrained by the Venturi effect into the oxygen-enriched trachea as the jet ventilator was activated. The flaming gas then was exhaled out of the mouth but also the nose under the wet towels, setting the patient's moustache ablaze and causing second-degree burns of his lip. It all happened in an instant!

13.6.3 Treatment

The plan to treat an airway fire should be well rehearsed mentally and ideally also in simulation. If an airway fire is suspected, either due to visualization of flames, unusual smells, or even auditory cues such as a "whoosh" or a "pop," then fire should be assumed and treatment begun immediately. Treatment can always be stopped if fire is not present, but waiting to initiate treatment can have devastating consequences. ▶ Box 13.5 outlines the steps that should be taken if an airway fire is suspected. At the first sign of a problem, the procedure should be halted. The laser and electrocautery unit should be stopped and placed away from the field in standby mode. The field should be flooded with saline. At the same time, fresh gas flows should be stopped, and the endotracheal tube should be removed simultaneously. The quickest way to stop fresh gas flows is to disconnect the circuit at the elbow and remove the endotracheal tube. Surgical drapes and towels should be immediately removed. Once the fire is extinguished on its own or with saline or wet towels, ventilation can be reinitiated as needed. A thorough inspection of the area should take place to ensure that fire does not persist or that burning debris is not present. The patient should be reintubated, and the trachea should be bronchoscopically examined for signs of damage. Consultation with an ENT physician should occur, and rigid bronchoscopy may be considered. Oxygen should be provided as needed. The procedure should be aborted, and attention should be turned to patient rescue and treatment. If the airway fire has caused ignition of equipment and drapes, the drapes and equipment should be removed, extinguished, and safely discarded. The patient should be examined for burns externally as well as within the airway.

13.7 Intracavitary Fires

Intracavitary fires in the abdomen, pelvis, chest, and sinuses are all possible when ignition devices such as fiber-optic light, lasers, and ESUs are used in the presence of fuels like bowel gas or plastics and the oxidizer oxygen. One of the reasons carbon dioxide is used for insufflation is that it is noncombustible. But this is not a foolproof technique. An intra-abdominal fire occurred during an elective laparoscopic cholecystectomy in the insufflated abdomen after the use of the ESU [17]. During investigation of the cause of the fire, it was found that one of the carbon dioxide tanks used for insufflation of pure CO2 instead contained 86% oxygen, but the pin index pattern was that same as for pure CO2, allowing the tank to be mounted to the insufflation machine. In this case after the fire was recognized, the abdomen was opened and flooded with saline. The procedure continued and that patient survived.

13.8 Thermal Injury

Fire is not the only cause of heat injury to patients in the operating room. Any warm or hot device or substance that can come in contact with the patient can cause a burn injury resulting in tissue damage. Potential sources of thermal injury are listed in ▶ Box 13.6 and described below.

Box 13.5 Management of Airway Fire

- Stop the procedure
- Remove the endotracheal tube
- Stop fresh gas flow
- Remove burning materials from the airway
- Flood site with saline or water
- Once extinguished, resume ventilation with minimal oxygen
- Examine the oropharynx, hypopharynx, and airway
- Reintubate if necessary
- Consider bronchoscopy and ENT consultation
- Perform patient assessment and begin necessary treatment

Box 13.6 Causes of Operating Room Thermal Injury

- Forced air warmers
- Heated fluid bags or bottles
- Warming mattresses or blankets
- Recently sterilized instruments not allowed to cool
- Unintended ESU activation or hot tip after activation
- Lasers
- Fiber-optic light sources, cables, and connectors
- Exothermic reaction of cement
- Surgical drills, burs, and saws

13.8.1 Maintenance of Normothermia

Warming devices are frequently used to maintain normothermia and can be very safe if used properly but can also be linked to thermal injury if not applied appropriately.

13.8.1.1 Forced Air Warming

Forced air warming devices are routinely used in the intraoperative and postoperative period. These devices consist of a heating mechanism for warming air and blowing it through tubing into a two-layer blanket that inflates like an air mattress. One layer has small holes that allow a gentle diffuse amount of heated air to be applied evenly to the patient's skin over a large area. These double-layer blankets must be applied appropriately and the hoses attached as indicated according to manufacturer's instructions. The use of a forced air warmer hose shoved under a regular bed blanket, a practice known as "hosing" on an anesthetized patient, can easily lead to the air blowing on just one small part of the body causing overheating and a skin burn. A review of ASA closed claims data [18] showed that 87% of burn injuries from forced air warming were attributed to the use of the hose without the appropriate double-layer blanket. Another possible mechanism of burn injury is applying the air blanket to poorly perfused extremities such as in a case where there is arterial occlusion to the lower extremities. The limb will get warmer and warmer but due to lack of circulation won't carry the heat back to the rest of the body, resulting in burn injury to the skin and perhaps deeper tissue.

13.8.1.2 Warming Mattresses and Blankets

In addition to forced air warmers, fluid-filled warming mattresses and electrical blankets have been used in the operating room. As with most thermal injuries, tissue damage is a function of the temperature and the duration of exposure. Burns from electrically powered warming equipment represent only 29% of total burns from warming devices, but more than half are water mattresses [19].

When using warming devices, the minimum temperature to maintain normothermia should be used, and all equipment should be inspected for damage and faults. Alarms from warming devices should be heeded, and the cause for the alarm should be aggressively investigated. Devices should never be customized or used inappropriately. All manufacturer instructions and recommended use for safety should be strictly adhered to. Even when appropriate warmers are used in the indicated fashion, the device and its application to the patient should be monitored frequently during use and the area assessed after use.

13.8.1.3 Heated Materials

Materials such as water bottles and IV fluid bags have been heated in microwaves or blanket warming cabinets and then used for maintenance of temperature as well as for positioning of patients. This practice has been linked to patient burns because the materials were not designed to be used on anesthetized patients in this manner or for long periods of time that are typical during an operation. In the 1994 ASA closed claims analysis on burns from warming devices, 64% of the burns reported were from warmed intravenous fluid bags or plastic bottles [19]. All of these were preventable. Do not use anything that is not intended and manufactured for patient warming.

13.8.2 Thermal Injury from Other Sources

13.8.2.1 Sterilized Instruments

Thermal injury resulting in patient burns may also result from recently sterilized instruments. In particular the flash sterilization process, now known as immediate-use steam sterilization, can result in very warm instruments being delivered to the operating room without an appropriate cooling time. The use of these instruments on patients or resting the instruments on a patient's exposed skin may result in a burn and blistering. These instruments will be hot to touch if they are handled by the surgeon, but some items may not be handled before application to the patient. The temperature of these instruments should be verified as safe before they are rested on a patient's skin or used in the procedure.

13.8.2.2 Electrosurgical Units

ESUs and electrocautery can cause a surgically precise thermal reaction on tissue at the intended site, but the active electrode tip may remain hot after use in the surgical field. If the hot electrode tip is rested on the patient's skin, a burn can occur. The electrode should always be returned to the approved plastic holster. ▶ Box 13.7 outlines recommendations for safe use of electrosurgical units.

13.8.2.3 Fiber Optics

Thermal injury and burns may occur with the use of fiber-optic equipment in the operating room. Fiber-optic devices are used in endoscopic procedures, in headlamps, and in other types of surgical instruments such as retractors. Light is transmitted from a light source through fibers in a cable to the device and ultimately to the illuminated end. The light source, damaged fiber-optic cables, metal connectors along the cable, and the illuminated end can all heat up and cause thermal injury if allowed contact with the patient [20]. Attention should also be given to the light source generator which may unknowingly come in contact with one of the patient's extremities if it is allowed to be pulled too close to the operating table.

Box 13.7 Steps to Prevent ESU Injury

- Routine inspection of the device by a biomechanical engineer
- Appropriate education of surgeon and operating room team
- Follow all manufacturer's instructions and precautions
- Inspection of the unit and cables daily before use
- Test safety alarms and never silence alarms
- Document serial number of device on each case
- Do not place devices on or around ESU that may create interference
- Appropriate placement of dispersion pad
- Reusable equipment should be clean and in working order
- Never reuse disposables
- Never use ESU in the area of flammables
- Alert team when ESU will be used in high-risk procedures
- Limit current and activation time
- Recognize the presence of implanted cardiac devices
- Report any malfunctions and take unit out of use
- Follow all institutional policies and procedures
- Only the operating physician should activate the device
- The active end of the electrode should be in sight before activation
- Do not allow debris to build up on active electrode tip
- Always holster device when not in use
- Recognize that the tip may remain warm after activation

13.8.2.4 Lasers

In addition to serving as a source of ignition, especially in airway fires, lasers can also induce unintended thermal burns. In addition to skin and mucosal injury, direct or indirect laser light exposure can cause serious and potentially irreversible corneal and retinal injury. The anesthetized patient's eyes should be protected from laser light by taping the eyes closed and also use of saline-soaked eye pads and perhaps laser-resistant goggles depending on the type of laser being used. Remember that reflected and scattered laser light can cause eye and skin thermal injury.

13.8.2.5 Bone Cement

Bone cements such as polymethyl methacrylate undergo an exothermic free-radical polymerization process, which causes the cement to heat up considerably. This polymerization can reach temperatures of 82–86 °C in the body [21]. Temperatures in this range on the skin and sensitive tissue such as nerves can cause thermal injury. There has also been a case report of a thermal burn from bone cement used in a total hip arthroplasty [22].

13.9 Chemical Burns

Chemical burns in the operating room can result from the use of common skin preparation solutions as well as accidental exposure to caustic materials. Chemical burns and skin irritation from skin prep solutions are more likely to occur when the solutions are not allowed to dry and

when they remain in contact with the skin for long periods of time [23]. Povidone-iodine can be irritating to the skin. When this wet solution gets under the patient's body or under the tourniquet cuff, irritation, maceration, friction, and pressure can compound each other and lead to skin burn or ulceration [24]. Somewhat similar to the recommended procedure with alcohol skin prep solutions, iodine solutions should be prevented from pooling and soaking the linens in contact with patient skin, especially in dependent areas, and it should be allowed to dry before applying tourniquets or draping. An impervious drape around tourniquets can help prevent prep solution contact with the skin. Replace the tourniquet or dispersion pad if prep solution runs under it.

Chlorhexidine gluconate (CHG) has been associated with a risk of chemical burns in neonates and children. Forty-four cases of chemical burns were found in preterm infants after the application of chlorhexidine [25]. These infants were 26 weeks or younger or were infants that weighed less than 1000 grams. In five of the cases, the injury resolved but left scarring, discoloration, or keloids. Death was reported in five cases with most attributed to comorbidities attributed to prematurity, but the chemical burns were considered a possible contributory factor. Due to the risk of chemical burns, CHG should not be used in neonates.

Quaternary compounds used to clean the surgical table and stretchers for transport can also cause skin burns. These substances may also be used in the cleaning of surgical tools. These burn injuries are rare if standard precautions of adequate drying time and avoidance of contact with patient skin are followed.

Accidental chemical burns may also occur due to mislabeled solutions in the operating room. In 2013, according to the Institute for Safe Medication Practices (ISMP), which operates the National Medication Errors Reporting Program, several cases of chemical burns have been reported from accidental use of glacial acetic acid (99.5%), a highly concentrated form of acetic acid, instead of a 4–5% solution [26].

The application and removal of adhesive tape, electrocardiogram pads, and surgical drape adhesive may cause chemical burns or physically denude the skin which may scar as much as a burn.

13.10 Electrical Burns

13.10.1 Electrosurgery Units: ESU

Currents greater than 50 Hz are more likely to create burns rather than electric shock. ESUs utilize this high-frequency (500 kHz) AC current to create heat, which can cut and coagulate tissue. This is known as diathermy. The electrical current passed into the patient from the tip of the ESU instrument is allowed to safely return to the ESU generator unit by way of a dispersion pad placed away from the incision site. Dispersion pad surface areas are large enough to allow current dispersion and to minimize heating and damage under the pad, if it is properly applied. Recommendations for the safe use of dispersion pads are listed in ▶ Box 13.8. Modern isolated electrosurgery units will completely stop delivering energy if the dispersion pad is not on the patient at all, but if the pad is applied poorly with wrinkles and is partially lifted or has dried out nonconductive areas, this may not be

Box 13.8 Recommendations for Dispersion Pad Safety

- Only approved pads should be used
- Do not reuse disposables
- Pads should be applied close to the surgical site
- Apply pad to a clean and dry site
- Use appropriately sized pads for the patient
- Confirm that pad is securely adhered to the skin
- Never reposition a pad using the same pad
- Place pad over a well-perfused area with large muscle mass
- Do not place over implanted hardware
- Do not place pad over scar tissue
- Consider clipping hair before placement or avoid hairy areas
- Avoid pad placement over joints or bony protrusions
- Place pad after patient has been positioned
- Document site and skin condition before and after pad placement and removal
- Adhere to safety alarms and recheck pad as necessary
- Avoid placing a pad distal to a tourniquet
- Avoid placing pad near implanted cardiac devices
- Avoid placing pad over tattoos as certain inks may contain metal

sensed properly by the machine, and then the current may still flow across a smaller skin area and cause a burn. Also if the dispersion pad is too close to the incision or is placed over metal implants, a burn can occur.

13.10.2 Electrocautery

Electrocautery uses DC electrical current to heat a metal wire until glowing, which is applied to tissue to burn or coagulate a specific area of tissue. Current does not pass through the patient typically, but heat is passed to the tissue from the wire. This is typically used by dermatologists, ophthalmologists, and plastic surgeons. ECUs are smaller and may be battery operated.

13.10.3 Electrical Faults

Electrical faults from equipment or wiring can lead to electric shock in the operating room. Electrical shock often leads to burns that present with only a small surface lesion on the skin but much more significant tissue damage underneath. A very high index of suspicion is needed when examining and caring for these patients.

13.11 Magnetic Resonance Imaging

There are several mechanisms for burns to occur in the magnetic resonance imaging (MRI) unit including electromagnetic induction heating, antenna effects, and closed-loop current induction [27].

Monitor cables, external objects, and implants can be heated during MRI resulting in burns. Manufacturer guidelines and facility protocols should be followed when patients are undergoing MRI. Only monitors and cables approved for MRI use should be used in the MRI unit.

There are a few simple safety precautions that can be followed to minimize the chance of burns during an MRI procedure. Sedated patients will not necessarily be able to alert of a warming sensation or a burn. Therefore heightened precautions should be undertaken when sedation is utilized. Patients should be screened for metallic objects, and they should always change into a hospital gown. When patients are placed on the table, skin-to-skin contact should be avoided to prevent current loops [27]. Only manufacturer-approved padding should be used to insulate patients. Monitoring cable and other lines should be routed in a straight line out of the MRI tube and not coiled. Coiling can allow induction of current leading to burns. Trained technicians should operate the MRI machine, and standard operating procedures should be followed. Patients should always be observed while in the MRI unit, and institutional fire safety precautions should be followed.

13.12 Conclusion

Patients expect that they will be safe from danger when undergoing surgery and protection from burns is no exception. Burns of any type in the operating room are an unexpected event, but they should not be completely unanticipated.

We have outlined various types of burns that can occur. The risks of burns in the operating room should be recognized by the members of the anesthesia care team, and methods for prevention should be considered and undertaken. This includes education of all members of the operating room team on risk assessment and methods that can be used to minimize the potential for burns.

In the unfortunate event that a burn occurs, whether a significant injury due to fire, or a minor skin burn from adhesive, the operating room team should recognize the injury, report and document the injury, and as a quality measure assess system policies and procedures to see if they were followed or if they need to be improved. Patients and family members should be informed of the potential risk of burns and if a burn were to occur appropriate treatment delivered as needed. Surgical fires and other burn injuries are rare but are almost always preventable, and with appropriate training, education, and attention to risk factors, operating room teams can protect patients from these potentially catastrophic events.

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Eye Injury

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_14

14.1 Introduction

Some studies show that ocular injury occurs during 0.1–0.5% of general anesthetics and is mostly corneal in nature in patients whose eyes are taped shut during the case [1, 2]. When the eyes are left untaped during general anesthesia, the incidence of ocular injury has been reported to be as high as 44% [2, 3].

General anesthesia reduces the tonic contraction of the orbicularis oculi muscle, causing lagophthalmos, a condition in which the eyelids do not close completely, in 59% of patients [1]. Additionally, general anesthesia reduces natural tear production and tear-film stability. This results in the drying of the corneal epithelium leading to reduced lysosomal protection. The protection afforded by Bell's phenomenon (in which the eyeball turns upward during sleep, protecting the cornea) is also lost during general anesthesia [4].

Intraoperative eye injuries have been mentioned in insurance claims across the globe. They account for 2% of medicolegal claims in Australia and the United Kingdom [1, 5] and 3% in the United States. Claims against anesthesiologists for eye injuries analyzed as part of the ASA Closed Claims Project accounted for 3% of all claims in the database (71 of 2046). While the payment frequency for eye injury claims was higher than that for non-eye injury claims (70% vs. 56%; $P \leq 0.05$), the median cost of eye injury claims were less than for other claims ($24,000 vs. $95,000; $P \leq 0.01$). There was a low median payment ($3000) for claims for corneal abrasion, while the median payment for claims involving movement was ten times greater than for non-movement claims ($90,000 vs. $9000; $P \leq 0.01$) [6]. (Table 14.1).

Table 14.1 Incidence and amount of payment in eye injury cases [6]

Type of claim	Number of claims with payment	Median payment (× $1000)
All movement claims ($n = 21$)	16 (76%)	90*
During general anesthesia ($n = 16$)	14 (88%)	108
During MAC ($n = 5$)	2 (40%)	35
Non-movement ($n = 50$)	34 (68%)	9
All corneal abrasions ($n = 25$)	16 (64)	3†
Non-abrasion ($n = 46$)	34 (74%)	83
All other claims ($n = 25$)	18 (72%)	75

Adapted from Gild et al. [6], with permission
Note: Claims with no payment are excluded
*$P \leq 0.01$ between median payment for eye injuries caused by movement and other eye injury claims
†$P \leq 0.01$ between median payments for corneal abrasions and other eye injuries

14.2 Mechanisms of Eye Injury

In the ASA closed claim analysis, two distinct subsets of eye injury associated with anesthesia were identified. The first, 25 of 71 claims (35%), was characterized by corneal abrasion and a low incidence of permanent injury (16%) during general anesthesia. Patient movement characterized the second subset of eye injury during ophthalmic surgery (21 of 71; 30%). Blindness was the outcome in all cases in the second subset. Seventy-six percent of these cases (16 of 21) occurred during general anesthesia, and the remaining 24% [5] occurred during monitored anesthesia care (MAC) [6].

Corneal abrasions are the most prevalent ocular injuries in the perioperative period. Anesthesia and analgesia inherently mask the natural response to pain, preventing the patient from sensing and reacting to the noxious stimulus of ongoing corneal exposure. Reviewers in the closed claims analysis were able to identify a mechanism of injury in only 20% of claims for corneal abrasion.

Prolonged surgical procedures (>7 h) associated with acute blood loss, hypotension, and hypoxia leading to posterior ischemic optic neuropathies as well as direct pressure to the periorbital region of the eye from positioning leading to increased intraocular pressure have also been implicated in eye injuries [7].

14.3 Corneal Abrasions and Mechanisms of Occurrence

In non-ocular surgery, eye injuries are relatively uncommon. There may be pain, discomfort, and occasionally visual loss when they occur. As mentioned earlier, corneal abrasions are the most frequent ocular complications reported in the literature following general anesthesia [8–11].

They are a very painful postoperative burden to the patient. The 1992 ASA closed claim analysis showed that of the 3% of all claims in the database attributable to eye injury, 35% of these claims represented corneal abrasions with a 16% incidence of permanent eye injury [6]. Corneal abrasions occurred during general anesthesia, MAC, and regional anesthesia.

Corneal injury can occur secondary to various mechanisms. These can be due to mechanical injury, chemical injury, exposure keratopathy, and tear film destruction. There are several causative factors under mechanical injury, ranging from direct corneal trauma from facemasks, stethoscopes, identity badges, and other foreign objects and surgical drapes which come in contact with the patient's eyes accidentally. These injuries may occur secondary to loss of pain perception, inadequate closure of eyelids, decreased corneal reflexes, or a decrease in basal tear production. It is necessary to have in place prophylactic strategies that can prevent corneal exposure and maintain tear film.

The reported incidence varies depending on the methodology of detection. The incidence has been reported as high as 44% in a small prospective study of general surgical patients, where fluorescein staining of the corneal epithelium was used [9]. In a large prospective study ($n = 4652$) of patients undergoing neurosurgical procedures, an incidence of 0.17% of corneal abrasions was reported based on symptoms and confirmed by fluorescein staining [8]. In a review of 60,965 patients by a group in North America, an incidence of 0.056% was reported as sustaining eye injuries ($n = 34$). Corneal abrasions were the most common [$n = 21$, (0.036%)] or 60% of all eye injuries reported in this study [10]. Other injuries were conjunctivitis, blurred vision, red eye, chemical injury, direct trauma, and blindness. Independent factors associated with a higher relative risk of eye injury included:

- Long surgical procedures, (odds ratio, 1.16 per hour of anesthetic care; CI, 1.1–1.3)
- Lateral positioning during surgery (odds ratio, 4.7; CI, 2–11)
- Operation on the head or neck (odds ratio, 4.4; CI, 2.2–9.0)
- General anesthesia (odds ratio, 3.0; CI, 2.2–38)
- Surgery on a Monday (odds ratio, 2.7; CI, 1.4–5.3)

A specific cause of injury could only be identified in 21% of these cases [10]. These corneal abrasions with their multiple etiologies can lead to sight-threatening keratitis and permanent scarring. In a report in the 1970s, patients whose eyes were naturally closed or covered by adhesive tape during general anesthesia did not develop exposure keratitis and showed negative fluorescein staining in the immediate postoperative period. The development and deployment of the handheld slit lamp has made eye examination easier, more convenient, and precise. The detection of tiny corneal injuries can now be achieved with the use of the slit lamp in fluorescein-stained eyes which otherwise could have been missed or gone undetected under direct light observation.

In the study using a handheld slit lamp [11], corneal injuries were detected in a few patients with adhesive tape protection or hydrogel patch with higher incidence than was reported in other studies [8, 9], hence greater accuracy of detection. Having studied the use of hydrogel and adhesive tape protection, this group started advocating for the use of the convenient handheld slit lamp immediately postsurgery to check for postsurgical eye injuries, which would provide instructions for the use of protective eye drops or ointment after surgery to avoid eye discomfort and even permanent ocular sequelae [11]. Therefore, the handheld slit lamp is more accurate and represents a better way of evaluating corneal injury during general anesthesia.

This study of 76 patients also showed that there was less ocular damage in the hydrogel group than the adhesive tape group ($p < 0.01$). Twelve eyes (15.8%) in the hydrogel patch group and 30 eyes (39.5%) in the adhesive tape group showed ocular injury immediately after surgery. All eyes with positive staining recovered spontaneously within 24 h. At this time, there is no stan-

dard method of protecting the cornea during general anesthesia for non-ocular surgery.

Now, since it is considered that direct trauma and destruction of tear film are the major culprits in corneal abrasion, it is imperative that strategies that reduce both phenomena be employed in the reduction of same. Currently the practice of perioperatively taping the eyelids closed is not without its shortcomings. The practice of instilling ointment is uncommon. Both practices have shortcomings, including foreign body sensation and blurred vision. Thus, it may be time to standardize eye protection (Table 14.2).

Table 14.2 *Comparative chart of hydrogel eye shields with medical adhesive tape* to prevent exposure keratitis

Item	Medical adhesive tape	Hydrogel eye shields
Principle effect	Mechanical closing	Mechanical and moisture closing environment
Duration of action	Longer time in surgery	Over 8 h
Safety	Easy to pull up skin in friable patients and cause irritability	Good compatibility
Water percentage	No	Over 70%
Protection	Weak	Strong
Adhesiveness	Strong	Suitable
Convenience	Disposable	Disposable, without dirtying, convenient
Sight dim/ irritation	No	No
Skin irritation	Can cause serious irritation	No
General effect	Common	Better

Adapted from the chart comparing Jujiu eye shields with other methods used in the prevention of exposure keratitis but here only showing differences between the hydrogel eye shield and adhesive tape [11]

Anatomy Review The cornea is an avascular structure that is comprised of five histologically distinct layers. A pre-corneal tear film that is composed of three layers – lipid, aqueous, and mucin – protects the cornea. The outermost lipid layer prevents evaporation of the aqueous layer and acts as a lubricant. The aqueous layer oxygenates the corneal epithelium. The main function of the mucin layer is to create a hydrophilic surface for the corneal epithelium. The pre-corneal tear film regenerates by blinking; therefore, the absence of blinking during general anesthesia makes the cornea susceptible to injury/damage [12] (Figs. 14.1, 14.2, and 14.3).

The cornea is highly sensitive to hypoxia, corneal oxygen partial pressures dramatically decreasing even with as little as 30 s of hypoxia [13]. This leads to corneal edema and the potential for epithelial layer loss. This epithelial loss leads to corneal abrasion. Hence any physiological factor that leads to a reduction in corneal blood flow has the potential to predispose patients to corneal injury. Malpositioning of the head, pressure from incorrectly applied facemasks, or any application of mechanical objects, be it for a brief period, that causes undue pressure to the eye hence reduction in arterial blood flow or elevated intraocular pressure can predispose patients to corneal injury.

14.4 Function of the Cornea

The cornea has a threefold role: protection, transmission, and refraction.

Protection The cornea is critical in keeping intact the fragile intraocular contents, which are needed to maintain the function of the eye. The corneal epithelium is a tight, protective, stratified squamous epithelium. This comprises five to seven layers of cells, which are firmly attached to the underlying stroma. Like other epithelia, the corneal epithelium continually sheds cells to the environment. In this way, it helps impede the progress of pathogens into the relatively deficient stromal tissue.

The cornea provides three modes of protection:

1. Mechanical protection
2. Transport protection
3. Light protection

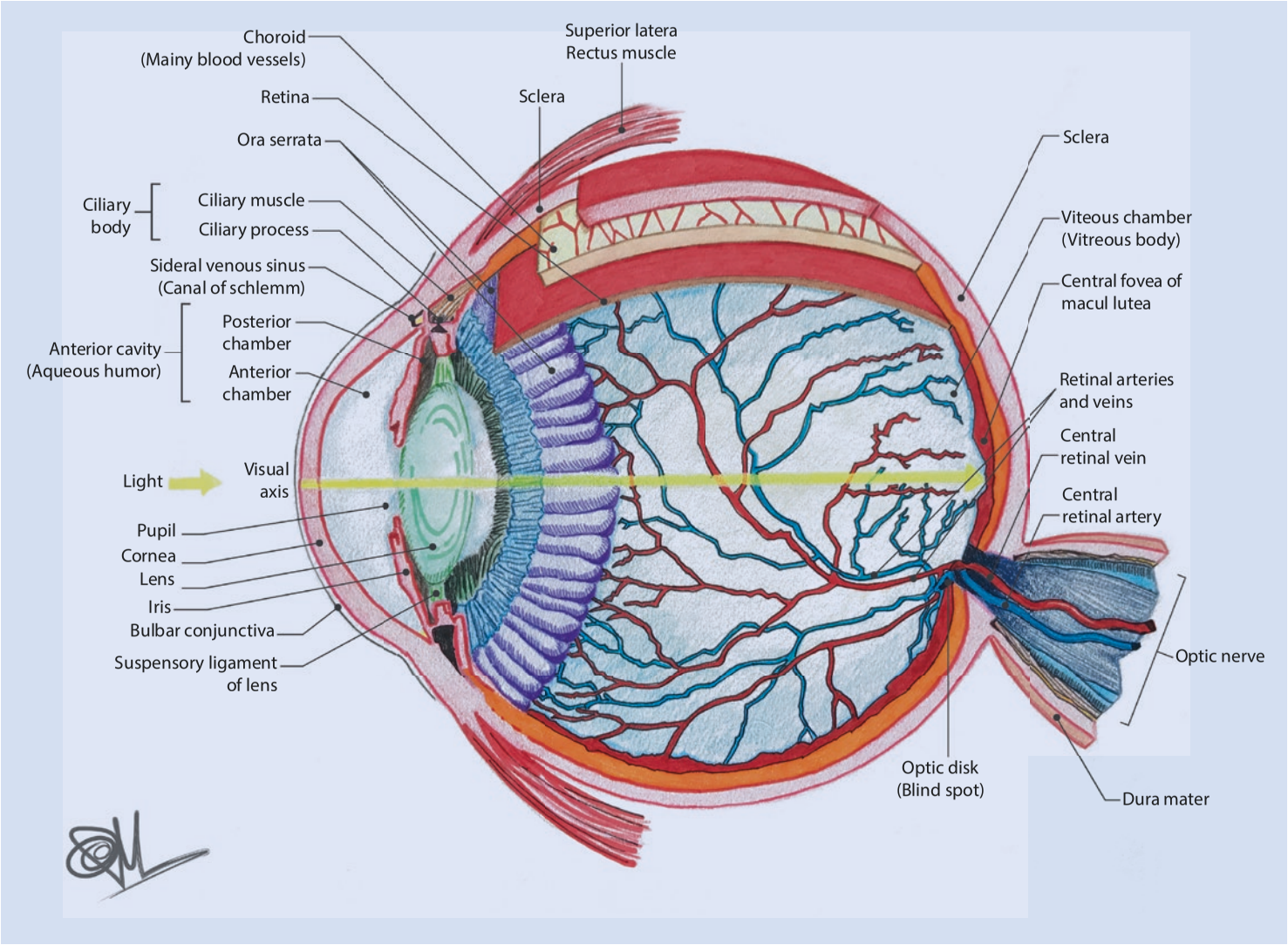

Fig. 14.1 The vertical section of the right eye from the nasal side. Illustration by Equiano Mosieri. (Adapted from ▶ scienceclarified.com)

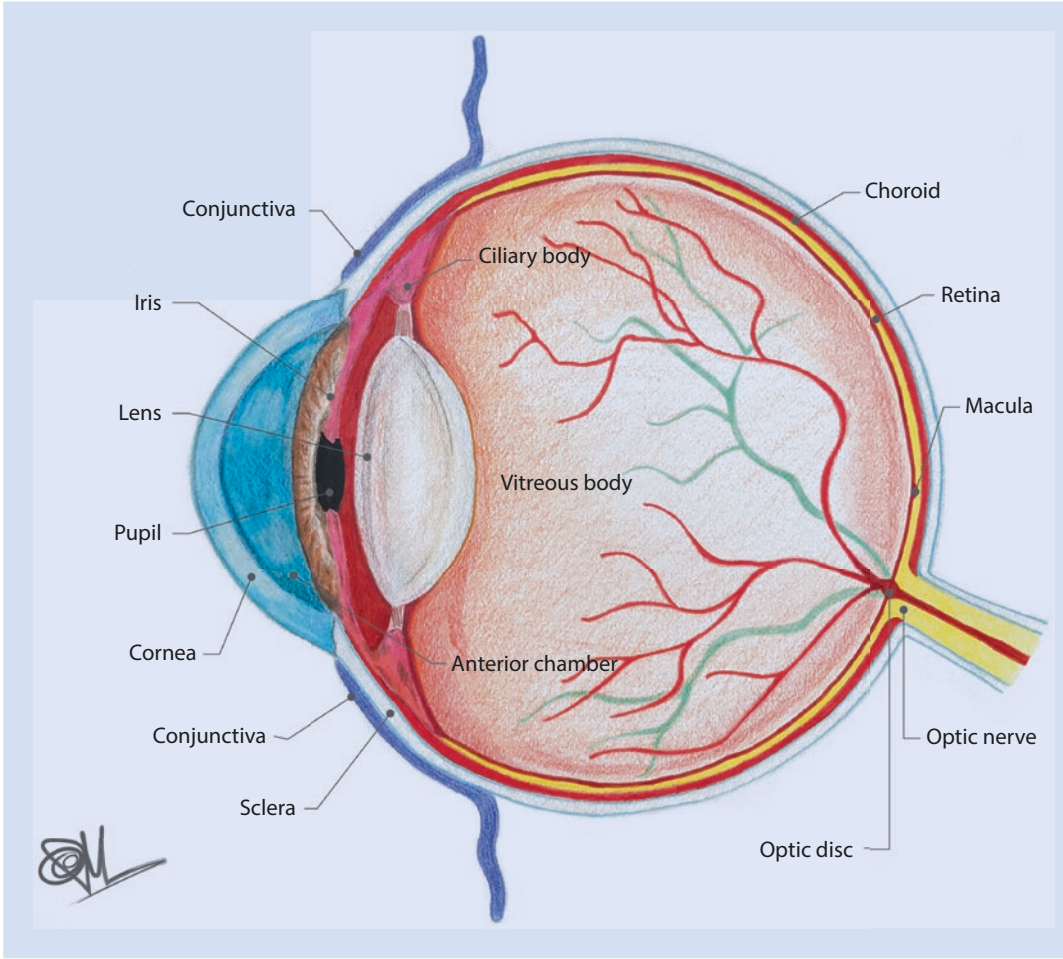

Fig. 14.2 Simplified eye diagram. Illustration by Equiano Mosieri. (Adapted from ▶ allaboutvision.com)

Mechanical protection is achieved by highly aligned and tough collagenous lamella, which are arranged to withstand biaxial loads and therefore provide significant mechanical protection to the intraocular contents.

Transport protection is provided by the corneal epithelium. Since it is the leading surface of the ocular system, it is subject to chemical, mechanical, and pathological insult. It handles this difficult environmental insult by generating and sloughing cells, while it still continuously preserves tight junctional complexes at all times [14]. A continuous supply of proliferative basal cells derived from stem cell niches at the limbus ensures the sturdiness of the endothelial coverage of the stroma [15]. If stem cell niches are not compromised, any damage to the epithelium is repaired quickly (within 3–5 days). Any loss or damage to stem cell niches presents a very serious condition for which there are limited treatment options. The cornea and the lens are thought to act together as cooperative special filters which protect the retina from toxic UV radiation.

Transmission The cornea is able to transmit about 95% of the incident radiation in the accepted visible spectrum. The cornea has to be maintained in a relatively dehydrated state. If cornea stroma were allowed to absorb fluid to equilibrate internal pressure, it would become opaque. So corneal structural architecture needs to be maintained and protected, hence high vigilance during surgery and anesthesia.

Refraction The corneal curvature is involved in refraction but exact mechanism of its control and maintenance is not well understood.

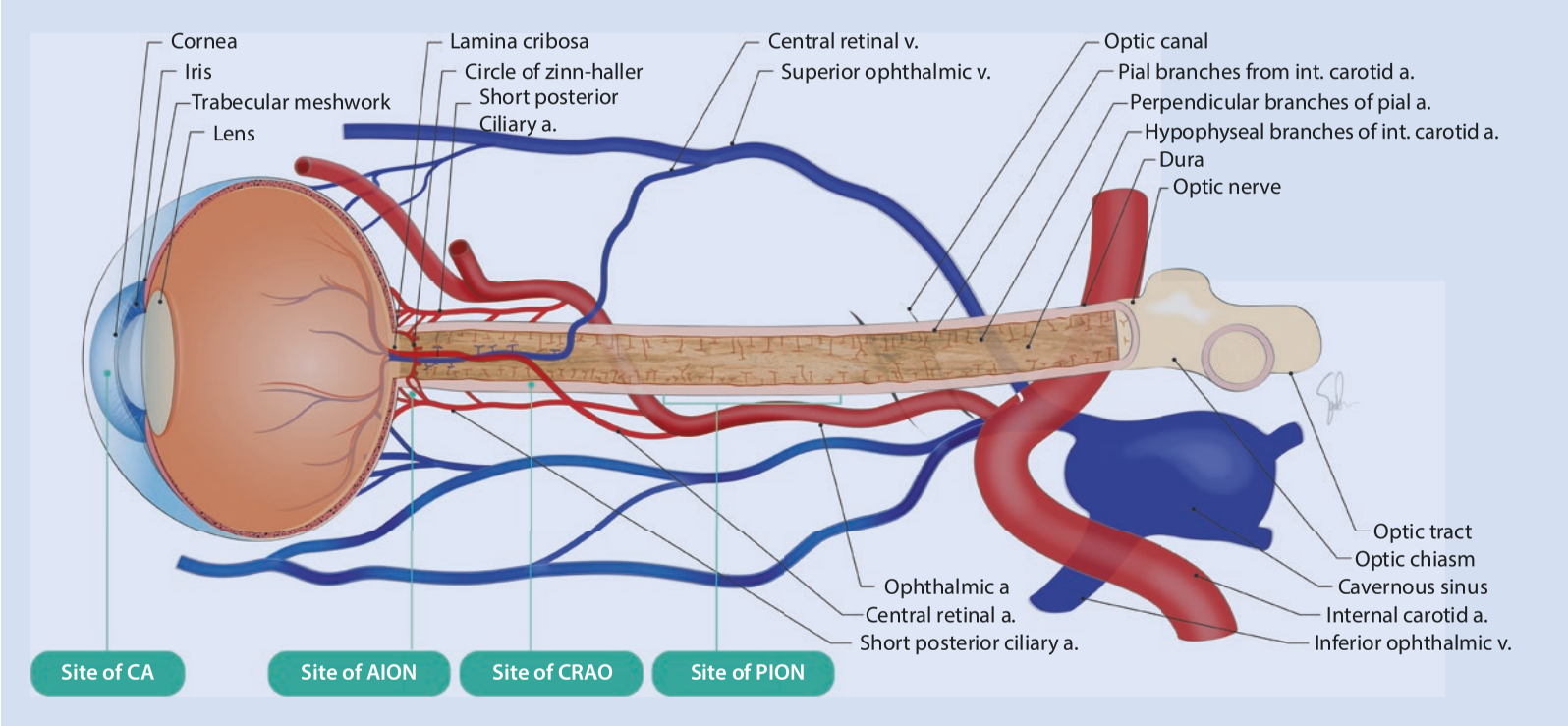

Fig. 14.3 Diagram showing the sites of occurrence of different eye injuries and the causes. Illustration by Frances Mak. (Adapted from Mendel et al. [17])

The Neurovasculature of the Eye Branches of the internal carotid artery provide the arterial supply of the optic nerve and the retina. The central retinal artery solely supplies the retina. Veins of the retina empty into the cavernous sinus. The location of anterior ischemic optic neuropathy (AION) is anterior to the lamina cribrosa. The cause of AION is most probably secondary to occlusion of the posterior ciliary artery. Posterior ischemic optic neuropathy (PION) occurs posterior to the laminar cribrosa. The cause of PION is improper pial vascular supply. Central retinal artery occlusion (CRAO) can be caused by emboli or any factor that can cause globe compression that results in loss of blood supply of the surface layer of the optic disk. Corneal abrasions (CA) are due to decreased tear production and inhibition of the corneal reflex and any factor that contributes to either.

14.5 Injuries Due to Patient Movement

In the closed claims analysis, the medium payment for claims that involved patient movement was ten times greater than for non-movement claims ($90,000 vs. $9000; $p \leq 0.01$) [6]. Anesthesiologist reviewers declared care rendered in general anesthesia "movement" claims as meeting standards in only 19% of claims [6].

14.6 Injuries Due to Prone Position

Significant physiologic changes are associated with the prone position (Fig. 14.4). If proper attention to detail is not paid to properly apply padding and place supporting bolsters, there will be undue and significant pressure on the abdomen and thorax. Increased thoracic pressure leads to raised central venous pressure and a reduction in left ventricular filling. This will in turn lead to reduced ventricular volume, stroke volume, and cardiac output and eventual reduction in blood pressure.

Usually surgery in the prone position is a necessity when access to posteriorly positioned anatomic structures is required. The prone position is known to be fraught with many complications, which could be associated with the type of surgery and the physiological changes that occur with increased pressure to anterior anatomic structures. In a systematic review of 53 papers,

Fig. 14.4 **a–c** Significant physiologic changes are associated with the prone position

Kwee et al. [16] noted that several studies discussed postoperative visual loss, with fewer studies addressing other complications which had lower levels of evidence. Postoperative visual loss and cardiovascular complications, including hypovolemia and cardiac arrest, had the most studies and the highest level of evidence. Among the evidence-based recommendations are careful planning for optimal positioning, careful padding of pressure points, timing, and an increased level of vigilance when operative prone positioning is

required. Most complications are due to inappropriate pressures to vital structures and cardiovascular and pulmonary changes and can result in prolonged hospitalization, permanent disability, or death. Postoperative visual loss can result from inappropriate orbital pressure, and this can also be a permanently debilitating condition. Half the papers addressed postoperative visual loss (POVL) though it had a low incidence rate, and 13 of the papers (25%) discussed cardiovascular complications (hypovolemia and cardiac arrest).

Increased thoracic pressure will also lead to respiratory changes that include reduction in lung compliance and high peak airway pressure which will lead to reduced venous return and cardiac output and eventual reduction in blood pressure.

Abdominal and pelvic compression will lead to raised intra-abdominal pressure, venous pooling secondary to inferior vena cava compression, and eventual reduction in venous return, cardiac output, and blood pressure (◘ Table 14.3).

14.7 Postoperative Visual Loss and Other Ophthalmic Injuries Associated with the Prone Position

The rate of POVL associated with the prone position is estimated to be between 0.05% and 1%.

14.8 Ischemic Optic Neuropathy and Orbital Compartment Syndrome (OCS)

Direct orbital pressure can lead to trauma. This can lead to pain, conjunctival edema, chemosis, hemorrhage, and visual loss.

Ischemic optic neuropathy (ION) is caused by damage to the optic nerve secondary to increased intraocular pressure and orbital venous pressure. ION is classified depending on if it occurs anterior to the lamina cribrosa, anterior ION, or posterior ION. Posterior ION is more common postoperatively and is more severe than anterior ION.

Direct pressure on the orbits causes an increase in intraocular pressure (IOP). This increase in combination with raised intra-abdominal pressure reduces venous return in the orbit, thereby increasing venous pressure and edema. If fluid replacement has been high and with crystalloids more than colloids, the edema can be aggravated, thereby worsening intraocular pressure. Orbital apex congestion can result in orbital compartment syndrome (OCS) and an ischemic orbit. Decreased perfusion pressure on the optic nerve results in ION. Even in the presence of sufficient supportive facial padding, ION and OCS are well-established risks.

14.9 Central Retinal Artery Occlusion (CRAO)

Hypotension, compression, vasospasm, and emboli can all lead to CRAO. It has been particularly linked to plaque displacement from carotid arteries which can lead to blockage of the central retinal artery. It is almost always irreversible.

14.10 Cortical Blindness (CB)

Emboli to the posterior cerebral artery territory or significant hypotension and bilateral watershed infarctions affecting the visual cortex can lead to cortical blindness. There is a possibility of improvement in the succeeding weeks, but complete recovery of sight is unlikely.

14.11 Acute Angle-Closure Glaucoma

The prone position can cause a forward shift in the lens-iris diaphragm. This impinges on the drainage angle recess and obstructs the aqueous humor outflow, thereby increasing intraocular pressure and hence optic nerve injury in those patients predisposed to acute angle-closure glaucoma, even in short surgical procedures.

Types of anesthesia used for eye surgery (this section will not include illustrations of the anatomy and nerves that are targeted for blocks):

- General
- Local with sedation
- Monitored anesthesia care
- Block with or without sedation
  - A higher incidence of eye surgery injury is associated with eye block coupled with sedation rather than with sedation alone. These injuries are generally associated with the block placement which can result in

Table 14.3 Summary of identified causes of postoperative vision loss (POVL) and malpractice claims

Identified cause of POVL	Pathophysiology	Clinical presentation	Incidence range	Post op injury malpractice claim incidence (1980–2011)	Permanent eye injuries (1980–2011)	Median claim payment (1980–2011)
Corneal abrasion	Decreased corneal protection through inhibition of corneal reflex and decreased tear production [18]	Complaints of blurry vision, tearing, redness, photophobia, foreign body sensation [19]	0.17–44% during the perioperative period [19]	31% (1980–1994) 18% (1995–2011) [20]		
Ischemic optic neuropathy	Not well understood; proposed mechanisms include increased intraocular pressure and ophthalmic vein congestion [21]	AION: painless and progressive deterioration of vision, optic disk edema which resolves spontaneously in 7.9–11.4 weeks	89% of POVL occurring from spine surgery;	Optic nerve injuries 5% (1980–1994)	49% 1980–1994	$128,100
		PION: acute painless visual loss in one or both eyes that can progress to complete blindness [22]	Posterior ION (PION) accounts for 60% of these cases [25]	38% (1995–2011) [23]	73% 1995–2011 [23]	$424,750 [23]
Central retinal artery occlusion	Emboli and direct pressure on the globe [24]	Typically manifests unilaterally with "cattle tracking" of the arterioles with a "cherry-red" spot visible during fundoscopic exam [25]	11% of spine surgeries [26]			
Cortical blindness (CB)	Ischemia or extreme hypoperfusion of the occipital lobes [27]	Deteriorating vision that results in partial or bilateral POVL [27]	0.0038% of POVL cases due to CB [26]	–		

Adapted from Mendel et al. [17] Vision loss during non-ocular surgery

permanent injury in most cases. Peripheral nerve blocks however are associated with temporary injuries. The most major cause for concern is local anesthetic toxicity which can result in brain damage and death.

14.12 Preparation for Eye Surgeries

Depending on the type of case and patient comorbidities, both surgeon and anesthesiologist should discuss and agree on the type of anesthetic, i.e., general anesthesia, monitored anesthetic care, local anesthesia with sedation, and block with or without sedation that will be a safe option for the patient.

14.13 Consent for Anesthesia: What Should Be Discussed in Patients at Risk for Perioperative Visual Loss?

In a 2016 APSF Newsletter, Stoelting [28] succinctly summarized the discussions carried out by the APSF Board of Directors Workshop in 2015, which will be part of the information proposed to be passed onto these groups of patients and their responsible carers with full understanding. The APSF Board of Directors Workshop on October 2015, in conjunction with the ASA Annual Meeting in San Diego, CA, addressed the topic, "From APSF Educational Videos to Your Practice: How to Make it Happen." Lorri A. Lee introduced the APSF videos that dealt with perioperative visual loss (POVL) and the companion video that presented various scenarios for obtaining informed consent for those patients at risk for POVL. The importance of recognizing that posterior ischemic optic neuropathy (PION) following spine surgery is not caused by pressure on the globe, unlike central retinal artery occlusion (CRAO), was stressed. PION seems to be associated with venous congestion of the head (head down prone position). There is increasing acceptance that the informed consent process should include the risk of POVL in a select group of patients. It was acknowledged that the importance of the informed consent to the patient was also dependent on those responsible for the patient's care being cognizant of the strategies designed to reduce the risk of POVL (► Box 14.1).

Box 14.1 Risk Factors Associated with Ischemic Optic Neuropathy After Spinal Fusion Surgery: The Postoperative Visual Loss Study Group [29]

- Obesity[a]
- Male gender[a]
- Wilson frame[a]
- Lower % colloid administration[a]
- Longer anesthetic duration
- Greater estimated blood loss

[a]Significantly and independently associated with developing ischemic optic neuropathy after spinal fusion surgery

Box 14.2 Advantages of Educational Videos in Advocating Best Practice Changes [30]

- Readily available and free
- Viewed at learner's convenience
- Provide a concise and clear message
- Can be shared by others
- Enduring but can be updated as needed
- Publicly available (accessible to patients)

APSF believes that educational videos provide advantages compared with traditional written information or report when addressing anesthesia patient safety issues and advocating for "best practices" to reduce the possibility of the adverse events described in the video in ► Box 14.2.

There are also POVL resources at the APSF website: ► http://www.apsf.org/resources/povl/

Simulated Informed Consent

Scenarios for Patients at Risk for Perioperative Visual Loss (POVL) (► Box 14.3): ► http://www.apsf.org/resources/povl-consent/.

APSF believes that increased awareness and understanding of risk factors associated with POVL is a timely patient safety topic. Peer-review literature and data from the ASA POVL Registry are evolving in a way that suggest a patient profile at risk for POVL and the steps to take in the surgical and anesthetic management that might reduce the incidence of this devastating complication.

From the APSF data, it seems that the inclusion of the risk of POVL in selected patients in the informed consent for surgery and anesthesia is increasingly being accepted. It is noteworthy that

Box 14.3 APSF Recommendation for Best Practices in Patients at Risk for Perioperative Visual Loss (POVL) [28]

Informed consent should include remote risk of POVL

- If the risk of POVL is not part of the surgical informed consent, it should be part of the anesthesia informed consent.
- The informed consent should include a discussion of risk factors and steps to take to reduce the likelihood of POVL.
- Controlled hypotension is not recommended.

those responsible for caring for these patients are aware of evolving information and strategies designed to reduce the risks of POVL.

14.14 Monitoring During Eye Surgery

Monitoring during anesthesia should include ASA standard monitors, as well as strictly monitoring the level of neuromuscular blockade by using TOF for patients undergoing general anesthesia. In monitored anesthesia care cases, monitoring should also include end tidal CO2 monitoring of spontaneous ventilation in patients.

14.15 Positioning During Eye Surgery

Patients should be positioned comfortably. There should be a preoperative discussion with the patients about the use of restraints to prevent falls and to prevent sudden reaching for their eyes and other unplanned sudden movements. This can be a cause of some of the eye injuries that can occur from patient movement.

14.16 Prevention of Eye Injury

Methods to prevent perioperative corneal injuries include simple measures like simple manual closure of the eyelids shut, use of ointment, paraffin gauze, bio-occlusive dressings, and suture tarsorrhaphy. It is noteworthy that none of the protective strategies are completely effective. Vigilance is key and always required. Since corneal injuries occur by direct trauma, exposure keratopathy, or chemical injury, the anesthesiologist's duty is to ensure proper eye closure to prevent exposure keratopathy. If cleaning materials are inadvertently split into the eye, chemical injury can occur. The only antiseptic skin preparation that is not toxic to the cornea is povidone-iodine 10% aqueous solution. This is therefore the agent of choice for skin preparation of the face when required. [31]

Postoperative visual loss is a much rarer complication in anesthesia. The most frequent cause is ischemic optic neuropathy [31]. Ocular blood flow is determined by arterial pressure, ocular venous pressure, and ocular vascular resistance. Thus, arterial hypotension, elevated venous pressure or raised intraocular pressure, increased resistance to flow, or decreased oxygen delivery (via anemia or hypoxemia) can lead to ischemia of the optic nerve.

Blood flow to the retina is under autoregulatory control and maintained at a constant level until intraocular pressure reaches 40 mmHg. Blood flow to the optic nerve at the disk stops at an intraocular pressure of 60 mmHg, though flow is maintained in the choroidal and retinal circulation [1]. Infarction at this watershed area leads to anterior ischemic neuropathy and gives rise to a visual defect, with a pale edematous optic disk and edema of the optic nerve in the posterior scleral foramen.

The posterior part of the optic nerve is supplied by the pial braches of the ophthalmic artery. These vessels are not capable of autoregulatory control; hence, the posterior part of the optic nerve is more susceptible to ischemia in the event of a drop in perfusion pressure or anemia, leading to posterior ischemic optic neuropathy. There is a slower onset of visual field defect and mild optic disk edema.

The patients at higher risk of ischemic optic neuropathy include those with diabetes, hypertension, smoking, and polycythemia. Other associated factors include prone positioning (doubles intraocular pressure), surgery causing major blood loss and hypotension (e.g., spinal surgery), cardiopulmonary bypass, and bilateral neck dissection.

Postoperative blindness may also be caused by central retinal artery occlusion, by either an emboli from carotid or cardiac lesions or from

direct pressure on the eye, in conjunction with perioperative ischemic optic neuropathy. Fundoscopic examination shows a pale retina with a "cherry-red spot" [25].

14.16.1 Closed Case Claims

Of note is that the median payment for claims involving movement was ten times greater than that for non-movement claims ($90,000 vs. $9000). Hence the legal burden laid on the anesthesiologist's responsibility to ensure patients' immobility especially during ophthalmic procedures carried out under general anesthesia. Of utmost importance is the emphasis on the use of intraoperative neuromuscular monitoring of this patient subset to ensure a positive and good overall outcome for all concerned parties.

Reviewers were only able to identify a mechanism of injury in only 20% of the claims for corneal abrasion. Anesthesiologist reviewers declared the care rendered in the general anesthesia "movement" claims as meeting standards in only 19% of claims [6] (► Box 14.4).

Source: American Society of Anesthesiologists Task Force on Perioperative Visual Loss (2012). Practice advisory for perioperative visual loss associated with spine surgery: an updated report by the American Society of Anesthesiologists Task Force on Perioperative Visual Loss [32].

14.16.2 Conclusion

In conclusion, great attention to detail should be paid during all types of anesthesia. During general anesthesia, simple maneuvers such as carefully taping the eyes shut and using special eye-shield gels go a long way to reduce the occurrence of corneal abrasions. Special precautions should be taken to ensure that no mechanical object or undue pressure is applied to the patient's eyes and that chemical skin preparation does not gain access to the patient's eyes. Early referral to the ophthalmologists of those patients with eye complaint should be encouraged.

APSF believes that increased awareness and understanding of risk factors associated with POVL is a time safety issue. Data from the ASA POVL Registry and peer-reviewed literature are evolving and seems to be pointing to at-risk patients for POVL and necessary steps to take in the surgical and anesthetic management that might reduce the incidence of this devastating complication. There also seems to be increasing acceptance that the informed consent for surgery and anesthesia should include the risk of POVL in selected patients. Those responsible for patient care should be cognizant of the changes and strategies designed to reduce the risk of POVL.

Box 14.4 Practice Advisory for Perioperative Visual Loss Associated with Spine Surgery: Advisory Statement

American Society of Anesthesiologists Task Force on Perioperative Visual Loss.

Practice advisory for perioperative visual loss associated with spine surgery (updated report, 2012).

Preoperative preparation:

- Inform patients who will undergo prolonged spine surgery in the prone position with or without substantial blood loss of the risk of postoperative visual loss.

Intraoperative management:

- Monitor blood pressure continually. Aim to maintain MAP within 20–25% of baseline.
- Administer colloids along with crystalloids to maintain euvolemia for patients who have substantial blood loss.
- Monitor hemoglobin or hematocrit periodically during cases with substantial blood loss.
- Position the head at the level of the heart or higher and in a neutral forward position, i.e., without significant neck flexion, extension, lateral flexion, or rotation when possible.
- Avoid direct pressure on the globe to prevent central retinal artery occlusion. (Perform frequent eye checks every 15–20 min with a mirror attachment to the headrest. This ensures that prolonged inappropriate external orbital pressure is avoided.)
- Consider staging spine procedures in high-risk patients.

Postoperative management:

- Vision should be assessed when patient becomes alert after anesthesia.
- If there is potential visual loss:
  - Urgent ophthalmologic consultation should be obtained.
  - Additional management may include optimizing hemoglobin or hematocrit, hemodynamic status, and arterial oxygenation.
  - Consider magnetic resonance to rule out intracranial causes of visual loss.

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Severe Peripheral Nerve Injury

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_15

15.1 Introduction

In the setting of anesthesiology practice, nerve injuries can occur during general anesthesia as a result of patient positioning and/or tourniquet placement. During regional anesthesia, there is the potential for direct injury to the nerve. Perioperative nerve injuries (PNI) are the third most common cause of anesthesia-related litigations [1]. In the American Society of Anesthesiologists (ASA) closed claims analysis, nerve injuries comprise 15–16% of the claims. Etiology of nerve injuries can be multifactorial. The most likely pathologic mechanisms of injury include stretch, compression, ischemia, and environmental abnormalities [2]. The majority of these PNIs are preventable. This chapter classifies identifiable risk factors and how they can be evaded. Clinical manifestations of commonly encountered nerve injuries are described, so the perioperative service providers can quickly recognize a peripheral nerve deficit. The diagnosis can be aided by EMG, nerve stimulation, and certain imaging techniques. An overview of surgical and nonsurgical management techniques is described.

15.2 Risk Factors and Causes of Nerve Injury

Risk factors are often multifactorial, and it is helpful to classify these into various categories: patient-related, anesthesia-related, and surgery-related causes.

15.2.1 Patient-Related Factors

1. Preexisting neurologic disease: Preexisting neurologic disease or nerve injury, although sometimes insufficient alone to cause clinical symptoms, limits the neurologic reserve of a nerve, meaning that it is more susceptible to develop clinical deficits from a second injury (the double crush syndrome) [3]. Diabetic patients may develop neuropathy of peripheral nerves. These patients are at greater risk of a secondary, possibly subclinical, insult that may result in a permanent nerve injury [4].
2. Hypertension: A retrospective analysis of 380,680 patients in a 10-year period identified hypertension as a risk factor for PNI [2].
3. Vascular injury: Ischemic vascular injuries may be related to an embolic phenomenon, direct trauma, or vasoconstriction of the artery of Adamkiewicz that causes anterior spinal cord artery syndrome (ASAS). Vascular injury may also arise from watershed infarct related to hypotension or vasoconstriction [5].
4. Infectious etiology: Postsurgical inflammatory neuropathy is a cause of PNI that can present as pain and weakness in a focal, multifocal, or diffuse pattern including epineural perivascular lymphocytic inflammation, axonal degeneration, and microvasculitis [6].
5. Chemotherapy: Patients on chemotherapy are more susceptible to peripheral nerve injuries when compared to healthy individuals as shown in case reports [7, 8].
6. Body habitus extremes: Obesity, bulky musculature, underweight, and malnutrition are also risk factors for PNIs.
7. Tobacco use: Smoking has been identified as a risk factor for PNI [2].

15.2.2 Anesthesia-Related Factors

1. Mechanical trauma: Injury to the nerve may occur directly with a regional block needle or catheter. Direct nerve perforation and injury to the fascicle or perineurium is possible; nerve edema and hematoma are known complications. Peripheral nerve blockade-related PNI is most severe with intrafascicular injection [9]. Anatomic variance of the spinal cord can make it more susceptible to direct trauma during neuraxial techniques; this includes low-lying conus, inaccurate determination of vertebral interspace, and incomplete midline fusion of the ligamentum flavum [5].
2. Local anesthetic use: Local anesthetics decrease neural blood flow in a concentration-dependent manner. The addition of epinephrine to local anesthetic solution makes a susceptible nerve more prone to injury, especially in patients with microvascular disease [10]. The internal milieu of the nerve fascicle is maintained by an intact perineurium and vascular endothelium. High concentrations of extrafascicular

anesthetics can produce axonal injury independent of edema formation. Injection of local anesthetic agent within the nerve fascicle is clearly neurotoxic and may damage the perineurium [11]. And other incidental injection of chemical agent into intrathecal space may cause spinal cord injury [12].

3. Improper positioning: In most litigation claims, patient positioning is considered to be the responsibility of the anesthesiologist who provided anesthesia service to the patient. It is important to be mindful and avoid placing patients in positions that will anatomically change the orientation of the nerve, causing stretching or compression injuries. It is helpful to perform a check before surgical draping. Positions known to predispose to PNI include arm abduction of more than 90°, shoulder girdle compression, pronation of arms, lateral rotation of the shoulder in combination with shoulder abduction, contralateral neck flexion, full elbow extension, compression of ulnar nerve by the table edge when tucking arms at the sides, and wrist extension [13]. ◘ Table 15.1 lists positioning devices that are placed by surgical staff in general; the anesthesiologist should be aware of potential nerve injury that may result.

◘ **Table 15.1** Causes of nerve injuries

Positioning devices	Perioperative factors
Table straps	Coagulopathy or presence of hematoma near the nerve
Leg holders	Infection/presence of abscess near the nerve
Shoulder braces	Hypovolemia and hypotension
Positioning frames	Dehydration
Headrests	Hypoxia
	Electrolyte imbalance
	Hypothermia

15.2.3 Surgery-Related Factors

1. Compressive dressings and casts: The underlying cause of all tissue damage is inadequate perfusion. Ischemia may be due to occlusion of major vascular structures or restricted capillary perfusion. Metabolism continues despite inadequate perfusion, and tissue acidosis ensues, with failure of membrane pumps. As a result, sodium ions accumulate intracellularly, water moves into the cells, and intracellular volume increases. Tissue edema results and contributes to ischemia by increasing tissue pressures and preventing the movement of fluid and nutrients from the capillaries into the cells [14].
2. Tourniquet pressure and duration: PNI may result from inadequate blood supply when tourniquets are placed with high pressures, prolonged immobility, or a hematoma surrounding a nerve. Pneumatic tourniquet pressures of more than 400 mmHg are known to be associated with postoperative nerve injury [15]. The minimal effective pressure should be used for occluding blood flow to the extremity. General guidelines suggest using tourniquet pressures no greater than two times the systolic pressure for the lower extremity and 70–90 mmHg greater than the systolic pressure for the upper extremity. Additionally, because tourniquet time is an independent risk factor, tourniquet times should be limited to less than 2 h to decrease the risk of neural ischemia [16].
3. Prolonged bed rest: Postoperative bed rest for a prolonged period is a recognized risk factor for ulnar neuropathy. It could be implicated in other PNIs also [17]. The timing and goals of physical therapy should be discussed.

15.3 Clinical Manifestations of Nerve Injury

Certain peripheral nerves are particularly predisposed to mechanical injury because of their anatomical location. The terms entrapment or compression neuropathy are used when the nerve is compressed, stretched, or angulated by adjacent anatomic structures to such an extent that dysfunction occurs. While there are several classifications of nerve injuries (◘ Tables 15.2 and 15.3) in

Table 15.2 Classification of nerve injuries

Lundborg classification	Physiological conduction block		Myelin damage	Axonal damage	Axon + endo damage	Axon + endo + peri damage	Axon + endoneurium + perineurium + epineurium damage
	Type A	Type B					
Sunderland classification	I			II	III	IV	V
Seddon classification	Neurapraxia (transient block)			Axonotmesis (lesion in continuity)	Neurotmesis (division of a nerve)		
Recovery and prognosis	Recovery in weeks to months. Good prognosis			Good prognosis	Guarded prognosis. Surgery may be required	Poor prognosis. Surgery necessary	Poor prognosis. Early surgical intervention needed

clinical practice, nerve injuries are often on a spectrum of severity.

Sunderland II and above are considered non-degenerative.

In most cases, injuries resolve within 6–12 weeks. More than half of the patients typically regain complete sensory and motor function within a year.

15.3.1 Upper Extremity Peripheral Nerve Injury (Table 15.4)

15.3.1.1 Brachial Plexus Injury

Brachial plexus is innervated via C5–T1 nerve roots. If upper nerve roots are involved (C5, C6), a typical "waiter's tip" position is seen in which the hands are by the side, medially rotated, and pronated. This is due to involvement of *musculocutaneous*, *axillary*, and *suprascapular* nerves. If the lower nerve roots C8–T1 are involved, numbness in the ulnar nerve distribution and a "claw hand" can be observed [19].

Table 15.3 Definitions of closed versus open injury

Closed nerve injury	Open nerve injury
Nerve injuries in continuity without disruption in continuity of nerve. Spontaneous recovery is possible. Surgery is indicated only if no recovery after 3 months	Open injury along the nerve course provoked by knives, propellers, glass, or scalpel. Immediate surgery is required in open nerve injuries

15.3.1.2 Ulnar Neuropathy

Ulnar nerve injury is significantly more common than any other nerve injury. Sensory deficit is characterized by tingling or numbness along the fifth/little finger. Weakness of abduction and/or adduction of the fingers can be present, while motor involvement is appreciated by an ulnar claw hand which entails hyperextension of the metacarpophalangeal joints and flexion at the distal and the proximal interphalangeal joints of the fourth and the fifth fingers [18]. For majority of patients with ulnar neuropathy, manifestations began 2–7 days after surgery. Symptoms are most often mild, confined to sensory deficits, and were completely reversible [20].

15.3.1.3 Median Nerve Injury

The median nerve is supplied by C5–T1 nerve roots. Median nerve injury usually results from invasive procedures around the elbow and direct injury via regional anesthesia techniques. Early symptoms are pain and paresthesia confined to a median nerve distribution in the hand, i.e., involving primarily the thumb, index, and middle fingers as well as the lateral half of the ring finger. Motor manifestations include weakness of

Table 15.4 Specific clinical manifestations of upper extremity nerve injuries [18]

Nerve	Sensory deficit	Motor deficit
Median nerve	Numbness over the index finger	Weakness of abduction of the thumb
Ulnar nerve	Numbness over the little finger	Weakness of abduction and/or adduction of the fingers
Radial nerve	Numbness over anatomical snuffbox	Weakness of extension at the distal interphalangeal joint of the thumb and of the wrist and finger extensors
Musculocutaneous nerve	Numbness along lateral aspect arm	Weakness of flexion of the elbow
Circumflex nerve	–	Weakness of abduction of the shoulder
Brachial plexus	Combinations of sensory lesions within the median, ulnar, radial, musculocutaneous, and circumflex nerve territories	Combinations of motor lesions within the median, ulnar, radial, musculocutaneous, and circumflex nerve territories

Table 15.5 Most common nerve injuries as per ASA closed claims analysis [19]

1. Ulnar nerve	28%
2. Brachial plexus	20%
3. Lumbosacral nerve root	16%

abduction and opposition of the thumb (also referred to as "ape hand"), weak wrist flexion, and the forearm being kept in supination. The muscles of the thenar eminence become wasted, and the hand appears flattened [18].

15.3.1.4 Radial Nerve Injury

The radial nerve may be compressed at the axilla by pressure against the vertical portion of an anesthesia screen or an arm board positioned at an incorrect height. The resulting deficit is primarily motor manifested as weakness of extension at the distal interphalangeal joint of the thumb and of the wrist and finger extensors resulting in "wrist drop" (Table 15.5).

15.3.2 Lower Extremity Peripheral Nerve Injury (Table 15.6)

15.3.2.1 Nerve Injuries in Lithotomy Position

The most commonly injured lower extremity nerve in patients undergoing surgery in lithotomy position is the common peroneal nerve. This nerve is supplied via L4–S2 and is responsible for foot dorsiflexion and toe extension. Thus common peroneal nerve injury can lead to "foot drop." However, similar to upper extremity injuries, sensory deficits are more common than motor deficits. Sensory manifestations are described along the anterolateral border of the leg and the dorsum of the digits except those supplied by saphenous and sural nerves [18]. The sciatic nerve can be injured in the lithotomy position as well. Sciatic nerve injury has also been reported postcoronary artery bypass graft, possibly from prolonged nerve pressure along with low perfusion pressure.

15.3.2.2 Femoral Nerve Injury

The femoral nerve can be injured with compression at the pelvic brim by retractors as seen in gynecological procedure, lithotomy position, and direct invasive procedures (central line placement, arterial line insertion) in the femoral region. Sensory deficit is seen as numbness over the anterior thigh and medial aspect of the leg along the distribution of saphenous nerve. Motor deficit is usually first recognized as a difficulty in climbing stairs due to weakness of flexion of the hip and knee extension.

Table 15.6 Specific clinical manifestations of lower extremity nerve injuries

Nerve	Sensory deficit	Motor deficit
Femoral nerve	Numbness over the anterior thigh and medial aspect of the leg	Weakness of flexion of the hip and knee extension
Obturator nerve	Numbness in the upper medial ventral thigh region	Weakness of adduction of the hip
Sciatic nerve	Numbness below the knee	Weakness of ankle dorsiflexion and plantar flexion. Also, weakness of knee flexion, if the lesion is proximal
Common peroneal nerve	Numbness along the lateral aspect of the leg below the knee	Weakness of dorsiflexion of the ankle and toes
Tibial nerve	Numbness along dorsal aspect leg	Weakness of plantar flexion of the ankle and toes

15.3.2.3 Pudendal Nerve Injury

The pudendal nerve might be injured during orthopedic surgeries and gynecological injuries. In hip arthroscopy, pudendal nerve injury may occur in as many as 10% of cases. Probable mechanism involves nerve compression. Clinically, pudendal nerve injury presents as perineal and groin pain followed by a sensory deficit, which may be aggravated by sitting position. Rarely there

might be sexual dysfunction. Recommendations for prevention or reducing the risk of pudendal nerve injury include limiting traction to only critical portions of the operation and use of good padding on the footplate and at the perineum by the use of a large pelvic support.

Peripheral nerve injuries can have demoralizing effects on patients with decreased ability to perform daily functions and routines. A retrospective database review of 490 patients with peripheral nerve injuries showed negative psychosocial effects, which were more pronounced in case of proximal upper extremity peripheral nerve disorders when compared to single site nerve compression neuropathies. The impact on quality of life was strongly correlated with pain and depression [21].

15.4 Evaluation and Diagnosis

Evaluation and diagnosis of peripheral nerve injuries begin with a detailed history to detect any preexisting nerve deficit and thorough physical examination to determine the site of lesion. Physical exam should be able to show if the nerve deficit is sensory or motor and involves single or multiple nerves. In actuality, nerve injuries are on a spectrum. The localization of the nerve deficit is based on the distribution of abnormal findings. Ideally, the evaluation of perioperative nerve injuries involves a consultation with a neurologist particularly if there is a motor or mixed deficit. Electromyography (EMG) and nerve stimulation studies are also important in determining the extent of injury. These electrophysiology tests can help distinguish between nerve dysfunction due to *axonal degeneration* (such as with PNI) and nerve dysfunction due to *demyelination* (such as with chronic compressive lesions including carpal tunnel syndrome). Certain imaging modalities might prove helpful as well.

15.4.1 Electromyography

EM may reveal evidence of denervation of the affected muscles and can be used to determine whether any motor units remain under voluntary control. EMG can help determine if a deficit was present preoperatively, as denervation signs take approximately 3 weeks to develop [22]. When evoked potentials are studied, reduced amplitude in evoked responses indicates axonal loss, and increased latency indicates demyelination.

15.4.2 Nerve Conduction Study

Nerve conduction study (NCS) is a measurement of the speed of conduction of an electrical impulse through a nerve. NCS can determine nerve damage and destruction. It tells us the function of both motor and sensory nerves. The conduction velocity and the size of muscle response theoretically estimate the number of axons and muscle fibers activated. NCS evaluates the functional integrity and localizes the focal lesion [23].

15.4.3 Imaging

MRI and ultrasound are the two advanced modalities most frequently used to assess upper extremity nerve entrapment [24]. 3 Tesla MRI can provide high-resolution imaging to visualize the peripheral nerve and confirm the site of lesion. It can be particularly helpful if used in adjuvant to EMG/NCS.

15.5 Management of Severe Nerve Injury

The recovery time of the injured nerve depends on various external factors including most importantly early nerve exploration and repair. However, it should be known that axonal regeneration rate is as slow as only 1–2 mm per day and there is almost no treatment to accelerate this process [25]. Irreversible motor unit degeneration starts 12–18 months after denervation of the muscle but may persist for 26 months [26]. Recovery and regeneration of sensory nerve may take even longer (Table 15.7).

15.5.1 Endogenous Nerve Healing in Response to Injury

Acute inflammatory changes at the site of the peripheral nerve lesion include an increase in local leukocytes that, along with the Schwann cells, help to clear the cell body of myelin debris [29, 30]. The concomitant interaction of Schwann

Table 15.7 The effects of neurotrophic factors in peripheral nerve regeneration [27, 28]

Neurotrophic factors	Effect
Nerve growth factor (NGF)	Survival signaling, neurite outgrowth
Glial cell line-derived neurotrophic factor (GDNF)	Sensory regeneration
Brain-derived neurotrophic factor (BDNF)	Positive modulation of peripheral nerve myelination
Neurotrophin-3 (NT-3)	Negative modulation of peripheral nerve myelination
Ciliary neurotrophic factors (CNTF)	Survival of motor neurons

cells and surrounding environment promotes axonal sprouting, typically at a rate of 1–4 mm per day [31, 32]. Electrodiagnostic testing evaluates the degree of nerve injury and determines whether there is an early reinnervation at 6 weeks. If there is no evidence of reinnervation at the end of 3 months, surgical intervention should be considered [33].

15.5.2 Surgical Treatment

15.5.2.1 Timing of Nerve Repair

Mackinnondemonstrated that early nerve repair results in improved functional outcomes. There is an accepted window period of 12–18 months for muscle reinnervation to occur to achieve functional recovery before irreversible motor end plate degeneration occurs [34]. It is worth noting that there is no definite evidence to support this nerve regeneration as late as 26 months after injury and reconstruction [28]. More proximal nerve injuries, such as a brachial plexus injury, involve distances of up to a meter and require periods of more than 2–3 years for regenerating axons to reach and reinnervate the hand muscles. In such cases, it is well recognized clinically that there may be little or no restoration of function [25]. Timing of nerve repair depends on the type of nerve injury sustained, condition of the wound, and vascular supply to nerve bed [35]. Historically primary nerve repair was performed 3 weeks after initial injury to provide time for full Wallerian (anterograde) degeneration. Currently, primary repair is performed within 72 h and up to 7 days after nerve injury [36]. However, when immediate repair criteria are not met, delayed repair is required.

15.5.2.2 Direct Repair

Direct nerve repair with epineural microsutures is the gold standard surgical treatment for severe axonotmesis and neurotmesis injuries. Epineural repair is performed when a tension-free coaptation in a well-vascularized bed can be achieved [28]. The modality of direct repair is shown as in [37].

- *End-to-end repair*: The simplest class of surgical repair from a technical standpoint is the end-to-end repair. In this surgical procedure, the entire nerve trunk is sutured as a unit by application of sutures placed in the epineurium or by placement of a single suture through the axial center of the injured nerve trunk [38]. Correct fascicular positioning can be confirmed by the continuity of the nerve's surface structures such as blood vessels (vasa nervorum) within the epineurium [39].
- *Epineural sleeve repair*: In this technique, the epineurium covering the distal stump is rolled back, and then a 2 mm nerve segment is resected. The newly created epineural sleeve is pulled over in the proximal nerve end and is sutured to the epineurium 2 mm proximal to the coaptation site with two sutures. The epineural sleeve provides a biological chamber for the axoplasmic fluid leakage from transected nerve ends providing a neuropermissive environment for growing axons [40].
- *End-to-side repair*: End-to-side repair offers a promising technique for repair of peripheral nerve injuries when the proximal nerve stump is unavailable or a significant gap between two ends exists. The origin of reinnervating axons is currently widely discussed. Some authors assume that the nerve fibers invade from the donor nerve axons that are damaged during nerve preparation for coaptation [41]. Others provide evidence based on double-labeling studies for collateral (nodal) sprouting from the undamaged axons of the donor nerve at the coaptation side [42].

15.5.2.3 Nerve Grafting

- *Nerve autografts*: When there are nerve gaps that cannot be approximated and coaptated without tension, current gold standard of repair is autologous nerve grafting. Nerve grafts revealed superior results when compared with direct repairs that may be performed under excessive tension producing nerve ischemia [43]. The harvested fascicular graft undergoes Wallerian degeneration [44] and provides mechanical guidance by creating a supportive structure for the ingrowing axons. Sensory cutaneous nerves are commonly used as donor nerves for autografting because their harvest results in acceptable morbidity consisting of sensory loss in the area supplied by the harvested sensory branch. Currently used donor nerves include sural nerve, lateral antebrachial cutaneous nerve, anterior division of the medial antebrachial cutaneous nerve, dorsal cutaneous branch of the ulnar nerve, and superficial sensory branch of the radial nerve [45].
- *Nerve allografts*: In gaps where the reconstruction requires a length of graft exceeding available nerve autografts, the application of allograft material from cadaver donors is the only clinical option currently available. Allograft nerve provides guidance and viable donor Schwann cells enabling growing host axons to pass from the proximal to distal stump and reinnervate the intended organs. Although allogenic nerve tissue has low immunogenic potential compared to the skin, muscle, or bone, it does require immunosuppressive treatment to prevent rejection of the graft [46].

15.5.2.4 Conduit Repair

- *Biologic conduits*: Biological conduits include arteries, veins, mesothelial chambers, pre-degenerated or fresh skeletal muscle, and epineural sheath [47]. Utilization of vein grafts has been studied most extensively to promote axonal growth by providing an environment rich in collagen, laminin, and Schwann cells encountered in adventitia of vessels [48].
- *Artificial conduits*: Various materials including synthetic polymers, extracellular matrix components, and supportive therapies (cytokines, cells) were used in animal studies to serve as nerve regeneration conduit [49]. Materials used include non-resorbable polymers (silicone and expanded polytetrafluoroethylene) and resorbable conduits (polyglycolic acid polymer, polylactide-caprolactone polymer, polyglycolic acid polymer coated with cross-linkedcollagen, and type I collagen [50].

15.5.3 Nonsurgical Methods

1. *Nerve regeneration by electric stimulation*: Animal studies demonstrated that as short as 1 h of direct nerve electrical stimulation immediately after repair of a transected femoral nerve in the rat promotes a dramatic increase in the kinetics of target muscle reinnervation [51]. In a clinical pilot study, 1 h of electrical stimulation was applied after median nerve decompression at the wrist for 21 patients with carpal tunnel syndrome and thenar atrophy [52]. The electrical stimulation group showed evidence of accelerated axonal regeneration and target reinnervation through motor unit number estimation and sensory and motor nerve conduction studies.
2. *Nonthermal laser amnion wrap*: Photochemical tissue bonding creates a covalently bonded nerve wrap around a nerve coaptation, using an Nd/YAG laser, photoactive dye, and a nonimmunogenic amnion wrap [53]. Collagen fibers in the amnion wrap are covalently bonded to collagen in the epineurium. This bond adds strength to the repair, concentrates neurotrophic and neurotropic factors inside the coaptation where they are needed, excludes inflammatory mediators from the extrinsic tissues, and contains regenerating axons, guiding them distally toward the motor or sensory target.
3. *Thermal laser welding*: Thermal laser achieves tissue bonding by denaturation of structural proteins, which anneal and join when cooled. Tse and Ko reported successful nerve coaptation by laser welding in 1985; however, this was followed by reports of frequent dehiscence of 12–41% [54]. To prevent dehiscence, one or two stay sutures can be placed before laser welding; it is worth noting that nylon stay sutures will lose their tensile strength when irradiated with a CO_2 laser.

4. *Glue repair*: Advantages of an adhesive glue for nerve repair include ease of use, less tissue trauma, maintenance of nerve architecture, better fascicular alignment, and less scarring compared to microsutures [54]. The ideal nerve glue should not cause fibrosis that can lead to nerve compression, and, in the case of substance interposition between nerves, it should not act as a barrier to nerve regeneration. The glue should provide adequate mechanical strength to prevent gapping or rupture at the initial repair and during the postoperative period. A systematic review of fibrin glue for peripheral nerve repair revealed 14 animal studies, 1 cadaver study, and 1 human study [55]. Most found fibrin glue repair to be equal or superior to suture repair. However, in clinical practice, concerns remain about the lack of adequate tensile strength for fibrin glue repair alone, so currently fibrin glue is predominantly used as an adjunct to microsutures or to coapt nerves where suturing is not possible, for example, intervertebral foramina.

15.5.4 Role of Stem Cells to Augment Peripheral Nerve Repair

Stem cell infusionhas been successful in promoting regeneration and remyelination of the injured spinal cord and peripheral nerve [56]. To serve as a realistic therapy, candidate transplant cells should be easily accessible, rapidly expandable in culture, capable of survival and integration in host tissue, and amenable to stable transfection and expression of exogenous genes [57]. To find such a cell, emphasis has shifted toward using stem cells or progenitor cells as therapy for injury in the peripheral and central nervous systems. Based on their apparent plasticity and ease of harvest, bone marrow stromal cells have attracted the attention of several groups interested in finding a suitable replacement for host stem cells [58, 59].

15.5.5 Role of Hyperbaric Oxygen

Hyperbaric oxygen can also exert its beneficial effect in peripheral nerve repair and regeneration by enhancing or preventing the production of growth factors. Yu et al. found that hyperbaric oxygen reduced the gene expression of GDNF after 1 day of injury, as confirmed by immunehistochemical staining [60]. Some of the growth factors, such as basic fibroblast growth factor, are ineffective in stimulating healing under ischemic conditions even at high doses. But when treated with hyperbaric oxygen, growth factors recover their function and become highly effective again [61]. Hyperbaric oxygen increases the production of bFGF, vascular endothelial growth factor, and TGF-ß1. At cellular level, hyperbaric oxygen will maintain the tissue levels of ATP; restore mitochondrial dysfunction; inhibit, prevent, or reduce the ischemic reperfusion injury; and have significant antioxidant and anti-apoptotic effects. The treatment window for acute peripheral nerve lesions appears to be around 6 h [62].

15.5.6 Role of Lithium

Glycogen synthase kinase 3β inhibitors, especially the mood stabilizer lithium chloride, are also used as neuroprotective or anti-inflammatory agents. Lithium exerts its action in Schwann cells by increasing the amount of β-catenin and provoking its nuclear localization [63].

15.5.7 Role of Electroacupuncture

In a model of crushed sciatic nerve in rabbits, electroacupuncture promoted nerve regeneration. Low-frequency pulsed electromagnetic field was ineffective on rat sciatic nerve regeneration [62].

15.5.8 Low-Intensity Ultrasound

Low-intensity ultrasound in combination with poly(DL-lactic acid-co-glycolic acid) conduits was found to have significantly greater number and area of regenerated axons at the mid-conduit of implanted grafts. Low-intensity ultrasound stimulation on silicone groups was found to induce a mass of fibrous tissues that covered the nerve conduits and retarded axon regeneration [64].

15.6 Summary

Peripheral nerve injuries are frequent and avoidable complications perioperatively. While most patients with PNI have complete recovery, some can have permanent deficit. Identification of the patient risk factors and surgical risk factors, along with proper patient positioning and appropriate intraoperative management, is paramount in evading PNI which is the third most common cause of litigation for anesthesiologists. Certain peripheral nerves are particularly predisposed to mechanical injury because of their anatomical locations. Proper position and awareness of the anatomical vulnerability can decrease the risk of the PNI. Surgical positions known to have a high risk of nerve injury should be avoided wherever possible. The tourniquet pressure and duration must be minimized. Factors that predispose a patient to PNI include coagulopathy or presence of hematoma near the nerve, infection or presence of an abscess near the nerve, hypovolemia, hypotension, dehydration, hypoxia, electrolyte imbalance, and hypothermia. The use of compressive dressings, casts, and tourniquets are also important risk factors.

Most nerve injuries are manifested as sensory deficits and have a complete recovery. Nerve injury can be recognized by EMG, nerve stimulation studies, and MRI. Management options include surgical and nonsurgical options. Surgical techniques include direct repair including end-to-end repair, end-to-side repair, and epineural sleeve repair. Nerve grafting can be done as autografts or allografts. Conduit repair is achieved via using biological materials or artificial materials. Early nerve repair results in improved functional outcomes. Nonsurgical methods that have shown potential include electric stimulation, nonthermal laser amnion wrap, thermal laser welding, and glue repair. Various novel techniques such as stem cell regeneration, hyperbaric oxygen, lithium, electroacupuncture and PEMF, and low-intensity ultrasound could prove helpful.

15.7 Review Questions

1. Which nerve is the most commonly injured perioperatively?
2. What is the gold standard of surgical treatment for severe axonotmesis and neurotmesis injuries?
3. What should be the ideal tourniquet application time to prevent the neural ischemia?

15.8 Answers

1. Ulnar nerve injury is significantly more common than any other nerve injury. Over 90% of ulnar nerve injuries have no known cause. They can occur even with ideal positioning and padding.
2. Direct nerve repair with epineural microsutures is the gold standard surgical treatment.
3. It should ideally be less than 2 h to prevent neural ischemia. A safe time limit of 1–3 h has been described. It has been recommended to assess the operative situation at 2 h, and if the anticipated duration is >2.5 h, then use a 10-min deflation interval at that point and at subsequent 1-h intervals. In pediatric patients, inflation time of <75 min has been recommended for lower extremities.

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Catastrophic Perioperative Complications and Management in the Trauma Patient

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_16

16.1 Summary: Aims and Scope

In the last two decades, the care of the surgical patient has changed dramatically. New equipment, monitors, and pharmacologic agents have transformed surgical technique and improved outcomes. Patients once deemed "too sick" for the operating room are found frequently on operating room schedules nationwide.

Today, anesthesiology for the healthy patient in most developed countries is extremely safe. However, perioperative complications still occur. These events can be catastrophic for patients and may have serious implications for residents, surgical and anesthesiology staff, and nurses. Prompt recognition and management of these incidents may reduce or negate complications. This is based on a fundamental base of knowledge acquired through several avenues and practiced with other team members to maximize outcomes. Engagement of all caregivers impacts outcomes. Many organizations do not have the structural components or education to recognize or manage these catastrophic events.

This chapter will provide educational material for the many students, as well as nurses, residents, or attending physicians who participate in perioperative medicine. It will focus on the most serious perioperative complications and include a discussion of the pathophysiologic and pharmacologic implications unique to each. Additionally, it will provide medicolegal information pertinent to those providing care to these patients. All chapters will be written with the most current and relevant information by leading experts in each field.

16.2 Acute Management of the Trauma Patient

16.2.1 Preparation for the Arrival of the Trauma Patient

Inadequate preparation and equipment placement can negatively influence the outcome of the traumatic patient. It is critically important that each individual member of the trauma team knows their role and has the necessary preparation and skills for an unpredictable situation. As soon as the patient presents through the doors, an expedited and highly coordinated process must ensue to ensure maximum survival potential. The Advanced Trauma Life Support (ATLS) training program was developed to provide uniformity in the assessment and management of trauma patients [15]. Since then, the program has been adopted nationally by the American College of Surgeons Committee on Trauma (ACSCOT) and has provided the latest evidence for the most effective trauma care. With the proper preparation, even catastrophic perioperative complications can be dealt with to maximize survival potential.

16.2.2 Pre-arrival and Triage

Pre-arrival notification is imperative to the success of the trauma team. Local EMS systems ought to have a protocol in place to alert the team and provide information with regard to patient status. Upon notification to the emergency room, many hospitals use an overhead paging mechanism to alert staff. This alert should include the level of severity, the location in the hospital, and the time of arrival, for example, "Code Yellow-Room 32-Level 1-15 minutes." This notification should activate a coordinated sequence of events involving the trauma surgeon, anesthesiologists, nursing team, technicians, radiologist, and operating room representatives. If time allows, a gathering of personnel in the room prior to arrival will allow the designation of tasks to ensure that the proper equipment is set up based on the specific needs of the patient. At this meeting, the individual that received EMS report would give a summary including key details that should be known by everyone on the trauma team. For example, "Patient is a 26-year-old male involved in a motor vehicle collision. He is having a hard time breathing and has a possible head injury and a right leg injury." The first step in room preparation should begin promptly with the appropriate personal protective equipment for each member of the team. Mask, gloves, and gowns should be dawned as personal safety is top priority. From this point forward, the room can be tailored to meet the needs of the patient with the guidance of the trauma surgeon. For example, airway difficulty may prompt the anesthesiology team to set up for possible intubation and radiology at bedside for immediate chest X-ray along with a chest tube kit for easy accessibility [14].

Table 16.1 Glasgow coma scale, reported from 3 to 15, with 15 being the best and 3 being the worst possible score. A score of 8 or below corresponds to severe brain injury, 9–13 indicates moderate injury, and 13 or above indicates mild injury

Glasgow coma scale	Score
Eye opening	
Spontaneous	4
To loud voice	3
To pain	2
None	1
Verbal response	
Oriented	5
Confused, disoriented	4
Inappropriate words	3
Incomprehensible words	2
None	1
Motor response	
Obeys commands	6
Localizes pain	5
Withdraws from pain	4
Abnormal flexion posturing	3
Extensor posturing	2
None	1

Triage of trauma patients will typically classify into a three-tiered system which is indicative of the resources that will be necessary for the care of that patient. For example, a level 1 trauma (highest acuity) will require utilization of more resources than a level 3 trauma (lowest acuity) (Table 16.1). This system is utilized to ensure that all necessary resources are available to the trauma team. Level 1 activation should trigger the greatest number of personnel, while a level 3 activation indicates the need for a routine trauma team consult. Hospitals that have a tiered system of triage and trauma team activation correlate to more efficient resource utilization and better patient outcomes than hospitals lacking such a system [35]. Additionally, hospital systems should have a protocol in place to upgrade a trauma patient if they are not placed into the correct tier. For example, when a patient believed to be involved in a low-speed collision presents in acute respiratory distress with a blood pressure of 80/50, the necessity to quickly upgrade from a level 2 to a level 1 is imminent to ensure the best possible care and greatest availability of resources for trauma team.

16.2.3 Pre-arrival Room Preparation

Meticulous room preparation can heavily impact the already chaotic parameters of a traumatic patient. With multiple team members attempting to access the patient, it can become highly clustered and make it difficult for team members to perform their job adequately. Proper placement of the bed, monitors, cabinets, and tables ensures quality, efficient care. Technicians should arrange equipment to allow smooth transition of care from EMS to the trauma team. Typically, this starts with bed placement in the room. First, zero a weighted bed and place a draw sheet to allow easy movement of the patient once transferred from the EMS cart. Slightly angling the cart and placing a side rail down often indicate for EMS to transfer the patient on that side upon arrival. This may be important to ensure access to equipment during the transfer from EMS cart to bed. Following transfer, if space allows, center the bed in the room to allow maximum space for all team members to perform their tasks. Figure 16.1 indicates the proper positioning of all team members in the trauma room.

16.3 Airway Management

Airway management in a trauma setting is complicated by the potential for neurologic injury and compromised airway anatomy. The risk of spinal manipulation, and difficulty in establishing a usable airway, requires diligent understanding of the potential harms of airway management and the techniques used to avoid them.

The LEMON score is an organized and standard way to assess the airway of traumatic patients.

- *L* requires the attending provider to *L*ook at the cervical and facial region and examine for facial or neck trauma, large incisors, presence of beard, large tongue, or orofacial soft tissue

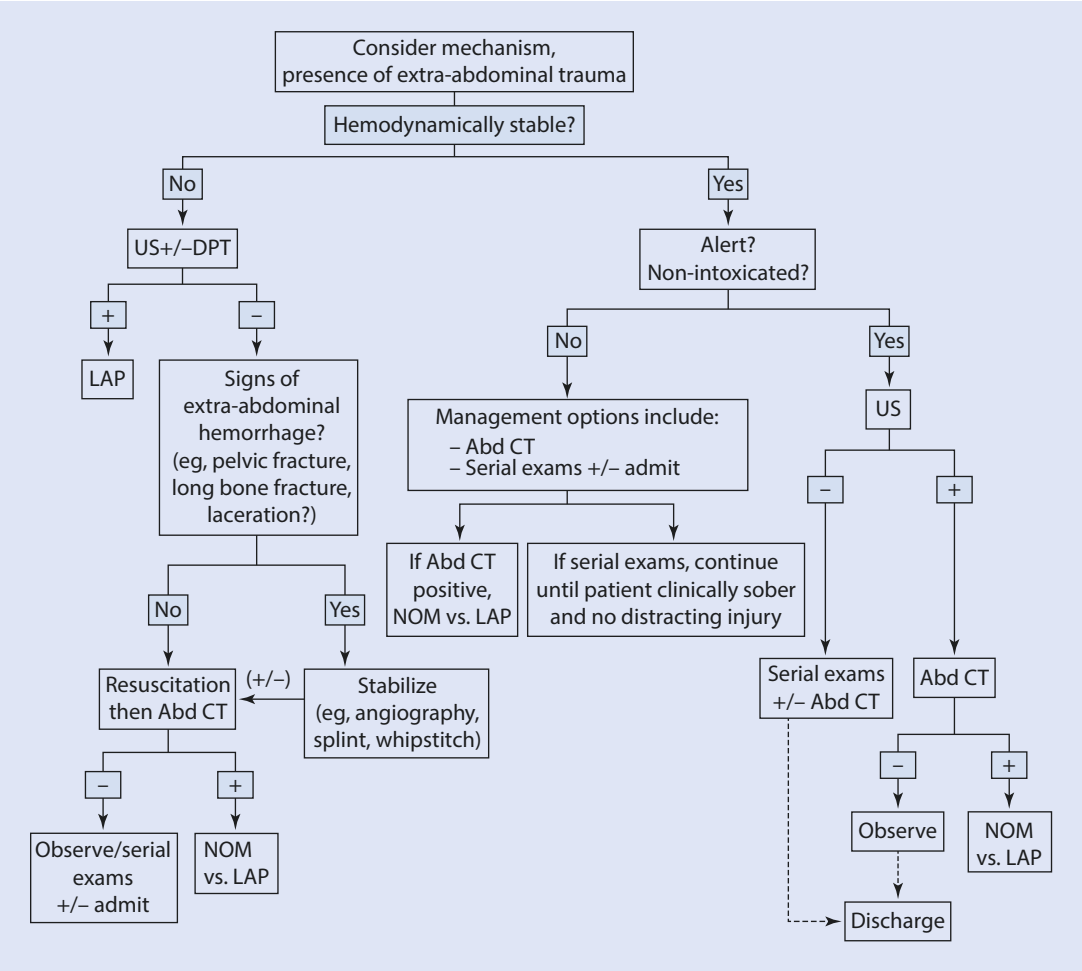

Fig. 16.1 Anesthesia for trauma. New evidence and new challenges (must request access)

stiffness. One point is added for each of the conditions listed if they are present. For example, if the patient has large incisors and a large tongue, two points are added.

- *E* stands for *E*valuate. The 3–3-2 finger rule is used for this section, to specify an interincisor distance <3 fingers, mentum to hyoid distance <3 fingers, and floor of the mouth to thyroid notch distance <2 fingers. One point is assigned for each abnormal finding.
- *M* stands for *M*allampati score, which is a traditional evaluation of the oral cavity to assess for ease of intubation. Inability to visualize the uvula suggests a grade 3 or 4 view during laryngoscopy. One point is assigned for Mallampati grade 3 and 4 view.
- *O* stands for *O*bstruction of any cause, including if signs and symptoms are there and obstruction cannot be visualized. One point is assigned to the presence of airway obstruction.
- *N* stands for *N*eck mobility. One point is assigned to the presence of neck mobility caused by any reason, including cervical collar.

With a maximum of 10 points, the LEMON score gives a rough estimation of ease of airway consolidation in the traumatic patient [11, 41, 47].

If oxygen levels and the external ventilation are viable at time of first response, definitive airway establishment may be detrimental and not required [24, 46, 48]. Evaluation of the airway is key as trauma may not be overt. Full airway examination should be completed; however, due to immobilization, injury, and lack of time, extensive assessment is not always an option. History

should be taken only when practical and is not essential when treating acute injuries [3].

Initiation of emergent airway consolidation requires routine protocol and procedures of airway management combined with special knowledge of several common factors that may alter protocol in a traumatic setting [5]. Oxygen should be administered, the airway should be cleared, and many airway management procedures may be utilized including suction, oral airway, and bag-mask ventilation and intubation. A manipulation of the neck can cause movement of the spinal cord leading to neurologic injury [30]. During all proceedings the maneuvers must maintain manual in-line immobilization to decrease the risk of cervical spine injury [30].

Definitive airway establishment is not essential in all patients with airway injury. Indications for emergent airway establishment would include hypoxia, agitation, respiratory distress, shock, cardiac arrest, a score of less than 8 on the Glasgow coma scale, and altered mental status. If a definitive airway is not established initially, regular reassessment is necessary [30]. Despite the damaged anatomy often present in trauma cases, RSI can be successful and is the most frequently used maneuver for airway establishment [28, 30]. The decision to pursue surgical, RSI, or external airway management depends on the stability of the patient's condition as well as preference, equipment, available personnel, and the clinical scenario. Video laryngoscopy and fiber-optic bronchoscopy are options which may lessen the amount of cervical movement during intubation; however, their use is limited by the presence of debris, blood, and mucus [28]. Failure to intubate an unstable patient necessitates the establishment of a surgical airway [5].

Absolute indications for a surgical airway are listed below:

- Trauma victims
- Airway obstruction
- Hypoventilation
- Persistent hypoxemia (SaO 2 < 90%) despite supplemental oxygen
- Severe cognitive impairment (Glasgow coma scale [GCS] score < 8)
- Severe hemorrhagic shock
- Cardiac arrest
- Smoke inhalation victims
- Major cutaneous burn (body surface area > 10%)

16.3.1 Traumatic Facial Injury

Condylar fractures and mandibular and zygomatic arch injuries can cause difficulties in opening the jaw because of mechanical impediment or muscular spasms. Trismus may resolve with neuromuscular paralysis, but bony blockages may require surgical removal. Nasal intubation is not recommended due to risks in disturbing the basilar skull. Basilar skull fractures due to nasal intubation increase the risk of intracranial infection and meningitis [6].

16.3.2 Airway Compression

Neck trauma significantly increases the dangers of intubation. Cervical spine injuries can cause hematoma in the retropharyngeal space which can compress the airway and complicate intubation despite no external signs [16]. For this reason, it is important to consider the timing of the injury as movement of the airway may dislodge hematoma [16]. RSI may be suitable during spontaneous ventilation to prevent eventual closure of the airway due to hematoma. Surgical airway should be utilized following failure of RSI.

16.4 Perioperative Management of Cardiovascular and Chest Injuries

Injuries to the cardiovascular system and chest wall largely contribute to trauma-related mortality and morbidity. Vital organs are vulnerable in this region, and due to the non-compressible nature of hemorrhage in this area, trauma-related deaths are relatively common when they otherwise could have been preventable. One-fourth of trauma deaths are due to chest trauma alone. Hemorrhage in the torso overall results in a mortality of 70–80%. This is due, in part, to inability to control bleeding with tourniquets and increased use of anticoagulant agents for prophylaxis of other cardiovascular disorders [7].

16.4.1 Hemothorax

Hemorrhage resulting in shock is the leading cause of early in-hospital trauma-related deaths.

Remember that most patients perish from traumatic injury in the first 4 h upon arrival, and hemorrhagic shock is a leading cause of this. It is the second most frequent cause of death in trauma patients overall [40]. Injuries to chest wall vessels or intra-abdominal organs can cause hemorrhage in the chest cavity when the diaphragm is ruptured. Blood accumulates in the pleural space, called a hemothorax, and it results in a wide array of clinical presentations. Diagnosis is made via chest X-ray with at least 150 mL of blood present in the chest cavity when the patient is upright. E-FAST examination can identify fluid in the pleural cavity with greater sensitivity than CXR and is a much faster procedure to do. In an unstable patient with blunt trauma, insertion of bilateral chest tubes is warranted for both diagnostic and therapeutic purposes [7].

Urgent thoracotomy is indicated in the light of a massive hemothorax, which is 1500 mL or more of blood in the thoracic cavity. This has been challenged in recent literature, suggesting patient clinical status is a more important indicator for the need of this procedure. Early preparation for thoracotomy has led to better outcomes, and thresholds have been suggested to be lowered to 1000 or even 500 mL of blood. Perioperative management includes volume replacement as the main therapeutic modality for hemorrhagic shock. A massive transfusion protocol has been shown to be beneficial with early surgical consult. Angiography is not standard but can be considered for the diagnosis and treatment of intercostal vessel injury [33].

It is useful to examine for aortic injury in those who are hemodynamically unstable or with significant injury. This is usually done via contrast chest CT for stable patients and via transesophageal echocardiogram for those who are unstable.

16.4.2 Blunt Cardiac Injury (BCI)

BCI is involved in 20% of all deaths due to motor vehicle collisions, with a wide range of presenting pathologies, from myocardial bruise to cardiac rupture and beyond. The right ventricle, is most commonly injured due to its proximity to the chest wall, although injuries to more than one chamber occur in more than half of all cases. Crush injuries, deceleration injuries, direct impact, or transmitted compression forces all can result in BCI, with some instances leading to a penetrating injury after sternal or rib fracture.

Initial assessment should be done in all patients with significant blunt trauma to the chest. In these patients, an ECG should be done to assess for arrhythmia, ST segment abnormalities, heart block, and signs of ischemia. E-FAST exams can be done to assess for hemopericardium and tamponade. BCI can be ruled out if the patient has all of the following [12]:

1. Hemodynamically stable assessment
2. Normal ECG
3. Normal E-FAST examination

Hemopericardium results in a necessary rapid resuscitation and urgent surgical treatment, as survival in those with clinical status deterioration is marginal. The attending physicians should repeat E-FAST protocols in those that fail to improve or as their status worsens, even if hemopericardium was not present initially.

Biomarkers of BCI are not solidified in the literature to be a strong recommendation, but they have been suggested to be used in cases of difficult assessment. Some studies have shown that in stable patients with a normal ECG, an elevated creatine kinase MB level is a nonspecific finding for the diagnosis of BCI. Likewise, troponin I and troponin T levels are more specific and have been suggested to be helpful, but they are not sensitive enough to have clinical utility as a screening test [12]. For example, cardiac dysfunction may have preceded BCI and lead to it, leading to increased levels of these biomarkers and lend a potential false clinical history.

16.4.3 Penetrating Cardiac Injury (PCI)

While BCI offers a good likelihood of survival if the proper precautions are taken, penetrating cardiac injuries (PCIs) are highly lethal and offer a small likelihood of survival. The probability of arriving alive at the hospital after such an injury is between 6% and 20% [37]. Again, the most common injury is to the right ventricle due to proximity to the chest wall, followed by the left ventricle. These injuries usually result in hemorrhagic shock or cardiac tamponade, with hemorrhagic shock

being the main cause of death at the scene. An additional threat is that the pericardium is quite non-compliant, with only 50 mL of blood needed to lead to cardiac tamponade, so lethal injury can occur with very little blood loss.

Immediate and rapid evaluation is absolutely necessary in these patients, through a thorough physical examination followed by immediate FAST exam of the heart, pericardium, and thorax to evaluate for hemothorax, hemopericardium, tamponade, and pneumothorax [38]. In those with hemopericardium, urgent thoracotomy and cardiorrhaphy are urgently required even when stable. Those with left-sided hemothorax could have a self-draining hemopericardium and are at risk of rapid decompensation. As previously discussed, this is a catastrophic perioperative complication, and the proper handling of these issues is rapid diagnosis, massive transfusion to establish hemodynamic stability, and a bit of luck.

16.4.4 Aortic Injury

Sudden shearing forces, such as those in rapid deceleration injury, can occur and severely damage the aorta. The proximal descending aorta is most at risk due to the ligamentum arteriosum being a transition point between the fixed descending aorta and the mobile aortic arch. These injuries are responsible for 15% of deaths in MVAs [21].

There are three types of blunt aortic injury:

1. Complete transection of the aorta. This usually ends with patients dying at the scene or shortly after arrival.
2. Full-thickness aortic injury resulting in hemodynamic instability and persistent bleeding.
3. Partial-thickness injury, most often with contained hematoma. These patients may or may not present as hemodynamically unstable.

As seen, a common theme is hemodynamic instability. The main challenge for the clinician in the light of perioperative management is to identify the injury before it progresses to complete rupture. This is difficult due to no specific clinical signs that allow for the rapid identification of aortic injuries, so they should be suspected in patients with high-speed MVA with frontal or side impact, falls from a great height, or rapid deceleration events.

Ekeh et al. suggested that CXR misses 11% of aortic injuries and was not an acceptable modality to rule out such injuries [20]. Angiography instead is the gold standard to diagnose aortic injury. However, it is not available in all centers, most patients who require aortic evaluation require CT imaging of other organ systems, so contrast CT is the most commonly used modality to diagnose aortic injury. It has a sensitivity of greater than 97%, specificity of greater than 85%, and a negative predictive value of 100%, leading to it being the choice modality for evaluation of aortic injuries [18].

The main medical management of these patients includes:

1. Prevention and control of hypertension that can lead to progression of the injury and subsequent hemodynamic instability
2. Control of coagulopathy, including hypothermia and acidosis
3. Correction of other life-threatening injuries and prioritizing such injuries such that the patient has the greatest chance of survival
4. Definitive surgical repair of the aortic injury

In those with hemodynamic instability due to aortic injury, urgent repair is indicated. It is also indicated in contrast extravasation on CT with rapidly expanding hematoma, large hemorrhages from chest tubes, and penetrating aortic injury [33].

16.4.5 Tension Pneumothorax

Tension pneumothorax is a common type of blunt chest trauma that requires immediate diagnosis and treatment with needle decompression, followed by chest tube insertion. All traumatic pneumothoraces should be considered for chest tube insertion; however, observation is possible for some patients with small pneumothoraces on a single side without respiratory disease and without a need for positive pressure ventilation. All symptomatic traumatic hemothoraces should be treated with chest tube insertion. Occult pneumothorax can be treated with observation and serial chest X-rays. Periprocedural antibiotics can be used to prevent chest tube-related infectious complications.

16.4.6 Cardiac Tamponade

Cardiac tamponade occurs when fluid accumulates in the pericardial sac, resulting in an increased pressure impeding cardiac filling, which leads to decreased cardiac output. The clinical presentation depends heavily on the duration of tamponade and the amount of fluid that has accumulated. Acute cardiac tamponade has a sudden onset and presents with symptoms resembling cardiogenic shock. Potential symptoms of acute cardiac tamponade include dyspnea, tachypnea, and chest pain. The decrease in cardiac output commonly leads to hypotension, and patients who develop cardiogenic shock may present with cool extremities, decreased urine output, and peripheral cyanosis.

Subacute cardiac tamponade comes on slowly over days to weeks, and patients may be asymptomatic early on. Potential symptoms include dyspnea, peripheral edema, chest discomfort, and being easily fatigued. Patients may also have hypotension with a narrow pulse pressure, but those with preexisting hypertension may continue to be hypertensive. Occult cardiac tamponade, also known as low-pressure cardiac tamponade, is a subset of subacute cardiac tamponade where patients may present with intracardiac and pericardial diastolic pressures between 6–12 mmHg. It is usually seen in patients who are severely hypovolemic.

Regional cardiac tamponade occurs with a localized collection of fluid applying pressure to a subset of heart chambers. In these patients, the usual signs and symptoms of cardiac tamponade are not present. This variant is most often found after pericardiotomy or myocardial infarction. Diagnosing regional cardiac tamponade can be challenging and may need advanced imaging techniques like CT or additional echocardiograph views like transesophageal or subcostal.

Physical exam findings, though not highly sensitive or specific, include Beck's triad (hypotension, muffled heart sounds, and elevated jugular venous pressure), pulsus paradoxus, and sinus tachycardia. Sinus tachycardia is present in almost all patients, but may be absent early on, or if the underlying disease process is associated with bradycardia. Elevated jugular venous pressure is also commonly present and may be associated with distension of the veins in the forehead and scalp. It is important to note that Beck's triad of symptoms is absent in the majority of acute cardiac tamponade cases. Additionally, patients with occult cardiac tamponade may present with the usual physical findings, but their presence is less common than in classic cases of cardiac tamponade.

Further evaluation of cardiac tamponade calls for an EKG, chest radiograph, and most importantly echocardiography. The EKG tends to show tachycardia and may also show low voltage. In subacute cardiac tamponade, a chest radiograph may show cardiomegaly. In acute cardiac tamponade, cardiomegaly is not usually found. In echocardiography, the major signs of cardiac tamponade include chamber collapse (usually the right-sided chambers), respiratory variation in volumes and flow, and IVC plethora. In patients with a moderate to large effusion, swinging of the heart within the effusion may also be present.

In cardiac tamponade with minimal to no hemodynamic compromise, conservative treatment with hemodynamic monitoring and serial echocardiograms is a viable option in the preparation of the patient for surgery. Definitive treatment of cardiac tamponade involves removing the pericardial fluid either by percutaneous or surgical drainage. Echocardiography-guided catheter pericardiocentesis is the treatment of choice, but surgical drainage may be preferred if:

1. The fluid is localized.
2. The fluid reaccumulated after catheter draining.
3. There are coagulopathy concerns.
4. There is a need for biopsy material.

Caution with pericardiocentesis should be taken if the patient has severe pulmonary hypertension. General anesthesia may worsen hemodynamic compromise, so catheter drainage may be required prior to surgical drainage to reduce the severity of the cardiac tamponade. In cases of aortic dissection or myocardial rupture, pericardiocentesis may worsen bleeding, and surgical drainage should be performed. Surgical drainage is also preferred in cases of traumatic hemopericardium and purulent pericarditis [2, 27, 36].

16.5 Perioperative Management of Burn Injuries

Roughly 450,000 people present with burn injuries every year in the USA. About 40,000 of those are hospitalized, and approximately 3400 die from their injuries or complications [9]. The most common complications from burn injuries are decreased cardiac output, inhalational injury, infection, renal damage, CNS dysfunction, compartment syndromes, and coagulopathy. Patients with burn injuries should be initially treated as multiple trauma patients [4].

The priority in managing burn injuries is assessing the airway. It is vital to evaluate for signs of inhalation injury, laryngeal injury, obstruction, or preexisting abnormalities. A patient's airway may not appear injured, but airway edema may follow fluid resuscitation. In patients with significant risk of inhalation injury, it is safer to intubate early than wait until after airway swelling has occurred.

Fluid resuscitation is another vital step as delay could lead to hypovolemia and burn shock. Fluid requirements for each patient may vary depending on size/depth of the burn, associated injuries, or level of opioid usage for pain management. There are many fluid resuscitation formulas, but current recommendations state that to achieve adequate fluid resuscitation, a urinary output of 0.5–1 ml/kg/h should be maintained. Patients should initially be started on isotonic crystalloids followed by colloids. However, the exact time to start using colloids is still debated, though the general trend is to start them before the previously recommended 24 h [4].

Burn injuries can lead to altered pharmacological and physiological responses to medications. For example, succinylcholine can cause hyperkalemia and induce cardiac arrest, and it is recommended to avoid the use of succinylcholine in burn patients 48 h after injury. Additionally, burn patients will also have decreased sensitivity to nondepolarizing muscle relaxants (NDMRs) [4]. Medication choices for a burn-inflicted individual should be driven by that patient's hemodynamic and pulmonary status, as well as the potential difficulty of securing that patient's airway. An additional long-term consideration is that patients suffering from burn injuries will likely be on elevated amounts of opioids for pain management. As these medications are being used and as they reach a steady state, they should not be stopped to achieve intraoperative anesthesia. Instead the dose may be increased, or they may be combined with other drugs to achieve anesthesia. One option for induction and maintenance is ketamine. It may also be the agent of choice when manipulation of the airway needs to be avoided (i.e., after fresh graft placements). Benzodiazepines are often added to decrease the probability of dysphoria, and glycopyrrolate is often added to counter the increased secretions caused by ketamine.

16.6 Perioperative Management of Gastrointestinal and Abdominal Injuries

16.6.1 Intro

While traumatic torso injuries compose a relatively small portion of emergency room visits, they contribute disproportionately to morbidity and mortality. Blunt or penetrating traumatic injury to the abdomen affects solid organs, viscera, and vasculature [41]. Blunt trauma comprises 80% of abdominal injuries seen in the emergency department [32]. In blunt force trauma, the spleen is most commonly injured, with retroperitoneal and liver damage following. In penetrating trauma, the organ involvement is somewhat unpredictable. Among civilians, vehicle accidents, blows to the abdomen, and falls are the most frequent causes of blunt trauma, while gunshot and stab wounds are the most frequent causes of penetrating trauma [41]. Complications of hemorrhage, peritonitis, or evisceration are immediate indications for emergency surgical intervention. In the absence of these indications, "Selective Surgical Conservatism" has become the standard [41]. This involves performing a careful examination and proceeding to the operating room only with injuries present that nonsurgical interventions would not heal. In surgical patients, interdisciplinary care during the perioperative period directly affects long-term outcome.

The most lethal complication relevant to abdominal trauma is hemorrhage. Hemorrhage is responsible for 30–40% of trauma-related deaths, only second to central nervous system damage overall [26]. The majority of traumatic hemorrhages are related to abdominal injury, the most

serious of which are splenic and liver lacerations. Hemorrhage of more than 40% total blood volume will lead to hemorrhagic shock with circulatory system failure and cardiac arrest [25]. Several physiological compensation mechanisms exist, including sympathetic stimulation, decreased vagal tone, elevated heart rate, shunting blood to vital organs, and increased release of vasopressin. These systems function to conserve blood volume, maintain vital organ perfusion, and diminish peripheral blood flow. If the hemorrhage persists, it will overwhelm this compensation, and a lethal triad of hypothermia, acidosis, and coagulopathy will develop. This signals the failure of resuscitation. Acidosis results due to poor tissue perfusion and production of lactic acid which may be complicated further by respiratory acidosis. Coagulopathies result both from loss of clotting factors in the blood and activation of the coagulation cascade from the trauma [23].

A mainstay of treatment for hemorrhagic patients is massive blood transfusion. A massive transfusion protocol should be with massive blood loss, defined as loss of total blood volume during a 24-h period, half of overall blood volume during 3 h, or at a rate of over 150 ml/min [25]. While transfusion replaces the blood lost, it can further complicate a coagulopathy by diluting platelets and clotting factors. Blood must be considered a pharmacologic treatment, and the risks and benefits of administration must be assessed [25]. Blood is the idyllic resuscitation drug from a physiologic perspective, but transfusions carry their own risk. Transmission of infectious agents, overall availability, storage concerns, and religious reservations must be considered before transfusion is given. If bleeding is controlled, patient outcome then depends upon the timing and precision of fluid resuscitation, organ system response, and inflammatory mediators. The American College of Surgeons and American Association of Blood Banks recommendations state that transfusion should be guided by concurrent laboratory evaluations, for example, PT, PTT, platelet count, and fibrinogen levels. Intravascular volume maintenance and oxygen-carrying capacity should be specifically prioritized [25]. Attention should also be paid to clotting factor and electrolyte concentration. Early administration of high levels of fresh frozen plasma and platelets is critical to improving survival and reducing total need for red blood cells. Even if the patient survives resuscitation, death in subsequent days to weeks is possible due to organ failure from the original shock [25].

A rare but possibly fatal complication from massive transfusion is intra-abdominal compartment syndrome, which is an organ dysfunction from abdominal hypertension [32]. Incidence in trauma patients has been estimated from 1% to 14% [32]. Early recognition of intra-abdominal hypertension can prevent organ failure. The diagnosis must be considered in patients exhibiting an onset of organ failure with a distended abdomen, though abdominal distension is not a good predictor of intra-abdominal compartment syndrome. Oliguria and increased ventilatory requirements are also common symptoms. Increased jugular venous pressure, hypotension, tachycardia, peripheral edema, or evidence of hypoperfusion may also be present. Imaging is generally unhelpful, and absolute diagnosis requires measurement of the intra-abdominal pressure, which should be performed liberally [32].

Perioperative management considerations begin upon presentation and include rapid stabilization and patient selection. Penetrating trauma is usually clinically obvious, whereas blunt trauma may be subtle or missed. Stabilization of the patient and elimination of any immediate life-threatening injury should follow the advanced trauma and life support (ATLS) protocols. The initial absence of tenderness or pain on physical examination, even with hemodynamic stability, does *not* rule out the risk of abdominal trauma. This is especially true in patients with distracting injuries. For example, up to 10% of patients with seemingly isolated head trauma may have concurrent abdominal injury. A "seat belt sign" (ecchymosis over the seat belt area) indicates abdominal trauma in up to 33% of patients [32]. In hemodynamically unstable patients, immediate resuscitation with concurrent assessment is imperative. Laboratory tests are of limited value but are recommended as adjunct to clinical examination in patients with low risk of abdominal trauma [32, 41]. Urinalysis is recommended, as blood in the urine can herald abdominal injury in the absence of other clinically obvious signs. Radiographic images are useful but pose a risk as well. Patients must usually be stabilized before radiography is obtainable, and the risk of further injury during imaging must be considered. Bedside sonography – the focused assessment with sonography for trauma (FAST) – exam, diagnostic peritoneal lavage, or CT scan for evaluation of intraperitoneal fluid is used to diag-

nose injury with blood accumulation. The FAST exam images intraperitoneal sites most likely to accumulate blood: the splenorenal recess, the inferior portion of the peritoneal cavity (pouch of Douglas), and the hepatorenal space (Morison's pouch) in addition to the pericardial space [32, 41]. The FAST exam is most rapid, with CT scanning providing the best specificity.

CT is the most often used modality to diagnose abdominal trauma. An algorithm for the initial workup of blunt trauma to the abdomen is provided (Fig. 16.1). In these patients, failure of nonoperative treatment is predicted by older age, lower Glasgow coma scores (GCS), low admission systolic pressure, higher injury severity score, metabolic acidosis, and a requirement for transfusion. It is imperative for institutions to have foundationally solid management protocols.

Key Points

- Blunt or penetrating abdominal trauma is a major concern of patients presenting in the emergency department, with 25% needing surgical intervention (11).
- Patient selection, stabilization, and diagnostic workup are crucial factors in perioperative management. Sex, length of time from injury to surgery, shock at the time of admission, and cranial injury affect patient outcomes (11).
- The chief management distinction hinges on hemodynamic stability versus instability. When surgery is required, effective perioperative protocols contribute to long-term outcomes.
- The most threatening consideration of abdominal trauma is hemorrhage, particularly from liver or spleen damage. A mainstay treatment is massive blood transfusion, for which risks and benefits must be carefully considered.
- Signs of acute compartment syndrome after abdominal trauma surgery, including abdominal distension and oliguria, must be recognized.
- Patients with abdominal trauma have an estimated 12% (blunt trauma) or 58% (penetrating trauma) mortality, which can be reduced by effective perioperative and major risk management (11).

16.7 Perioperative Management of Musculoskeletal Injuries [44]

Musculoskeletal injuries are quite common in trauma-based medical situations. A wide range of pathologies exist, ranging from minor sprains to open fractures and amputation. Early appropriate management of these injuries can prevent long-term disability and loss of limb or life. ATLS guidelines suggest that the first line of defense against severe disability from musculoskeletal injury is recognizing and controlling hemorrhage and immobilizing fractures. Limb-threatening injuries should be identified quickly, specifically open fractures and areas of compromised vascular and nerve supply. Wound irrigation, debridement of damaged tissue, control of hemostasis, and antibiotic uses are all hallmarks of management.

16.7.1 Major Hemorrhage

The initial goal in a patient with major hemorrhage is to stop the bleed. Direct pressure, via tourniquet, pressure bandage, or manual force, should be used initially to complete this goal. Tourniquet use is more common in transport settings, and clinicians should be knowledgeable about how to properly remove a tourniquet. It should be removed cautiously and another tourniquet should be on hand to ensure a controlled environment. Tourniquets can be left until reassessment in the operating room where more technology is available to assist in stopping the bleed [10].

16.7.2 Open Fractures

An open fracture is direct exposure of the injured bone to the environment, usually as a result of a high-energy injury. Contamination has a larger potential in these fractures, and severe damage to local soft tissues is guaranteed. The timeliness of antibiotic administration is vital in reducing the likelihood of infection. A first-generation cephalosporin is the most commonly recommended antibiotic used in these scenarios, followed by surgical debridement and irrigation within 24 h, ideally sooner. The type of fixation depends on the level of soft tissue injury and contamination. Wound coverage should be per-

formed within 5–7 days [34]. Again, the most vital perioperative measure in these patients is proper antibiotic coverage and management of hemostasis in case of vessel damage. Femur fractures specifically have a higher likelihood of necessary blood transfusion. It has been estimated that 40% of all femur fractures require this, and even in the context of a closed femoral fracture, blood loss can be greater than 2.2 [13, 29].

16.7.3 Pelvic Injuries

A great deal of energy is needed to create a pelvic injury, and as such they are associated with extensive body-wide injuries such as head injuries, thoracoabdominal injuries, long-bone fractures, and resulting hemodynamic instability. Pelvic fractures with blood loss and hypovolemia have a mortality rate up to 20%. It is vital for clinicians to assess for vessel damage, specifically the pelvic venous plexus and internal iliac vessels, as injury can result in uncontrolled hemorrhage. Fluid resuscitation and hemorrhage control are vital along with stabilization of the pelvic ring, such as with a pelvic binder followed by external fixation [22].

16.7.4 Compartment Syndrome

Acute compartment syndrome (ACS) develops when an accumulation of fluid inside a confined muscular space leads to prolonged elevated pressure inside the space and a resulting ischemia of myoneural units. This is a surgical emergency, as irreversible muscular necrosis can begin as little as 6 h after initial injury. ACS is commonly due to a crush-type injury. Perioperative knowledge can help save a patient's limb, by assessing the 5 "Ps" in the setting of a swollen extremity:

1. Pain out of proportion
2. Pallor
3. Paresthesia
4. Pulselessness
5. Paralysis

Tools to measure intramuscular pressure are often used to diagnose, and a difference of less than 30 mmHg from diastolic blood pressure is concerning for ACS. Once it is diagnosed, emergent fasciotomies are done to save the limb. Perioperative management of these injury types solely deals with quick recognition and proper diagnosis.

16.7.5 Major Joint Dislocation

Neurovascular structures are at great risk in the setting of major joint dislocation, due to the close tethering of these structures to the joints themselves. Abnormal neurologic exams, distal extremities containing edema, and signs of vascular damage should raise suspicion for neurovascular damage in the setting of a major joint dislocation. Perioperative management, if surgery is needed, contains rapid joint relocation and stabilization in a splint. A hip dislocation is an orthopedic emergency due to risk of avascular necrosis and should particularly be indicative of immediate reduction and surgical consultation [1].

16.8 Perioperative Management of Neurological Injuries

Neurological trauma, including both traumatic brain injuries and damage to the spinal cord, remains a cause of death and disability despite a wide collection of robust evidence-based guidelines for immediate trauma care. Traumatic brain injury (TBI) remains the leading cause of death for individuals in North America between 1 and 45 years old, causing an estimated $9.1 billion in lifetime hospital costs and $51.2 billion in productivity losses [39]. Spinal cord injury is estimated to generate $500,000–$2 million in direct medical expenses over a lifetime [39]. Falls are the most common cause of TBIs, followed by motor vehicle accidents. The order is reversed when considering spinal cord injuries, as MVAs constitute the majority of spinal cord injury events [39, 45]. Approximately 20% of TBIs need operative intervention [41]. Paramount to treatment is avoidance of secondary brain insults, which can exacerbate cell death in vulnerable brain tissue. The goal of treatment in traumatic spinal cord injury revolves around stabilization of the spine and reduction of neurological dislocations. Perioperative considerations and management of neurogenic shock with physiologic derangement will assist providers in providing the optimal outcomes to patients suffering from neurological trauma.

16.8.1 Traumatic Brain Injury

The pathophysiology of traumatic neurological injury is separated into primary and secondary injury. Primary injury results from external mechanical insult occurring at the time of trauma, and extent of primary injury remains the single greatest predictor of patient outcome [17]. Secondary injury is a result of physiological molecular mechanisms, including inflammation, beginning at the time of trauma which causes further damage to the brain or spine over hours to days [41]. Secondary brain injury can lead to neuronal death, cerebral edema, and further increase in intracranial pressure which mediates more extensive damage. Hypotension, hypoxemia, and hyperglycemia are significant factors causing secondary injury [17]. Hypotension and hypoxemia have been demonstrated to be independently associated with morbidity and mortality, as well as outcome at 6 months [17]. Effective perioperative management may provide a window of opportunity to significantly reduce consequences of injury from TBI by treating standing secondary injuries and preventing medically or surgically induced secondary injuries.

Despite many provider groups having focused efforts at emergently treating hypoxemia, hypotension, hypercarbia, hypo- and hyperglycemia, is not uncommon for these parameters to persist or remain undetected as patients are rushed into surgery for a group that is unprepared. Therefore, while the emergency department team likely has performed an assessment, initial stabilization, and begun resuscitation, it is crucial for another assessment to be performed perioperatively. Effective perioperative management also includes quick evaluation, continued resuscitation (cerebral and systemic), early surgery, intensive monitoring, and anesthetic preparation [17]. Initial evaluation should begin with airway, breathing, and circulation, followed by rapid neurological evaluation and assessment of extracranial injuries, with particular attention to mechanisms of secondary injury.

The standard for rapid neurological assessment is use of the Glasgow coma scale (GCS) score and pupillary reflexes. The GCS score ranges from 3 to 15 and reflects coma severity according to responsiveness of three areas: eye opening, verbal, and motor response (Table 16.1). Anesthetic focus in TBI cases should be to maintain cerebral perfusion pressure (CPP), treat increased intracranial pressure (ICP), provide optimal surgical conditions, avoid secondary insult, and provide adequate analgesia and amnesia [17]. Increased ICP is associated with increased mortality and worsened outcome. Patients with a GCS of 8 or less and a CT showing mass lesion are indicated for ICP monitoring, though the strength of this recommendation is limited by a lack of randomized controlled trials [8, 17]. The majority of protocols recommend reduction of ICP to 20 mmHg or less. Appropriate sedation may reduce metabolic demand, thus lowering ICP. With a lack of clinical trial data supporting any specific protocol, sedation use and choice of agent should be individualized according to specific clinical circumstances and institutional expertise. Monitoring of CPP aids in evaluating the somewhat variable effects of these agents on ICP and blood pressure. CPP is defined as the difference between mean arterial pressure (MAP) and ICP (CCP = MAP-ICP) and provides a surrogate for measuring cerebral blood pressure (CBP). Low CCP is associated with secondary injury and worsened outcome. Autoregulation, which usually provides a constant CBP across a wide range of MAP (50–150 mmHg), is altered in approximately a third of TBIs. The recommended CPP goal is 60 mmHg for adults, avoiding levels below 50 mmHg or above 70 mmHg [8, 17]. However, when feasible, efforts to control CPP should first maintain ICP at low levels. This may have a larger effect on cerebral blood flow, obviate employment of fluids and ionotropic agents, and especially benefit patients with more severely impaired autoregulation [8]. Additionally, neuroprotective pharmacology in the perioperative period may be beneficial. Current evidence regarding pharmacological neuroprotection perioperatively suggests that CNS neuroprotection might reduce the incidence of new postoperative neurological deficits, without providing benefits for perioperative mortality [17].

16.8.2 Spinal Cord Injury and Trauma

Perioperative management of spinal trauma is similarly vital for the ability to treat previously occurring secondary injury as well as prevent operative secondary injury. Management focuses

on physiological principles, involving the rational use of immobilization, careful airway management, support of cord perfusion, and oxygenation with appropriate respiratory and hemodynamic sustenance [43]. Immobilization devices often complicate access to the airway. No intubation technique has proved superior, and clinical judgment must be employed regarding individual situations [19]. Spinal cord blood flow is often compromised in traumatic injuries to the spinal cord. Hypotension is particularly dangerous in these patients and usually results from hemorrhage from the original trauma, neurogenic shock, or a combination thereof. Neurogenic shock is more likely in patients with spinal cord injury. Neurogenic shock refers to systemic vasodilation resulting in insufficient tissue perfusion from loss of sympathetic control above the spine [19]. Increased blood pressure improves axonal function in motor and sensory tracts.

Several clinical studies have demonstrated benefit to aggressive hemodynamic management in patients with spinal cord trauma. However, little evidence exists regarding appropriate blood pressure goals or specific agents. Clinical trials regarding pharmacological neuroprotection overall present disappointing results, though mechanistic discovery continues to pose new therapeutic prospects [43]. There are no evidence-based guidelines regarding treatment timing, leaving surgical expertise and medical center protocols to determine best practice. Multimodal intraoperative monitoring (MIOM) may provide benefit to further reducing secondary damage from surgery. MIOM refers to collective monitoring of sensory- and motor-evoked potentials and spontaneous electromyography to help identify deterioration of the spinal cord, providing the opportunity to correct offending agents before provoking irreversible damage. However, the level of evidence is low that MIOM prevents or corrects new or worsening perioperative neurological damage [19].

The most important perioperative management principles in both traumatic brain injury and spinal cord trauma center around controlling and preventing secondary damage from surgery or anesthesia. Avoiding hypoxia and hypotension is particularly important. Management of traumatic brain injuries should focus on quick assessment, continued resuscitation, rapid surgical intervention, rigorous monitoring, and anesthesia preparation. In general, the management of cervical, thoracic, and lumbar spinal cord injuries depends upon institutional expertise and focuses on physiological principles like immobilization, adequate oxygenation, and blood pressure support. Because secondary injury significantly contributes to loss of function and mortality, the perioperative period provides a potentially powerful window for impacting patient lives.

16.9 Perioperative Management of Electrocution Injuries

Electrocution injuries are 5% of admissions to major burn centers (2014). The age distribution of these injuries is bimodal with the majority being split between young children (under 6 years old) and young adults. For young children, injuries most commonly occur in the home, and for young adults, injuries are most commonly work-related (i.e., mining and construction). Lightning strikes make up a small subset of electrocution injuries (2006).

Electrocution injuries can be divided into high- and low-voltage categories, with high-voltage considered injuries in which voltage is over 1000 V. High-voltage shocks are expected to cause more severe injury per second of exposure and lead to greater deeper tissue damage. Electrocution injuries can also be divided based on direct vs alternating current. Direct current causes a single contraction which tends to throw the person away from the electrical source. Alternating current tends to cause repetitive contractions which may lead to longer exposure and is considered the more dangerous of the two. All types of electrocution injuries can lead to cardiac, respiratory, skin/musculoskeletal, and neurological abnormalities. It is important to remember that the superficial skin injuries are not indicative of the full extent of damage.

Cardiac abnormalities can result from both high- and low-voltage injuries and can include arrhythmias, conduction abnormalities, and myocardial damage. Horizontal current flow (hand to hand) is more likely to lead to potentially fatal arrhythmias, while vertical current flow (head to foot) is more likely to lead to myocardial tissue damage. The most common arrhythmias are premature ventricular contractions and sinus tachycardia, but ventricular tachycardia and atrial fibrillation are both possible. Low-voltage alter-

nating current is more likely to lead to sudden cardiac death caused by ventricular fibrillation. High-voltage alternating current, or direct current, is more likely to lead to asystole. The EKG tends to show nonspecific ST-T wave irregularities that tend to resolve on their own. Patients not presenting with EKG changes are unlikely to develop life-threatening arrhythmias. Conduction abnormalities, like sinus bradycardia and AV block, have also been reported. Myocardial injury after an electrical shock can be difficult to diagnose as there are not specific EKG changes, symptoms, or abnormal myocardial pyrophosphate scans. Rare vascular complications include arterial spasm/rupture and venous or arterial thromboses.

Respiratory arrest following a shock is common, and the patient needs prompt ventilatory support to avoid hypoxia-induced ventricular fibrillation. Ventilatory support should continue until neurological function can be assessed.

The bone bears the most severe electrothermal injuries including periosteal burns, bone matrix destruction, and osteonecrosis. Electrocution can lead to fractures, as well as large-joint dislocation. Injuries may lead to edema and tissue necrosis that in turn can cause compartment syndrome and rhabdomyolysis. It is suggested to use creatine kinase serum levels to measure rhabdomyolysis and keep in mind that rhabdomyolysis can lead to acute kidney injury.

Electrocution can cause keraunoparalysis, which is a transient paralysis associated with peripheral vasoconstriction and sensory deficits. Due to this reversible autonomic dysfunction, patients may present with fixed and dilated pupils. This should not be taken as a sign to stop resuscitation efforts. Other neurological complications include loss of consciousness, memory problems, hypoxic encephalopathy, intracerebral hemorrhage, and stroke.

Electrical injuries need to be managed as multisystem injuries and management begins with fluid and cardiopulmonary resuscitation. All patients, regardless of the source of their electrocution injury, should have an initial EKG ordered. If the presenting patient has no history of loss of consciousness, the initial EKG shows no abnormalities, and if it is a low-voltage injury, then continuous cardiac monitoring is not absolutely necessary. However, if the patient fails to meet any *one* of those criteria, then continuous cardiac monitoring is required. After initial resuscitation, it is important to remember to run a full physical and labs to check for damage such as broken bones, neurological deficits, acute kidney injury, or tissue necrosis. More extensive deep tissue injuries may require debridement, fasciotomy, and wound exploration. Imaging (X-rays or CTs) should be obtained if there is suspicion of spinal injury or if there is a history of a fall and altered consciousness with abnormal neurologic findings. Additional radiographs should also be done for any area where the patient feels pain and where there is an obvious deformity or decreased range of motion.

Lightning strikes are considered a special circumstance. They lead to cardiac and respiratory arrest through delivery of a large quantity of direct current during a very short time frame. This rarely leads to extensive tissue destruction so aggressive fluid resuscitation is not needed. Aside from that, management should follow the usual protocol. Lichtenberg figures are rare and will resolve on their own in a few days. Cardiac arrest is due to asystole but frequently spontaneously resolves. The respiratory arrest tends to last longer and, if support is not provided, will lead to hypoxia-induced ventricular fibrillation [31, 42].

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Obstetrics

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_17

17.1 Introduction

When dealing with a patient who is pregnant, health-care providers are, for all practical purposes, taking care of two patients. A guiding principle for their care is "If momma isn't doing well, then no one is doing well." Care for an obstetrical patient has to take into account the physiologic changes of pregnancy that varies from the first trimester to the third trimester along with the effects of treatment on the fetus and the placenta.

During embryologic development, certain treatments and medication can affect formation of organs and tissues. Adverse events can damage the placenta leading to growth restriction of the fetus and even intrauterine fetal demise (IUFD).

Through an understanding of the bodily changes to the female parturient, the embryologic development of the fetus, and development of the placenta, management of these surgical patients can become less intimidating and help avoid perioperative complication.

Certain conditions exclusive to obstetrics can significantly alter normal pregnancy physiology and increase the risks of intraoperative complications. Surgical care of gravid women should not be withheld just because they are pregnant. This leads to the need for anesthesia/surgical providers to understand the physiologic changes of pregnancy to modify their care for this unique group.

17.2 Maternal Physiology

Changes to the female body systems begin almost immediately with conception. The early embryologic tissue produces hormones and tissues, factors that have an effect on almost every body system. Mechanical changes occur as the result of the growth of the pregnant uterus, enlarging breasts, organ hypertrophy, and tissue edema. The average gestation is 280 days, and although we discuss these effects based on trimesters, it is a continuum that peaks at 40 weeks (full-term pregnancy 37–42 weeks) and then gradually resolves usually by 6–8 weeks postpartum.

Beta human chorionic gonadotropin (BHCG) is the most common hormone measured to determine a pregnancy. It typically increases by 33-49% every 2 days and peaks around 10 weeks of gestation. Most qualitative pregnancy tests will turn positive around 25 IU. Ovulation typically occurs around cycle day number 14 during the average menstrual cycle of 28 days. Conception usually occurs around 1–2 days later. This means pregnancy changes are occurring even before a patient realizes they are pregnant by cessation of menses. This also can lead to a false negative pregnancy test until someone is 2 or more days late for menstruation.

Normal maternal weight gain with pregnancy is between 22 and 37 pounds (10–16.8 kg) [1] with the fetus, placenta, and amniotic fluid only responsible for 35–59% of this weight. Prior recommendations for weight gain of 30 pounds in pregnancy were based on this, but because of the current obesity rates, it has now been decreased to 15–20 pounds. The rest of the weight gain in pregnancy is attributed to changes in organ systems to meet the physiologic needs associated with pregnancy.

17.2.1 Cardiac

Some of the most dramatic changes occur in the cardiovascular system to maximize oxygenation to the fetus along with increased blood flow to the uterus, which in turn is passed on to the fetus via the placenta. The heart enlarges and rotates slightly which can increase its silhouette in radiologic studies. This enlargement along with hypertrophy results in a remarkable increase in stroke volume (SV). The heart rate (HR) increases by 15–20 beats per minute during pregnancy. Preload is increased by the upsurge in blood volume. Reduced vascular resistance through vasodilatation decreases afterload. All together this works to increase cardiac output (CO) very early pregnancy by 20% and peaks at around 50% by 32–34 weeks. Remembering SV × HR = CO, we can see the normal value of 4.88 increase to 7.34 L/min in the third trimester [2, 3]. Multi-gestations can result in an additional 20% increase in CO. This increase in CO can result in larger blood loss amounts in a shorter period of time with hemorrhage with masking of tachycardia until significant blood loss has occurred. CO is greatly affected by patient position and can be reduced by mechanical compression to the vena cava by the gravid uterus as early as 24 weeks. This reduces blood flow back to the heart. Placing the patient supine instead of a left lateral tilt can reduce CO by 25–30% [4].

Blood pressure (BP) in pregnancy is variable based on trimester. Initial drops in BP can be noted around 8 weeks of gestation and will gradually increase in midpregnancy and return to normal levels by term gestation. With this early decrease in BP around the time that pregnancy is diagnosed, many women with underlying hypertension may not be recognized. This can lead to diagnoses of preeclampsia when indeed the patient has chronic hypertension instead. Mean arterial pressure (MAP) on average is decreased by 5–10 mmHg and is mainly due to a decrease in systemic vascular resistance (SVR) leading to increased blood flow to the gravid uterus. During labor, there is a significant increase in CO and MAP caused by 300–500 ml increase in venous blood by a uterine contraction along with pain and anxiety increasing the heart rate. CO typically peaks immediately postpartum and will return to prepregnancy levels within 2–4 weeks after delivery [5].

Venous pressure increases in the lower extremities, as the pregnancy progresses, to as much as 25 cmH2O. This increases the risks of edema and varicose veins and, coupled with stasis, leads to deep vein thrombosis. Additionally, decreased colloidal osmotic pressure means pregnant patients are at increased risk of developing pulmonary edema with preeclampsia or fluid volume overload (increased cardiac preload). Brain natriuretic peptide (BNP) is still a reliable test for pulmonary edema/congestive heart failure in pregnancy [6].

Dyspnea is a normal feature of pregnancy beginning around 20 weeks of gestation and is usually mild in nature. It can imitate heart disease, but it usually doesn't occur at rest and isn't associated with additional symptoms such as chest pain with exertion, syncope, orthopnea, or paroxysmal nocturnal dyspnea [7]. If these additional symptoms occur, a further cardiac evaluation is warranted. Troponin is preferred over CK-MB when patients are in labor as uterine contractions can increase CK-MB [8].

Most pregnant women will exhibit a flow murmur with a S3 and systolic ejection murmur along the left sternal boarder from increased flow through both the pulmonic and aortic valves.

Cardiac rhythm is usually limited to a mild tachycardia and increased rate of benign isolated premature atrial and ventricular contractions thought to be associated with cardiac enlargement [9].

17.2.2 Respiratory

Upper airway edema and increased secretions can occur due to the increased estrogen levels during pregnancy. This can increase risks of anesthesia complications and difficulty in intubation. Coupled with increased vascularity of the nasal mucosa, epitasis frequently occurs [10].

The thoracic region undergoes significant changes beginning in the first trimester. Considerable increase in breast size and weight can apply pressure to the chest wall. Respiratory muscle function and maximum inspiratory and expiratory pressures are unchanged. Elevation of the diaphragm from an enlarging gravid uterus will decrease the resting lung volume. This reduces total lung capacity (TLC), functional residual capacity (FRC), expiratory reserve volume (ERV), and residual volume (RV). Patients during pregnancy have an increased progesterone level which leads to an increased respiratory rate. This coupled with an increase in tidal volume (TV) results in a rise in minute ventilation (MV). With these effects, the gravid women will have an increase in PaO2 and decrease in PaCO2 resulting in respiratory alkalosis. Oxygen consumption is increased, and with apnea associated with intubation, desaturation can occur in as little as 3 min [2].

17.2.3 Hematologic

A rise in blood volume starts at 6 weeks of gestation and increases during pregnancy with a climax at 40–50% by 30–34 weeks of gestation. Plasma volume increases by 50%, while erythrocyte development is at a slower rate and averages 400 ml. This results in an increase in hemoglobin (Hgb) but a dilution of the hematocrit (Hct). This is in anticipation for the significant blood loss that can occur at delivery.

White blood cell (WBC) also rises mildly as the pregnancy progresses. Adding in the stress associated with labor, some patients can develop leukocytosis (20,000 or higher WBC counts) at delivery. WBC counts alone shouldn't be used to diagnose infection. Clinical correlation is necessary to make an infection determination.

Pregnancy is associated with hypercoagulation with a significant increased risk of venous thromboembolic events (VTE), but most laboratory

values remain unchanged such as prothrombin time (PT) and partial thromboplastin time (PTT). Fibrinogen levels are increased, and values in the normal adult range can be associated with active bleeding such as placental abruption. Fibrin degradation products (FDP) are decreased and can be used in the evaluation of DIC, but D-dimer is elevated and cannot reliably predict or rule out VTE events [2].

17.2.4 Urologic

Kidney enlargement is noted during pregnancy along with dilation of the calyces, pelvis, vasculature, and ureters. The right ureter is typically dilated more than the left and on imaging can appear as hydronephrosis. Frequent urination is a common issue in pregnancy. This is related to increased production along with decreased bladder capacity from the enlarging uterus.

Increase in renal blood flow occurs in pregnancy leading to a 50% increase in glomerular filtration rate (GFR) by the end of the first trimester. This also results in an increase in creatine clearance. Blood creatine, BUN, and uric acid are decreased in pregnant patients. Significant increases in total body water (8.5 L by term) result in blood volume expansion by 1.5 L. Additional extravascular accumulation of fluid is noted in the tissue. This results in edema and a hemodilutional anemia. Additionally there is a slight decrease in serum potassium and calcium levels along with increased excretion of protein, glucose, and albumin. Plasma osmolality is decreased because of these changes mediated by the kidneys [2, 11].

17.2.5 Gastrointestinal

The average caloric increase needed for pregnancy and breastfeeding is between 200 and 300 kcal/day. Morning sickness is a common complaint early in pregnancy peaking around 8 weeks of gestation and usually gone by 14 weeks. Many patients also experience increased production of saliva (ptyalism). The tone of the gastroesophageal sphincter along with decreased motility of the stomach can increase the rates of reflux irritation of the esophagus. The data about increased risk of aspiration is mixed in the literature. Decreased motility of the intestine, increased water absorption, and compression of the intestines by the gravid uterus are noted. These factors, along with increased iron intake from prenatal vitamin therapy, can produce significant constipation.

The appendix changes position toward the right upper quadrant in pregnancy as the uterus enlarges. Significant increases in portal vein pressure increase the incidents of hemorrhoids. Increased progesterone production slows the emptying of the gallbladder. This along with increased production of cholesterol can increase the risk of gallstone and sludge formation.

Liver size is unchanged in pregnancy, but a few liver lab values are affected such as increase in alkaline phosphatase and fibrinogen. Bilirubin, aspartate aminotransferase (AST), alanine aminotransferase (ALT), gamma-glutamyl transferase (GGT), and lactate dehydrogenase (LDH) are unaffected [2].

17.2.6 Endocrine

A small increase in the size of the thyroid is noted, but hormone production for the most part remains close to non-pregnancy levels. Thyroid-stimulating hormone (TSH) levels are close in structure to HCG, so it is not unusual for the level to decrease in the first trimester as HCG levels peak around 8 weeks of gestation. Increased levels can be noted in the presence of hyperemesis gravidarum. Free T4 levels rise slightly in the first trimester and then decrease slightly during the remainder of the pregnancy remaining slightly lower than expected in non-gravid women [12].

Adrenal size increases during pregnancy leading to the increased production of aldosterone, corticosteroid-binding globulin, adrenocorticotropic hormone (ACTH), cortisol, and free cortisol as the pregnancy progresses. Cortisol levels can be 3 times higher by delivery.

The pituitary gland enlarges significantly during pregnancy with increased production of prolactin in anticipation for breast lactation after delivery. Decreased levels of follicle-stimulating hormone (FSH) and luteinizing hormone (LH) are noted due to increased estrogen and progesterone levels causing a negative feedback on the pituitary gland. The increased size makes it vulnerable to hypotension that can occur during a postpartum hemorrhage. The infarction of the gland can lead to Sheehan syndrome. This syn-

drome is noted as postpartum amenorrhea and infertility. Oxytocin levels increase during pregnancy and peak during active labor leading to uterine contractions.

The pancreas undergoes significant increased production of insulin as part of the physiologic changes to increase glucose delivery to the placenta and fetus. Pregnant women typically have fasting hypoglycemia and postprandial hyperglycemia. Some patients are not able to keep up with the needed insulin production and demonstrate gestational diabetes. This is associated with increased risks of type 2 (non-insulin) later in their lives.

Increased lipid levels are noted in pregnancy as cholesterol is needed for steroid synthesis and amino acids are an energy source for the fetus. Significant increases are noted in triglycerides, cholesterol, and low-density lipids (LDL). Slight increase in high-density lipids (HDL) is also seen in the gravid patient [2].

17.2.7 Skeletal

Calcium levels are decreased in pregnancy associated with the decrease in serum albumin binding of the calcium. Additionally, increased need for calcium by the fetus and increased meternal kidney excretion are noted [13].

Significant lordosis (anterior curvature of the lumbar spine) occurs to offset the enlarging uterine weight that changes balance. This can contribute to increase rates of back pain that occur late in pregnancy along with need for lumbar support when sitting or supine [2].

17.2.8 Other Systems

Although other body systems are affected by pregnancy, they have minimal impact on the perioperative management of catastrophic complication.

Box 17.1 Physiologic Changes in Pregnancy

Key laboratory values that are different in pregnancy

- Hemodynamic variables
  - Increased cardiac output
  - Decreased systemic vascular resistance
  - Decreased blood pressure
  - Increased heart rate
  - Decreased pulmonary vascular resistance
- Respiratory variables
  - Decreased function residual capacity
  - Increased minute ventilation
- Laboratory variables
  - Increased PAo2 and Pao2
  - Decreased Paco2
  - Decreased serum bicarbonate (Hco3)
  - Decreased hemoglobin and hematocrit levels
  - Increased white blood cell count
  - Decreased protein S levels
  - Decreased coagulation factors XI and XIII levels
  - Increased coagulation factors I, VII, VIII, IX, and X levels
  - Increased fibrinogen levels
  - Increased D-dimer levels
  - Increased erythrocyte sedimentation rate
  - Decreased serum creatinine levels
  - Decreased blood urea nitrogen level (BUN)
  - Decreased uric acid level
  - Increased alkaline phosphatase level
  - Increased aldosterone level
  - Increased serum cortisol, free cortisol, cortisol-binding globulin, and adrenocorticotropic hormone level
  - Increased insulin level
  - Decreased fasting blood glucose level
  - Increased triglyceride level
  - Increased cholesterol, low-density lipoprotein, and high-density lipoprotein levels

Data from Gabbe et al. [41], American College of Obstetricians and Gynecologists [42]

17.3 Fetal Development and Placenta

One of the biggest concerns raised by those who deal with surgical care and anesthesia for pregnant patients is the effects on the fetus. While the care of the mother is similar to a nonpregnant woman, and provides familiarity to a typical case, the addition of a growing fetus brings with it some trepidation. This can lead to reluctance to provide surgery or anesthesia out of worry the treatment could lead to miscarriage, fetal demise, or development of a fetal anomaly. Withholding treatment during pregnancy may lead to a more

detrimental situation with decline of the mother from her condition, which subsequently affects the growth and development of the fetus. An understanding of the stages of fetal and placental development can assist with preoperative and intraoperative planning [14].

Just like perfusion pressure and oxygenation can affect other organs and tissues in the body; the placenta with subsequent flow to the umbilical cord can be affected. Besides its ability to provide for exchange of oxygen and carbon dioxide, the placenta allows for the diffusion of nutrients such as glucose, proteins, and lipids to allow for fetal growth. The placenta acts as a selective barrier to prevent certain substances from crossing into the fetal circulation and potentially lead to adverse exposures. While the details of how the placenta acts as a selective barrier are beyond the scope of this chapter, certain general principles can be discussed. Lipid-soluble compounds cross the placenta easier than water-soluble. Larger molecules with higher molecular weight have a more difficult time crossing the placenta. Binding to plasma proteins can impact the amount of a substance that can pass through the placenta.

Fetal development can be simplified into stages upon which an exposure to a drug or therapy can have a different effect. Very few therapies are known teratogens. Few drugs have clinical trials in pregnant patients that can demonstrate safety of use during pregnancy. Most drugs are either felt to have little risk to the pregnancy or consideration of their use has to show maternal benefits outweigh the risks. Consultation with web based or books discussing the effects of drugs on pregnancies listed in the box will provide information about specific risks with medications [15].

Box 17.2 Drug Teratogen Resources

- Micromedex, Inc.
  - ► www.micromedex.com
- Reproductive Toxicity Center (REPROTOX)
  - ► www.reprotox.org
- Drugs in Pregnancy and Lactation 11th edition, 2017
  By Briggs GG, Freeman RK, Towers CV, Forinash AB
  Wolters Kluwer

The first stage is cellular division of the embryo. This is typically less than 31 days from LMP. Exposure to a substance typically results in an all or nothing effect on the fetus. During this phase the risk of miscarriages is highest with approximately 5–20% of pregnancies miscarrying. This makes it difficult to qualify if a therapy was the cause of the pregnancy loss or unrelated.

The next stage is organogenesis. From days 31–71 from the LMP, critical organs and tissues are developing and exposures to substances can potentially cause malformations. The incidence of major malformation is 2–3% in the general population, is usually polyfactorial in nature, and cannot be tied to a single therapy.

The third stage is the growth. This is where organs and tissues grow and the fetus enlarges in size. Exposure during this stage may lead to organ damage, restriction in function, or growth restriction of the fetus [16].

17.4 Fetal Monitoring

One of the guiding principles of fetal monitoring when surgical care of a pregnant patient is necessary is the willingness to act on the information. For this reason, the degree of fetal monitoring is varied according to gestational age of the pregnancy. The need for monitoring in a previable pregnancy typically is more basic, whereas the monitoring for a term pregnancy would need to be more advanced [17].

Another aspect of fetal monitoring has to deal with type of monitoring depending on access to the area of the uterus. Abdominal surgical procedures with a large incision may make continuous external fetal monitoring nearly impossible. Consideration for intermittent ultrasound assessment of the fetal heart rate may be an alternative. Consultation with an obstetrician preoperatively can help with anesthesia and surgical planning for the case [18].

Typically fetal cardiac activity is difficult to see on ultrasound prior to 7–8 weeks and auscultation with a Doppler prior to 10 weeks. The gravid uterus doesn't rise out of the pelvis until 12 weeks making continuous external fetal monitoring unreasonable until later in the second trimester.

The debate for fetal monitoring in pregnancy has to also take into account that the fetal monitoring could potentially pick up maternal condi-

tions that result in either decreased oxygenation or perfusion to the uterus and thereby the fetus. This gives the surgical team the opportunity to correct these issues. On the opposite side of the debate is that anesthesia affects the fetus and fetal monitoring may be unreliable. It isn't uncommon for the fetal heart rate baseline and variability to decrease with anesthesia and falsely give the impression of a need to intervene. This could potentially lead to an unnecessary emergency C-section. Because of these issues, the American College of Obstetricians and Gynecologist has published the recommendations in the box below.

Box 17.3 ACOG Guidelines for Fetal Monitoring During Surgery

- If the fetus is considered previable, it is generally sufficient to ascertain the fetal heart rate by Doppler before and after the procedure.
- At a minimum, if the fetus is considered to be viable, simultaneous electronic fetal heart rate and contraction monitoring should be performed before and after the procedure to assess fetal well-being and the absence of contractions.
- Intraoperative electronic fetal monitoring may be appropriate when all of the following apply:
  - The fetus is viable.
  - It is physically possible to perform intraoperative electronic fetal monitoring.
  - A health-care provider with obstetric surgery privileges is available and willing to intervene during the surgical procedure for fetal indications.
  - When possible, the woman has given informed consent to emergency cesarean delivery.
  - The nature of the planned surgery will allow the safe interruption or alteration of the procedure to provide access to perform emergency delivery.

In select circumstances, intraoperative fetal monitoring may be considered for previable fetuses to facilitate positioning or oxygenation interventions.

The decision to use fetal monitoring should be individualized and, if used, should be based on gestational age, type of surgery, and facilities available. Ultimately, each case warrants a team approach (anesthesia and obstetric care providers, surgeons, pediatricians, and nurses) for optimal safety of the woman and the fetus.

American College of Obstetricians and Gynecologists [14]

Considerations for fetal monitoring should at least involve a check of the heart rate prior to and after the conclusion of the surgical procedure and anesthesia [12]. In the first and early second trimesters, this may be all that is necessary. As the pregnancy reaches viability around 22–24 weeks, this can incorporate expansion of the monitoring to intraoperative evaluation with either intermittent or continuous monitoring depending on the type of surgery and access available to the lower abdomen. The level of monitoring should be done in consultation with an obstetrician who can base the decision on gestational age, surgery type, and available resources at the facility to act on any abnormal findings. Besides counseling the operative team, they can also counsel the patient and/or family.

17.5 Anesthesia for Pregnant Patients

The majority of the research related to the use of general anesthesia in pregnant patients is restricted to retrospective studies and registries making the conclusions limited. Most studies show that surgical anesthesia doesn't increase the risk of miscarriages or fetal anomalies [14].

The optimal timing of surgery and anesthesia for pregnant patients is in the second trimester where the risk of spontaneous miscarriages has decreased significantly and organogenesis is complete [19].

Consideration for options such as spinal or epidural anesthesia can reduce exposure of the fetus to agents. Care needs to be taken to avoid hypotension with adequate hydration to avoid hypotension, which can reduce uterine blood flow to the fetus.

Discussion of the physiologic changes associated with pregnancy earlier in this chapter should encourage the anesthesiologist to plan ahead for certain aspects of the surgical case. Theoretical delays in gastric emptying with relaxation of the gastroesophageal sphincter can potentially increase the risk of aspiration during intubation [20]. Treating pregnant patients with the notion that even if fasting they can aspirate may be prudent. Cricoid pressure, metoclopramide, and antacids should be considered. Edema of the face and neck associated with pregnancy, along with mild thyroid enlargement, may increase the challenges of intubation. Some studies show almost one third of term gravid patients may

have a class IV Mallampati airway [10, 21]. Increased rate of desaturation with apnea (in as little as 3 min), coupled with the airway changes, should encourage ready accessibility to airway tools such as glide scopes and alternatives to endotracheal tubes.

17.6 Perioperative Care for Pregnant Patients

Because of significant compression to the vena cava and aorta by the gravid uterus, pregnant patients should be placed in a left lateral tilt if possible. If not, at least a tilt of the hips with a fully padded 1 L IV bag, semicircular gel pad, or rolled-up blanket under the right buttocks can offer a tilt to the left. This will prevent deceased preload and cardiac output, which translates into uteroplacental hypoperfusion. Hypercoagulability in pregnancy can increase the risks of venous thrombotic events (VTE) including deep vein thrombosis (DVT). At a minimum, serial compression devices (SCD) should be applied. Because of the higher molecular weight of heparins (including low molecular weight heparin), the ability to cross the placenta is limited [16]. For higher-risk cases, additional VTE prophylaxis can be used in pregnancy.

Typically antibiotic prophylaxis for most types of procedures can be used with the exception of fluoroquinolones and tetracyclines [16]. Penicillin-, cephalosporin-, erythromycin-, and vancomycin-based prophylaxis are felt to be safe (consult teratogenicity databases or your hospital pharmacist about specific agents).

Maintenance of normal body temperature is important to prevent peripheral vasoconstriction, which could affect blood flow to the uterus with hypothermia. Care should be exercised to avoid increased body temperature as febrile illnesses have been discussed as a potential risk factor for miscarriage and congenital anomalies early in pregnancy.

17.7 Obstetrical Physiologic Changes Affecting Perioperative Care

Specific perioperative complications are discussed in detail in other chapters of this book. Some of these complications are managed via similar means as the nonpregnant patient. Because of physiologic changes discussed earlier in this chapter, certain complications in normal pregnancy require alterations in their management. Particular conditions exclusive to obstetrics can increase the risks of complications and/or require significant modifications to their management.

In normal pregnancy, airway management has to take into account that gravid women have increased edema, increased oral secretions, increased reflux, and increased gag reflex. Partnered with the potential to desaturate in a quicker manner, efficient placement of an airway is a concern. Maternal desaturation can quickly lead to fetal desaturation if the situation isn't rectified quickly.

During induction, edema can lead to a class IV Mallampati airway requiring additional tools since visualization of the epiglottis and vocal cords may not be possible [10, 21]. Edema especially late in pregnancy can affect placement of oral airways while trying to establish the airway. Additionally, this edema may prevent passage of the usual diameter of endotracheal tube. Smaller tubes may be necessary which can indirectly affect gas exchange and pressures needed to ventilate. Having the usual tools used for difficult airways and suction readily available prior to induction can prevent prolonged intubation and maternal desaturation. Because of the increased secretions and reflux, cricoid pressure and the use of anesthesia protocols to reduce the risks of aspiration should be considered.

Loss of an airway can quickly lead to maternal desaturation with little notice prior to the rapid drop of O_2 saturation. Re-establishment of the airway, ventilation, and oxygenation can be complicated by the decrease in total lung capacity. During an emergency, the tendency to provide increased volume and pressure while bagging with a facemask, along with relaxation of the gastroesophageal sphincter, can rapidly lead to stomach hyperinflation and aspiration of contents. Although placement of oral gastric or nasogastric tubes can deflate this hyperinflation, it is best to avoid this issue by carefully adjusting the volume and pressure while bagging until the endotracheal tube can be replaced.

There are progressive changes in cardiac and respiratory physiology (as discussed earlier in the chapter) as the pregnancy advances that can make ventilation complications unusual. Issues with bronchospasm and constriction from inflamma-

tion can be managed in the same fashion as with nonpregnant women. Typically the immune system is downregulated during pregnancy to prevent rejection of the fetus. This means that certain types of asthma may improve during pregnancy. The use of bronchodilators and glucocorticoids is typically safe in pregnancy (consult teratogenicity databases or your hospital pharmacist about specific agents). Ventilation-perfusion mismatch can be seen during pregnancy associated with pulmonary embolism and in some cases amniotic fluid embolism. Pregnancy is a time of hypercoagulation so there is an increased rate of venous thrombotic event (VTE). Management of VTE is unchanged by pregnancy with anticoagulation by heparin or low molecular weight heparin. Amniotic fluid embolism will be discussed later in this chapter.

Pulmonary edema can be associated with certain conditions such as preeclampsia caused by endovascular leakage. Treatment will be addressed under the preeclampsia pregnancy-associated hypertension heading.

Obstetrical hemorrhage is one of the leading causes of maternal/fetal morbidity and mortality [22]. Average blood loss for a vaginal delivery is 500 ml, a C-section is 1000 ml, and a cesarean hysterectomy is 1500 ml [23]. Blood and fluid loss in pregnancy usually is masked until a significant loss has occurred because of the increase intravascular volume and vasodilatation that occurs in pregnancy to increase blood flow to the uterus. This is coupled with the increase in cardiac output and slight baseline tachycardia in pregnant women. Signs of significant blood loss may not appear in the form of considerable tachycardia and hypotension until 25% of the total blood volume has been lost.

The delay of the customary signs of hypovolemia, joined with the rapid nature of blood loss that can occur with pregnancy, places a high emphasis on the need to anticipate potential blood loss and preemptively arrange for treatment [24]. Early identification of bleeding and communication with the rest of the OR team that bleeding is apparent should trigger treatment prior to the physiologic changes occurring. This leads to the need to proactively anticipate the conditions that can lead to rapid loss of blood and have protocols in place for massive transfusion to obtain necessary blood products in a timely fashion [24]. Adequate diameter IV access has to be obtained in gravid patients prior to the start of procedures, and additional IV access or central access may be needed in patients at high risk for blood loss.

Close monitoring of urinary output is an integral part of screening circulatory function and treatment response in hemorrhage via blood flow to the kidneys and production of urine. Foley cauterization with a closed drainage system should be considered for any procedure at high risk for blood loss in pregnant patients. Urine output of at least 0.5 ml/kg/h should be maintained during the operative course.

Recommendations for optimal blood product replacement for obstetrical patients have been modified from trauma protocols and are considered multicomponent [25]. Ratio of packed red blood cells/fresh frozen plasma/platelets is now 1:1:1 [26]. Hemorrhage in pregnancy can quickly lead to a consumptive coagulopathy with decreased fibrinogen. Fibrinogen levels are normally elevated above normal adult values in pregnancy. A normal value can be misleading. Disseminated intravascular coagulation (DIC) requires the addition of cryoprecipitate in pregnancy.

17.8 Obstetrical Conditions

17.8.1 Ectopic Pregnancies

Typically ectopic pregnancies occur in the fallopian tube and are diagnosed in the first trimester. Thanks to advancing ultrasound technology incorporated with BHCG levels, most ectopic pregnancies are diagnosed prior to rupture and bleeding. Patients may present emergently with acute abdominal pain, significant bleeding, and blood loss from their unrealized pregnancy. It is not unusual to find over a liter of blood in the pelvis from a ruptured ectopic. Hemodynamic instability can progress rapidly requiring preoperative and intraoperative volume resuscitation.

Certain types of ectopic pregnancies can result in even higher levels of blood loss or risks based on the site of implantation. Cornual ectopic pregnancy (implantation in the portion of the fallopian tube transversing the uterine myometrium or first portion of the fallopian tube) typically ruptures later in the first trimester or early second trimester. The amount of bleeding can be profuse and quickly become catastrophic [27].

This condition requires quick surgical intervention along with aggressive fluid/blood replacement. Again preoperative planning for the need of blood products and large-bore IV access along with rapid activation of massive transfusion protocol should be considered.

Seen more recently with the increased rates of C-sections is implantation of the pregnancy into the C-section scar. These can result in a scar dehiscence and perforation into the abdominal cavity or even the bladder resulting in a severe hemorrhage [28]. These patients may require emergent hysterectomy if they are actively bleeding. This requires planning for the need of blood products and potential coagulopathy that can occur with hemorrhage.

17.8.2 Molar Pregnancy

Hydatidiform moles are part of gestational trophoblastic disease (GTD) and are atypical pregnancies associated with placental hypertrophy. They are typically diagnosed during the first trimester by abnormally high BHCG and snowstorm pattern on ultrasound. When evacuation is indicated by suction D&C, there is a significant risk for blood loss and embolization of the tissue. Preparation for potential large blood loss with availability of blood products and oxytocin (Pitocin) to help the uterus to clamp down should be included in operative management. If embolization was to occur, significant hypoxia can happen along with an inflammatory reaction that can trigger a consumptive coagulopathy similar to amniotic fluid embolism (see management under that heading) [29].

17.8.3 Abnormal Placentation

This section includes issues with atypical locations of the placenta as well as invasion of placental tissue into the uterine myometrium. As the number of C-sections has increased for delivery, we are seeing increased numbers of patients with placental abnormalities typically related to scarring of the endometrial cavity.

A placenta previa is when part or the entire placenta covers the cervix. A vasa previa is when membranous umbilical vessels cover the cervix [30]. With labor significant bleeding can occur resulting in maternal/fetal distress and the need for emergent C-section. With a significant number of previa, the placenta may locate near the incision point for a low transverse C-section (the most common type). This can result in additional bleeding and difficulty reaching the fetus [31]. Modification of the uterine incision (classical c-section) may be necessary and result in more blood loss. The need for crystalloid and blood products may be necessary; therefore, the preoperative planning should include adequate IV access and the availability of blood products.

Placenta previa sometimes will occur because of a placenta accreta, placenta increta, or placenta percreta. All three of these conditions result when there is a loss of the decidua and there is invasion of the placenta into the underlying myometrium causing the placenta not to separate after delivery. Accreta is the term for when the placenta superficially invades the myometrium. Increta indicates deep myometrial invasion of the placenta. Percreta is the most serious situation as the placenta has invaded through the myometrium and into adjacent tissues such as the bladder, bowel, abdominal wall, and vessels. Catastrophic bleeding can occur if not recognized preoperatively, and attempts are made to manually extract the placenta [31].

If diagnosed preoperatively, referral to a tertiary care center with a multidisciplinary team should be considered. Typically, the availability of neonatology, general/vascular surgery, urology, interventional radiology, and gyn oncology may be required. The perioperative team should choose a room large enough to accommodate a large team. General anesthesia should be considered to allow for muscle relaxation and placement of retractors. Massive transfusion protocols should be readied, and large amounts of blood products should be available in-house if not in the operating room.

Some institutions may have the availability for interventional radiology to place occlusion balloons or embolize vessels [32]. Urology may consider placement of ureteral stents. Cell salvage equipment should be readied if available. Rapid infusion devices, central venous access, and arterial lines may be needed.

Typically, a fundal or posterior uterine incision is utilized and followed by closure of the uterine incision. This is followed by a cesarean hysterectomy to prevent further hemorrhage. Some small series have demonstrated the options for conservative management with closure of the uterine incision with the placenta left in place. This may be considered if no significant bleeding is encountered and the facility can emergently deal with a secondary hemorrhage.

A very rare type of pregnancy is an intra-abdominal pregnancy with implantation outside of the uterus. The attachment of the placenta to bowel, peritoneal lining, omentum, or any other intra-abdominal structure is highly vascular and invades into the structure preventing normal separation. If the placental attachment is disturbed, significant bleeding that is difficult to control occurs. Packing of the abdomen, sewing the edge of the placenta in place, or use of hemostatic agents may be required. Perioperative preparation for significant bleeding is necessary as discussed above.

17.8.4 Placental Abruption

This is the premature separation of the placenta from the uterine wall prior to delivery of the fetus. Typically associated with pain and uterine contractions, it can occur with varied signs depending on the amount of bleeding that occurs. Most likely to occur in the third trimester, it can be a source of fetal distress and may require emergent C-section.

These gravid patients can have significant bleeding leading to hemodynamic instability and consumptive coagulopathy requiring treatment with little prior preparation in the face of an emergent delivery [31]. As discussed in other parts of this chapter, rapid assessment for blood loss amounts and preemptive planning for the need to infuse large amounts of fluids and/or blood products is the mainstay of management. Need for platelets and cryoprecipitate may become necessary on short notice [22].

17.8.5 Uterine Inversion

Uterine inversion is when the uterine fundus invertly prolapses to or through the cervix. This can result in significant hemorrhage and quickly has to be attended to for successful resolution. It can occur when the placenta fails to release and traction is placed on the umbilical cord either during vaginal delivery or C-section. It can also occur spontaneously but less likely. In order for the obstetrician to replace the uterus, relaxation of the uterus may be required. Use of tocolytics such as terbutaline 0.25 mg SQ, magnesium sulfate IV or IM, halogenated inhaled general anesthetics, or nitroglycerin SL has been shown to be effective in these cases. Some incidences may require laparotomy to resolve. Close monitoring of blood loss and hemodynamic stabilization may be required during the replacement of the uterus [22].

17.8.6 Uterine Atony

Post delivery or post C-section, subinvolution of the uterus can occur leading to significant hemorrhage and hemodynamic instability. Certain risk factors such as prolonged use of oxytocin, high parity, infection, general anesthesia, multigestation, polyhydramnios, fetal macrosomia, fibroids, and uterine inversion can all contribute to this condition. This can occur immediately after delivery or can be delayed for hours or even days after delivery [22].

Quickly recognizing atony and a systematic protocol for its management can help limit the impact on the patient. Immediate uterine massage and emptying of the bladder are indicated. Anesthesia should increase oxytocin IV fluid rates and implement massive transfusion protocols or summon blood products for possible administration. Additional use of uterotonics is indicated in about 25% of cases. These include methylergonovine (Methergine) 0.2 mg IM but is contraindicated in cases of hypertension and preeclampsia. 15-Methyl prostaglandin F-2 alpha (Hemobate) 250 mcg IM or intramyometrial can be given every 15 min up to eight doses. This is contraindicated in patients with asthma. Misoprostol (Cytotec) 600–1000 mcg can be administered PO, SL, or PR once.

Additional surgical tamponade or vessel ligation can be employed. Use of intrauterine balloons such as the Bakri or Ebb can help when medications fail to resolve the atony. Alternatives include using several large (60 cc) Foley catheters or packing the uterus with Kerlix gauze [33].

If available, uterine artery embolization by the interventional radiologist may help reduce pulse pressure to the uterus. Vascular ligation by the surgeon with O'Leary stitches to the uterine vessels and/or utero-ovarian ligaments can have the same effect. Hypogastric (internal iliac) artery ligation has fallen out of favor because of limited success and risks. The obstetrician may employ uterine compression sutures such as B-lynch before the final option of hysterectomy is considered [34]. The perioperative management of these cases of postpartum hemorrhage is further discussed below.

Box 17.4 Uterotonic Medications for Postpartum Hemorrhage

Drug[a]	Dose and route	Frequency	Contraindications	Adverse effects
Oxytocin	IV: 10–40 units per 500–1,000 mL as continuous infusion or IM: 10 units	Continuous	Rare, hypersensitivity to medication	Usually none
				Nausea, vomiting, hyponatremia with prolonged dosing
				Hypotension can result from IV push, which is not recommended
Methylergonovine	IM: 0.2 mg	Every 2–4 h	Hypertension, preeclampsia, cardiovascular disease, hypersensitivity to drug	Nausea, vomiting, severe hypertension particularly when given IV, which is not recommended
15-methyl PGF	IM: 0.25 mg Intramyometrial: 0.25 mg	Every 15–90 min, eight doses maximum	Asthma, relative contraindication for hypertension, active hepatic, pulmonary, or cardiac disease	Nausea, vomiting, diarrhea, fever (transient), headache, chills, shivering hypertension, bronchospasm
Misoprostol	600–1,000 micrograms oral, sublingual, or rectal	One time	Rare, hypersensitivity to medication or to prostaglandins	Nausea, vomiting, diarrhea shivering, fever (transient), headache

Modified from Lyndon et al. [43], American College of Obstetricians and Gynecologists [22]
Abbreviations: *IV* intravenously, *IM* intramuscularly, *PG* prostaglandin
[a]All agents can cause nausea and vomiting

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17.8.7 Postpartum Hemorrhage

Postpartum hemorrhage is a catastrophic perioperative event and a leading cause of peripartum morbidity and mortality. In addition to the disorders mentioned above, there are additional obstetrical conditions that can cause hemorrhage. Genital tract trauma in the forms of cervical, vaginal, or perineal lacerations can require perioperative management. Additionally uterine rupture can occur especially in patients with prior C-section and necessitate an emergent C-section complicated by large blood loss. Retained placental tissue can cause significant bleeding and require operative intervention with dilation and curettage [22].

Certain comorbidities can also contribute to postpartum bleeding such as sepsis, inherited coagulation disorders (von Willebrand, hemophilia), conditions requiring anticoagulation, and thrombocytopenia. The thrombocytopenia can sometimes be gestational or related to obstetric disorders such as preeclampsia.

Successful management requires planning for these events. Having postpartum hemorrhage (PPH) protocols (with checklists) in place for rapid intervention should be considered for every obstetrical facility. These protocols should include

means to quickly summon needed or additional providers. Having necessary obstetrical and anesthesia supplies available on a PPH cart can increase the speed to treat [35].

Massive transfusion protocols should be developed in conjunction with the institutions blood bank so that anesthesia personnel and obstetricians can urgently obtain blood products when emergent needs arise [26]. Adequate anesthesia preoperative planning should consider the potential risk for hemorrhage with obstetrical conditions. Anticipatory use of rapid infuser lines, large-bore IV, and multiple IV access should be considered along with requests for blood products prior to induction of anesthesia.

Uterotonic agents should be rapidly available for administration in the OR, labor unit, and postpartum unit. Some recent studies have suggested the use of tranexamic acid 1 g IV as an adjuvant therapy to use for postpartum hemorrhage [36]. Consideration for availability of equipment such as cell salvage and personnel such as interventional radiologist can be proactively arranged.

17.8.8 Pregnancy-Associated Hypertension

Hypertension in pregnancy is a common disorder affecting between 5 and 10% of gravid females. Preeclampsia (hypertension with proteinuria) and gestational hypertension typically occur later in pregnancy but can occur any time after 20 weeks of gestation. It can sometimes be confused with underlying hypertension which can be masked by decrease in blood pressure early in a gestation when most patients are first seen for prenatal care. Preeclampsia is diagnosed by elevated blood pressure above 140/90 along with signs such as persistent headache, scotomata (spots in vision), right upper quadrant or epigastric pain, and non-dependant edema. Laboratory evidence of the disease can include proteinuria, hemoconcentration (increased hemoglobin and hematocrit), increased uric acid, increased LDH, and elevation of liver enzymes. Patients are felt to have severe preeclampsia when blood pressures are greater than 160/110. Although the etiology is uncertain, the treatment is delivery. Mild preeclampsia is typically observed until the patient is full term or develops severe preeclampsia signs. Severe preeclampsia warrants immediate delivery. If untreated, preeclampsia can potentially lead to eclampsia (seizures). Variations of this condition can include HELLP syndrome (hemolysis, elevated liver enzymes, and low platelets). HELLP syndrome is considered to be a severe form of these disorders. Sometimes patients can have preeclampsia superimposed on chronic hypertension.

Physiologically these patients have significant endovascular leakage leading to intravascular volume depletion, edema, ascites, and pulmonary edema. Additional effects can be renal and/or liver dysfunction along with decreased fetal blood flow. Additionally these women can develop DIC, placental abruptions, acute renal failure, liver hemorrhage (subcapsular hematoma), liver failure, acute respiratory distress (ARDS), strokes, and even death. These effects can vary between slow to rapid onset and progression [37].

Treatment is usually centered on delivery at a center that can handle the maternal conditions and fetus after delivery especially if premature and needing neonatal intensive care. Magnesium sulfate 4-6 g load over 20 min followed by 2 g/h IV is usually employed to prevent eclampsia (phenytoin is used instead of magnesium in certain parts of the world). This is continued until 24 h after delivery. The dosage may need to be reduced in the presence of decreased renal function. Hypertension episodes are managed with labetalol IV, nifedipine PO, or hydralazine IV. Labetalol IV is given as slow push 10–40 mg every 10 min for a maximum of 300 mg. Nifedipine PO is administered 10–20 mg every 20 min for a maximum of 50 mg. Hydralazine IV is administered 5–10 mg every 20 min for a maximum of 25 mg [38].

Perioperative care should consider the significant physiologic changes associated with these patients. Even though these patients have significant edema, they are intravascularly constricted; therefore, diuretics have little effect and can result in decreased uterine blood flow and fetal distress. Fluid management intraoperatively should lean toward the conservative side as the endovascular leakage can cause worsening generalized and pulmonary edema. Anesthesia should take into account these patients may develop thrombocytopenia. Even in patients with normal platelet counts, the function of the platelets may be sub-optimal which may increase the risk of complications associated with spinal or epidural anesthesia. Bleeding

risks can increase because of preeclampsia, and preoperative planning should consider need for blood products including packed red blood cells, platelets, and cryoprecipitate. Intravascular constriction can mask anemia and true blood volume. Elevated blood pressures can hide hypotension normally noted with excessive blood loss. Airway management in general anesthesia can be complicated by laryngeal edema and facial edema.

17.8.9 Eclampsia

Eclampsia is the incidence of seizure activity typically associated with preeclampsia. It can occur even in patients with little or no preeclampsia signs. It usually will occur without warning and usually only lasts for a few minutes. Delivery is indicated, but emergent C-section is not required. Eclampsia can occur perioperatively, and treatment is geared toward protecting the patient during their seizure with padding and positioning to avoid risk of aspiration. Protection of the airway and supplemental oxygenation are important. Medical treatment is usually magnesium sulfate as mentioned above. Use of benzodiazepines should be reserved to patients nonresponsive to magnesium and have both IV access and availability for intubation. Fetal sedation can occur with their use. Lorazepam 2 mg can be used as a slow IV push [37]. In rare cases of status epilepticus, general anesthesia may be considered.

17.8.10 Amniotic Fluid Embolism

Amniotic fluid embolus (AFE) is a rare condition caused by fetal debris entering the maternal circulation, which then triggers abnormal activation of proinflammatory mediator response systems. Estimates of incidence and mortality rates vary widely due to a lack of established standardized criteria; however, maternal mortality is believed to occur in 30–90% of cases. The incidence of AFE ranges from 1:15,000 to 1:53,000 deliveries. Nearly 70% of AFE present suddenly at time of delivery or immediately postpartum and typically present with an otherwise unexplainable combination of clinical manifestations often characterized by hypotension, fetal distress, pulmonary edema, acute respiratory distress syndrome (ARDS), cardiopulmonary arrest, hypoxia, coagulopathy, and/or seizure.

Although AFE can present in a multitude of ways, the rapid deterioration of a patient suffering from an AFE can be outlined in three progressive stages. In phase 1, pulmonary and systemic vasoconstriction leads to hypertension and severe O2 desaturation. Phase 2 follows immediately and results in decreased systemic vascular resistance and cardiac output. In phase 3, sudden cardiac failure, ARDS, and coagulopathy via DIC cascade ensue. No rapid test for AFE exists; therefore, the diagnosis remains clinical, and quick recognition is paramount to successful treatment as most maternal mortality occurs within 30 min.

Management and treatment of AFE are supportive and require rapid simultaneous interdisciplinary cooperation between OB/GYNs, RNs, anesthesiologists, and critical care personnel. Establishing large-bore IV access with pulse oximetry, continuous vital sign, and cardiac monitoring is essential. Respiratory support by anesthesia typically requires endotracheal intubation and mechanical ventilation. The basics of CPR-ACLS and massive transfusion protocols must be immediately available and initiated. Hemodynamic support requires judicious use of fluids, vasopressors, inotropes, and pulmonary vasodilators. Laboratory studies such as CBC, BMP, PT/PTT/INR/fibrinogen, and ABGs are very useful to track treatment success; however, treatment should never be delayed awaiting these results [39, 40].

17.9 Summary

Perioperative care of pregnant patients has to take into account the physiologic changes that occur during the progression of the gestation. It has to consider the effects the condition and its treatment have on the fetus. Withholding or limiting treatment because of pregnancy can lead to a more detrimental situation and increase the risks for mother and fetus. Fetal monitoring has to consider the gestational age of the fetus, ability to intervene upon abnormalities noted, and treatment options available at the particular stage of pregnancy.

Understanding of obstetrical conditions can assist anesthesia and operative personnel in their pre- and intraoperative management. Most of the

critical complications associated with pregnancy have to do with hemorrhage. Proactively anticipating and quickly intervening are key to the optimal management.

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Catastrophic Complications in Pediatric Anesthesiology

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_18

18.1 Introduction

The subspecialty of pediatric anesthesiology has made great strides since the open-drop technique described for anesthetizing patients in the nineteenth century. Anesthetic techniques for children have been described as early as 1842. Since the inception of anesthesiology, the pediatric population was observed to have a higher incidence of anesthetic complications than adult patients. In fact, the first recorded anesthetic-related mortalities were in children. Early literature describes cardiac arrest, ineffective anesthesia, nausea, and vomiting as sources of morbidity and mortality. Although not fully understood in the mid-1800s, the differences in airway anatomy and respiratory physiology were noted between children and adults (Table 18.1). For example, John Snow, an anesthesiologist who provided labor and delivery anesthesia to Queen Victoria, concluded in pediatric patients "the effects of chloroform are more quickly produced and also subside more quickly than in adults, owing no doubt to quicker breathing and circulation" [1].

Pediatric anesthesiology has dramatically evolved from the primitive technique of ether-soaked gauze covering an unsecured airway to micro-cuffed endotracheal tubes for proper airway management in premature infants. Although rare, catastrophic anesthetic complications still occur in children more often than in adults. Based on the American Society of Anesthesiology Closed Claims Project reports between 1970 and the early 1980s, almost half of pediatric injuries resulting in malpractice litigation were related to adverse respiratory events. Most of these claims were secondary to improper oxygenation or ventilation. According to this report, these complications could have been prevented with adequate pulse oximetry and end-tidal capnography monitoring [1]. Furthermore, catastrophic complications in the pediatric population occur more frequently in children under 3 years old who have severe comorbidities [2]. Cardiac arrest, hypoxic brain injury, permanent disability, and death are obviously the most severe complications. Each one is strongly related to difficulty with airway management [1, 2]. In fact, 20% of cardiac arrests in children of ASA 1 or 2 status during anesthesia are of a respiratory etiology. Additionally, anesthetic agents such as the volatile agents and depolarizing neuromuscular blockers have also been implicated to cause anesthetic-related complications such as bradycardia, hyperkalemic cardiac arrest, anaphylactic and anaphylactoid reactions, and malignant hyperthermia. In 2015, Ghassemi et al. published a systematic review and meta-analysis of acute severe complications of pediatric anesthesia. This paper reviewed 25 papers and summarized that the most common acute severe complications in pediatric anesthesia are related to airway management and the respiratory system [1]. Specific diagnoses are listed as difficult bag mask ventilation, airway obstruction, and laryngospasm. Cardiovascular events are the second most common etiology of severe morbidity and mortality in the pediatric population [1, 2]. Of note, cardiovascular events such as bradycardia and asystole frequently occur following severe desaturation. Thus, the origin of cardiovascular events seems to be secondary to respiratory complications. Table 18.2 is a brief description of diseases that are likely to have severe adverse airway and/or cardiovascular complications at induction of anesthesia.

As advances have been made in the practice of pediatric anesthesiology, catastrophic complications in children have decreased. This chapter is designed to review known challenges that anesthesia providers face and offer suggestions to avoid long term morbidity and mortality.

Table 18.1 Comparison of infant and adult respiratory physiology

Measurement	Infant	Adult
Functional residual capacity (ml/kg)	30	27–30
Minute ventilation (ml/kg/min)	100–150	60
Tidal volume (ml/kg)	6–8	6–8
Respiratory rate (per minute)	30–50	12–16
O2 consumption (ml/kg/min)	6	3

Table 18.2 Diagnosis likely to have airway and/or cardiovascular complications under anesthesia [3]

Diagnosis	Airway concern	Cardiovascular concern
Achondroplasia	Possibly difficult Sleep apnea	
Albers-Schonberg disease	Obligate mouth breather Nasopharyngeal bone overgrowth	
Albright hereditary osteodystrophy		QT interval Conduction defects
Alport syndrome		AV conduction defects
Amyotrophic lateral sclerosis		Possible K+ release and cardiac arrest
Andersen syndrome	Difficult ventilation Difficult intubation	Long QT syndrome Avoid succinylcholine
Antley-Bixler syndrome	Difficult intubation	
Apert syndrome	Difficult ventilation Difficult nasotracheal intubation	
Beare-Stevenson syndrome	Difficult intubation	
Beckwith syndrome	Difficult intubation Postoperative airway obstruction	
Behcet syndrome	Difficult intubation	
Brachmann-de Lange syndrome	Difficult intubation	
Carpenter syndrome	Difficult intubation	
Central cord disease		MH triggered by succinylcholine
CHARGE association	Difficult intubation	
Cherubim	Difficult airway	
Saethre-Chotzen syndrome	Difficult airway	
Chubby puffer syndrome	Upper airway obstruction	
CINCA syndrome	Difficult intubation	
Collagen diseases	Airway/difficult intubation	
Congenital heart block		Intraoperative arrhythmia
Cri du chat syndrome	Stridor Laryngomalacia Difficult intubation	
Crouzon syndrome	Difficult mask ventilation Postoperative airway obstruction	
9 p deletion syndromes	Difficult airway	
Duchenne muscular dystrophy		Hyperkalemic cardiac arrest with succinylcholine
Edwards syndrome	Difficult intubation	

(continued)

Table 18.2 (continued)

Diagnosis	Airway concern	Cardiovascular concern
Eisenmenger syndrome		Right to left cardiac shunt
Epidermolysis bullosa	Airway difficulty/scarring Avoid intubation	
Escobar syndrome	Airway difficulty increases with age	
Familial periodic paralysis		Monitor serum K+/EKG
Freeman-Sheldon syndrome	Very difficult intubation	
Goldenhar syndrome	Difficult mask/intubation	
Guillain-Barre syndrome		Avoid succinylcholine – increased K+ release
Hallervorden-Spatz disease		Avoid succinylcholine – increased K+ release
Hecht-Beals syndrome	Small mouth opening	
Histiocytosis X	Difficult intubation	
Hunter syndrome	Difficult airway	
Hurler syndrome	Difficult airway	Evaluate with EKG and echo
I-cell disease	Difficult airway	Evaluate with EKG and echo
Klippel-Feil syndrome	Difficult airway	
Klippel-Trenaunay-Weber syndrome		High output cardiac failure
Larsen syndrome	Difficult intubation	Congenital heart disease
LEOPARD syndrome	Difficult intubation	Serious arrhythmias
Leukodystrophy		Avoid succinylcholine
Marfan syndrome	Possible ventilation/difficult intubation	Danger of aortic dissection
Marshall-Smith syndrome	Difficult ventilation	
McArdle myopathy		EKG abnormalities Avoid succinylcholine
Meckel syndrome	Difficult intubation	Congenital heart disease
Median cleft face syndrome	Possible difficult intubation	
Moschcowitz disease	Nasotracheal intubation contraindicated	
Mucopolysaccharidosis	Difficult intubation LMA may not relieve obstruction	EKG to assess cardiac involvement
Myositis ossificans	Gentle fiber-optic intubation recommended	
Nager syndrome	Limited mouth opening Fiber-optic technique necessary Severe upper airway obstruction; tracheostomy may be necessary	Evaluate with echo

Table 18.2 (continued)

Diagnosis	Airway concern	Cardiovascular concern
Nemaline rod myopathy	Intubation may be difficult	
Niemann-Pick disease	Difficult ventilation from ascites and restrictive lung disease	
Noack syndrome	Possible difficult intubation	
Noonan syndrome	Possible difficult intubation	Evaluate with echo
Oculodento-osseous dysplasia	Difficult intubation	
Opitz-Frias syndrome	Difficult airway Aspiration risk	
Oral-facial-digital syndrome	Difficult airway	
Paramyotonia congenita		Check serum K+ levels
Patau syndrome	Possible difficult intubation	Evaluate with echocardiogram/EKG
Pierre Robin syndrome	Difficult intubation Anticipate fiber-optic technique	Evaluate for congenital heart disease
Plott syndrome	Airway obstruction Aspiration	
Pompe disease	Airway obstruction	Serious arrhythmias
Progeria	Difficult intubation	Assess cardiac status
Proteus syndrome	Difficult intubation	
Prune belly syndrome	Aspiration risk Intubation may be difficult	
Pyle disease	Possible difficult intubation	
Rieger syndrome	Possible difficult airway	
Rubinstein-Taybi syndrome	Possible difficult airway	
Schwartz-Jampel syndrome	Difficult intubation	Hyperkalemic cardiac arrest with succinylcholine
Seckel syndrome	Difficult ventilation/intubation	
Silver-Russell syndrome	Difficult ventilation/intubation	
Stickler syndrome	Difficult intubation Anticipate fiber-optic technique	
Thalassemia major	Difficult intubation	
Treacher-Collins syndrome	Difficult ventilation/intubation Consider fiber-optic technique	
Trismus-pseudocamptodactyly	Difficult intubation Consider fiber-optic technique	
Werdnig-Hoffman disease		Hyperkalemic cardiac arrest with succinylcholine
Williams syndrome		Cardiac arrest during induction

18.2 Complications Related to Drugs

Anesthetic management in the pediatric population can be vastly different than the adult population. There can be the potential for a multitude of complications related to various drug exposures in pediatrics if the provider is not aware of those potential complications (▶ Box 18.1). Oxygen, although not a drug per se, has many implications during pediatric anesthesia. Pure, high flow oxygen poses a fire hazard risk, and adequate steps must be taken to prevent the risk of an OR fire by monitoring the oxidizer, ignition source, and fuel and by taking steps to prevent that triad. It is critical to keep the oxygen concentration at its minimum to maintain adequate gas exchange while also avoiding hypoxic complications. High flow, concentrated oxygen has the potential to denitrogenate the lungs and cause absorption atelectasis. It can cause drying and irritation of the mucosal surfaces and can increase the incidence of oxygen free radicals which are toxic to proteins and lipids within membranes of cells [4]. In premature babies, high flow, concentrated oxygen can have significant implications in eye development, causing retrolental fibroplasia [4].

The inhalational anesthetics, as a rule, can depress the myocardium and, thus, are usually augmented with opioids to decrease their use. The typical inhalational anesthetics used in pediatrics are sevoflurane and desflurane with the former generally used in induction. Sevoflurane is not irritating to the airway and is used exclusively in induction in pediatrics [5]. Typically, 8% concentration is used until loss of consciousness, and then it is then dialed back to maintain anesthesia. If left at a high rate, sevoflurane can react with the desiccated CO2 absorbent which can result in an exothermic reaction causing airway damage [4]. Another side effect related to sevoflurane is, theoretically, damage to the kidneys because of compound A formation in the degradation of sevoflurane in the soda lime. It is not toxic to the kidneys if the fresh gas flow is at 2 L/min minimum [5]. Both sevoflurane and desflurane are bronchodilators, but desflurane is not used in inhalational induction due to airway irritation. Nitrous oxide should be used carefully due to the potential side effect of vitamin B12 inactivation, prompting neurologic disorders [4]. In any discussion regarding inhalational anesthetics, malignant hyperthermia must be discussed. Typically, the most susceptible pediatric populations affected by MH are those with neuromuscular disease. Mutations in the RYR1 gene account for susceptibility, and any child with neuromuscular disease should be thoroughly worked up prior to any use of anesthetics that may cause MH [6]. Cardiac arrest can occur in the pediatric population due to MH as well as hyperkalemia. Neuromuscular disorders must be extensively worked up prior to any depolarizing or volatile anesthetic use. The FDA has issued a black box warning for succinylcholine use in the pediatric population due to the potential for hyperkalemic cardiac arrest in children with undiagnosed myopathies receiving succinylcholine [7]. Additionally, one of the known side effects of succinylcholine is bradycardia and, in extreme cases, asystole, and thus if succinylcholine is used, it is generally favorable to have epinephrine or atropine on hand. Rocuronium might be a safer paralytic for use for RSI in pediatrics.

Although sugammadex, a cyclodextrin that forms tight complexes with rocuronium, thus inactivating it, has not been approved for pediatrics yet in the USA for reversal of nondepolarizing neuromuscular blockade with rocuronium and vecuronium, its use has the potential to decrease the use of succinylcholine in practice. Succinylcholine is the only depolarizing muscle relaxant. It is ultrashort acting and does not need a reversal agent due to its metabolism by cholinesterases. Conversely, succinylcholine can cause malignant hyperthermia, masseter spasm, myalgias, and rhabdomyolysis and can potentially cause hyperkalemic cardiac arrest

Box 18.1 Common Drug Side Effects in the Pediatric Patient

- Balance of oxygen to prevent hypoxemia and absorption atelectasis
- Inhalation anesthetics can depress the myocardium
- Inhalation anesthetics can cause emergence delirium
- Compound A formation in sevoflurane
- Bronchodilation with sevoflurane and desflurane
- NO2 can cause megaloblastic anemia
- Rocuronium is a common allergy

particularly in infants and children [4]. Keeping these factors in mind, with the increasing use of sugammadex, one could argue that non-depolarizing muscle relaxers may be of greater benefit in standard and rapid sequence induction.

Perioperative anaphylaxis is very rare in pediatrics, along the lines of 1:10–20,000 anesthetic procedures, but it is imperative to be prepared and recognize immediate anaphylactic reactions. The typical culprit for allergy is the non-depolarizing muscle relaxants, particularly rocuronium. Additionally, bradycardia might result as an adaptive mechanism to allow for complete diastole despite hypovolemia. It is critical to treat with atropine and epinephrine in this instance because atropine alone may precipitate cardiac arrest in the pediatric patient [4]. Anaphylaxis is best treated with epinephrine and volume expansion with fluids [8]. Anaphylaxis can be graded 1–4 with 1 being observation and 4 being treatment with 1–3 mg epinephrine intravenously. Grade 2 is treated with 10–20 mcg, and grade 3 reactions are treated with 100–200 mcg of epinephrine [4]. A side effect of anaphylaxis is Takotsubo's cardiomyopathy which is a result of either coronary vasospasm from anaphylaxis or epinephrine itself. It is critical not to overuse epinephrine in anaphylaxis. Overuse can result in worse outcomes including increased myocardial oxygen demand, arrhythmias from ventricular ectopy, tachycardia, and increased SVR. These combined may result in a worse neurological outcome post resuscitation [9]. The standard dose of epinephrine in the pediatric patient for anaphylactic shock and cardiac arrest is 0.01 mg/kg IV [4].

Complications can arise during mechanical ventilation as well. Ventilating the pediatric patient is not without complication. Typically, it is judicious to start at low tidal volumes and peak inspiratory pressures as to prevent volutrauma and barotrauma. Peak pressures should not exceed 15–20 cm H20, and tidal volumes should be increased slowly until peak pressures, ETCO2, and tidal volumes are in an acceptable range. Volutrauma and barotrauma take precedence over moderate hypercapnia to the point where it is better to maintain relative hypercapnia rather than increasing tidal volumes and peak pressures to result in normocapnia [4]. Even at low tidal volumes, an inflammatory response can be elicited and can be detrimental in the newborn and pediatric populations [10].

Judicious use of fluids is important in the perioperative period in pediatrics. As mentioned above, hypovolemia can have detrimental effects which can result in cardiac arrest. Sodium chloride should be used liberally in the absence of any contraindications, including volume overloading disease states, cardiac failure, and fluid retention [4]. If the child is on TPN, it is important not to discontinue it; rather, access should be obtained with a larger catheter for the potential of rapid infusion if necessary [4]. Neonatal fluid requirements can vary based on gestational age and birthweight. For term and low birthweight babies, 50–60 ml/kg per day is required for fluid requirements at 1 day of age and goes up 10–20 ml/kg per day up to 5 days for a total of 180 ml/kg per day. For very low birthweight and extremely low birthweight preterm babies, the fluid requirements are greater early on with 180 ml/kg per day usually around day 4 of life [11].

The pediatric population is prone to emergence delirium after general anesthesia, and attention has been raised to the use of intranasal dexmedetomidine as a premedication to reduce emergence delirium and MAC of sevoflurane. Savla et al. report a decrease in emergence delirium with 1–2 mcg/kg. Additionally, a reduction in MAC of sevoflurane by 36% for LMA insertion was observed [12]. He et al. also report a decreased incidence of agitation and a decrease in end-tidal sevoflurane concentration required for LMA removal with an infusion of 0.1–1 mcg/kg of dexmedetomidine [13]. Conversely, a combination of ketamine and dexmedetomidine has been used to prevent emergence delirium, PONV, and analgesia. Hadi et al. report that 0.15 mg/kg ketamine followed by 0.3 mcg/kg dexmedetomidine infused 10 min prior to emergence reduces the incidence of sevoflurane-induced emergence delirium, kept hemodynamic stability during extubation, and reduced opioid requirements after tonsillectomy [14].

Awareness under anesthesia in the pediatric population can range anywhere from 1 in 135 by direct questioning to 1 in 51,500 by spontaneous questioning. Awareness is most common in the induction and emergence of anesthesia and is most distressing under neuromuscular blockade combined with pain. Generally, episodes last 5 min or less but are nonetheless generally distressing. Depth of anesthesia monitors may be useful in helping prevent awareness by anesthetic depth [15].

18.3 Airway Complications in the Pediatric Patient

The pediatric airway is anatomically different than the adult, more so in the neonate to 1-year-old infants, as compared to adults (▶ Box 18.2). The head of the pediatric patient is noticeably larger in comparison to the adult counterparts, and the occiput is more prominent [16]. This can predispose to upper airway obstruction after induction due to the flexion of the head. A shoulder roll is recommended to aid the provider in aligning the oral, laryngeal, and tracheal axes [16]. The next anatomical difference between children and adults is that the tongue is relatively larger and the mandible is shorter. Additionally, the adenoids and tonsils are larger and the subject of ENT surgery at a young age. These things combined cause increased upper airway resistance and obstruction, complicating mask ventilation and, ultimately, intubation [16]. The larynx is higher in children, located at about C4 versus adults at C6. In the adult, the vocal chords are at a 90-degree angle to the trachea, while in pediatrics, it is more anterior/inferior to posterior/superior orientation which can make endotracheal intubation more traumatic and/or challenging [17]. The epiglottis in children is typically U shaped compared to a flat line in adults. The use of a Miller blade may be more advantageous in younger-aged children compared to the Macintosh which may be used in older children, as direct control over lifting the uvula can be obtained with a straight blade [16].

Physiologically, pediatric patients differ from adults in many ways which can ultimately dispose them to hypoxemia. Oxygen consumption is relatively higher in pediatrics on the order of 6 ml/kg/min vs. 3 ml/kg/min. Additionally, children have a lower FRC. These combined can predispose a pediatric patient to hypoxemia much quicker if steps aren't taken to adequately ventilate [16]. The rate of CO2 production is also higher in pediatrics compared to adults, 100 ml/kg/min versus 60 mL/kg/min. Tidal volume remains constant despite age, and so it is necessary to have an increased respiratory rate to prevent hypercapnia [18]. Finally, anatomic changes are more profound in the pediatric airway. Since Poiseuille's law governs resistance to flow, anatomic changes like laryngeomalacia, growths within the airway, and subglottic stenosis can profoundly affect the fresh gas flow by a factor of 16 [16]. Each of these disease processes must be addressed separately in the workup prior to any induction.

Mask ventilation is fundamental in airway management in pediatrics. Posterior displacement of the tongue can be relieved by an oral airway. The LMA also has 95–98% success rate in getting adequate ventilation in pediatrics [16]. Additionally, uncuffed endotracheal tubes were once used more often than cuffed tubes with the thought being that pressure would be minimized to the subglottis and resistance would be minimized. Now, the thought is that cuffed tubes minimize trauma and provide better ventilating conditions. Uncuffed tubes may actually be associated with more cases of laryngospasm [16]. Overall, the pediatric airway must be managed differently than the adult airway, keeping in mind anatomical and physiologic differences. The anesthesia provider must have access to all the materials in the difficult airway algorithm to prevent unnecessary causes of morbidity and mortality. Pediatric airway emergencies, although uncommon in healthy children, can happen much faster than in their adult counterparts. The introduction of LMAs has greatly reduced airway compromise in pediatrics and allows for lesser need for the surgical airway. Fiber-optic intubation through the LMA is considered the ultimate technique in the difficult pediatric airway before moving on to surgical cannulation or tracheostomy [19]. The risk of aspiration in pediatrics has decreased with the growing support of cuffed endotracheal tubes in pediatrics [20].

Bronchospasm, laryngospasm, and hypoxemia are the most frequent encountered adverse events in the perioperative setting with pediatric patients. Unrecognized, these can be life threatening and lead to cardiac arrest. The most common predic-

Box 18.2 Anatomic Airway Differences in the Pediatric Patient Versus the Adult Patient

- Head and occiput are larger
- Tongue is larger and mandible is shorter
- Adenoids and tonsils are larger
- Larynx is higher
- Vocal chords are anterior/inferior to posterior/superior
- Epiglottis is U shaped

tors are age of the patient, with increasing age showing a reduction in adverse events, type of surgery, use of desflurane, sleep disorders and obesity, URI, emergent procedures, and lack of a pediatric specialist in anesthesia [21]. Luce et al. report a decrease in the incidence of laryngospasm, postoperative desaturation, cough, and breath holding with the use of an LMA when indicated compared to tracheal intubation [22]. Additionally, there was a decrease in laryngospasm-related events when extubated deep with LMA with no change in outcomes when the LMA was removed in the awake child. It is important to have emergency drugs on hand when treating the perioperative pediatric patient. Despite optimizing risk factors for laryngospasm/bronchospasm, it is important to recognize those first initial signs and act accordingly. Positive pressure is the initial treatment for such events. If unresponsive, it is necessary to use succinylcholine for rapid relaxation in a patient with laryngospasm or bronchospasm to prevent bradycardia and cardiac arrest. Atropine and epinephrine should be on hand to treat bradycardia and cardiac arrest.

18.4 Allergic Reactions

The practice of anesthesia is pharmacologically unique, as patients are exposed to multiple medications within a relatively short time span. Each of these medications has the potential to induce a potentially life-threatening anaphylaxis [23]. Therefore, it is prudent for the anesthesiologist to be vigilant in observing patients for possible allergic reactions as symptoms may be masked by anesthetic agents as well as the surgical drapes. Anaphylaxis is the most severe type of allergic reaction and is defined as an acute allergic reaction resulting from a rapid, antigen-induced release of potent, pharmacologically active mediators from mast cells and basophils [23]. Clinically criteria for anaphylaxis have been defined by Sampson et al. (▶ Box 18.3).

Life-threatening anaphylaxis is rare, with lifetime risk in the general population of 1.6% and perioperative anaphylaxis reported up to 1/13,000 anesthetics [24]. These anaphylactic reactions have a reported mortality rate in a French Survey of 3–9% [25], with a more recent Australian study putting the mortality of 0–1.4% [26]. Perioperative anaphylaxis hypersensitivity reactions mediated by a sudden release of preformed and newly synthesized mediators from mast cells and basophils. Although causative agent cannot always be determined in perioperative anaphylaxis, common culprits have been determined to be neuromuscular-blocking drugs (NMDBs) (50–70%), followed by latex (12–16.7%), and antibiotics (15%) [27] in adult populations. However, in a pharmacovigilance study which included 266 children (<18 years old), 122 of these children developed an IgE-mediated anaphylaxis to the following: 41.8% reacted to latex, 31.97% reacted to NMBD, and 9.02% reacted to antibiotics.

Box 18.3 Clinical Criterial for Diagnosing Anaphylaxis

Anaphylaxis is highly likely when any one of the following three criteria is fulfilled:

1. Acute onset of an illness (minutes to several hours) with involvement of the skin, mucosal tissue, or both (e.g., generalized hives, pruritus or flushing, swollen lips, tongue, uvula)

And at least one of the following:

   (a) Respiratory compromise (e.g., dyspnea, wheeze-bronchospasm, stridor, reduced peak expiratory pressure [PEF], hypoxemia)
   (b) Reduced BP or associated symptoms of end-organ dysfunction (e.g., hypotonia [collapse], syncope, incontinence)

2. Two or more of the following that occur rapidly after exposure to a likely allergen for that patient (minutes to several hours):
   (a) Involvement of the sink-mucosal tissue (e.g., generalized hives, itch-flush, swollen lips, tongue, uvula)
   (b) Respiratory compromise (e.g., dyspnea, wheeze-bronchospasm, stridor, reduced PEF, hypoxemia)
   (c) Reduced BP or associated symptoms (e.g., hypotonia [collapse], syncope, incontinence)
   (d) Persistent gastrointestinal symptoms (e.g., crampy abdominal pain, vomiting)

3. Reduced BP after exposure to known allergen for that patient (minutes to several hours):
   (a) Infants and children: low systolic BP (age specific) or greater than 30% decrease in systolic BP
   (b) Adults: systolic BP of less than 90 mm Hg or greater than 30% decrease from that person's baseline

Sampson et al. [34]

Latex is a natural product derived from the rubber tree, *Hevea brasiliensis*, and has been associated with both immediate and delayed hypersensitivity reactions. Specific subpopulations at risk include atopic children, spinal bifida, children who underwent surgical procedures during neonatal period, and individuals who require frequent surgical instrumentations (i.e., catheterization). Additionally, children with specific food allergies including avocado, kiwi, bananas, or chestnuts are more prone to developing latex anaphylaxis as these share similar allergens with latex [28]. Diagnosis of latex allergies should begin with a clinical history by questioning about atopic dermatitis, allergic rhinitis, and prior exposure to surgery and/or latex, and prior reactions noted with balloon or rubber toys may help identify patients with latex sensitivities. Latex allergies suspected by clinical history should be confirmed with specific laboratory testing. Two tests are available, skin prick testing and detection of IgE to latex protein [29]. Prevention of anaphylaxis in pediatric population begins with limiting exposure to latex. Many hospitals now have phased out the use of latex-containing products to avoid exposing children in the first place, thus mitigating the development of hypersensitivity to latex. Additionally, reactions can be limited by identifying those children with a latex sensitivity, so further measures can be taken to establish a "latex-safe" environment, as the complete avoidance of latex products is key to preventing severe anaphylaxis. In addition to avoiding all latex products, schedule these cases as the first in the day, where aerosolized latex antigen is thought to be at its lowest level, or wait 90 min after the previous cases to decrease the amount of aerosolized latex antigen [29].

Neuromuscular-blocking drugs (NMDBs) have been the most common medication associated with perioperative anaphylaxis in adults. In pharmacovigilance data collected in France, it was noted that NMBD was the 2nd most common antigen associated with anaphylaxis [25]. Of the NMDBs, the current literature indicates that rocuronium is most likely to cause anaphylactic reactions compared to other NMBDs [30–32]. In an Australian analysis over a 10-year period, 80 cases of life-threatening anaphylaxis are associated with NMBD. Rocuronium was implicated in 56%, succinylcholine 21%, and vecuronium 11% [31]. Although allergies to NMBD are rare, when considering the use of an NMDB in a patient with a previous NMDB allergic reaction, cisatracurium may be a good alternative. It has been shown to have the least cross-reactivity when used in those who previous suffered anaphylaxis to rocuronium and vecuronium [31].

Antibiotics are the 3rd most frequent cause of drug-related anaphylaxis with a reported incidence of 9% [25] which is of concern in the field of anesthesia considering that nearly every patient undergoing surgery receives this for surgical prophylaxis. Most common agents are penicillins and cephalosporins [33].

18.4.1 Treatment

After a patient is diagnosed clinically with anaphylaxis, treatment is based on the severity of the reaction using Ring and Messmer grading. Grade I includes cutaneous symptoms (erythema, urticaria, with or without angioedema). Grade II includes cutaneous symptoms and may be associated with cardiovascular and/or respiratory symptoms. Grade III hallmark feature is cardiovascular collapse that may be associated with cutaneous symptoms and/or bronchospasm, and grade IV is cardiac arrest [35]. Immediate treatments are as follows: (1) withdraw the offending agent; (2) immediately discontinue anesthetic drugs when the anaphylactic event occurs during induction; (3) maintain airway with 100% oxygen; (4) provide early administration of epinephrine especially in grade II or IV reactions; (5) call for help, especially for grades III and IV; (6) place patient supine in Trendelenburg; and (7) abbreviate the surgical procedure if possible when it occurs during surgery [35].

18.5 Postoperative Complications

Postoperative nausea and vomiting (PONV) is one of the most common complications of pediatric-anesthesia. It is mediated by the vomiting center, thought to reside in the brainstem. It receives input from the pharynx, GI tract, higher cortical center (i.e., visual, gustatory, olfactory, and vestibular centers), and the chemoreceptor trigger zone (CTZ) [36]. PONV risk is typically calculated for adults with the Apfel score. However, the Apfel criteria are not fully applicable to children as the criteria were not developed or validated for pediatric

patients. In a study by Eberhart et al., they identified four independent risk factors for PONV: (1) duration of surgery ≥30 min, (2) age ≥ 3 years, (3) strabismus surgery, and (4) a positive history of PONV in child or in relatives (mother, father, siblings). PONV risk was 9%, 10%, 30%, 55%, and 70% for 0–4 risk factors met [37]. For patients with low risk of PONV, prophylactic treatment may be unnecessary. In children at higher risk for PONV, several steps can be taken to lessen the occurrence of PONV. First, consider avoiding known inducers of PONV, such as nitrous oxide, volatile agents, and postoperative opioids. Furthermore, consider utilizing anesthesia modalities which have low emetic potential such as regional anesthesia or total intravenous anesthesia using propofol. Finally, consider the use of prophylactic medications. Intravenous ondansetron (5-HT3 receptor antagonist) can be given at 50–100 mcg/kg up to 4 mg or dexamethasone 150 mcg/kg up to 5 mg. In cases of high PONV risk, combination therapy can be utilized using ondansetron and dexamethasone, as studies have supported a synergistic effect when used in combination [38].

Hypoxia in children, defined as an oxygen saturation <93%, in the postoperative setting should raise concerns, and O2 therapy should be initiated. Evaluate waveform to ensure its monitor is providing an accurate value, and adjust probe as appropriate. If hypoxia is true, consider the following: residual anesthetics, inadequate reversal if paralytic was utilized, respiratory depression, airway obstruction, and laryngospasm.

Postoperatively, airway obstruction can be observed clinically by a seesaw breathing pattern and subcostal or sternal retraction. Typically, the obstruction is caused by the tongue falling back and blocking the airway. Treatment includes insertion of oral airway if tolerated, neck extension, opening of mouth, and jaw thrust either alone or in combination [36].

Laryngospasm can be defined as is a reflex closure of the upper airway as a result of glottic musculature spasm. It is a protective reflex that acts to prevent foreign material entering the tracheobronchial tree [39]. However, during anesthesia, prolonged laryngospasm can result in life-threatening complications including hypoxemia bradycardia, negative pressure pulmonary edema, and cardiac arrest [40]. Risk factors for laryngospasm can fall under three categories: anesthesia related (light plane of anesthesia, inexperienced provider), patient related (younger age, reactive airway, smoke exposure, recent URI), or surgery related (airway procedures, tonsillectomy/adenoidectomy) [41]. Treatment measures should be initiated by removal of irritant stimulus, opening mouth, jaw thrust, and CPAP ventilation with 100% oxygen. Propofol (0.25–0.8 mg/kg IV) has been shown to treat laryngospasm in 76.9% of cases. However, the gold standard remains succinylcholine (0.1–3 mg/kg) given together with atropine (0.02 mg/kg) to avoid succinylcholine-associated bradycardia [41].

Post-extubation stridor is typically associated with use of a tight-fitting endotracheal tube, repeated intubation attempts, traumatic intubation/extubation, or coughing/straining on tube. This can result in mucosal trauma and airway edema and ultimately airway obstruction. Treatment options include humidified air for mild cases. For more severe cases, consider nebulized racemic epinephrine for immediate reduction of edema via vasoconstriction. Also, dexamethasone (0.5 mg/kg) may be helpful after the initial therapy, to reduce the airway edema associated with post-extubation stridor [36].

Negative pressure pulmonary edema (NPPE) is a complication that arises after relief of an acute upper airway obstruction, most commonly laryngospasm. This results in the development of increased negative intrathoracic pressures which ultimately results in increased permeability of pulmonary capillaries resulting in pulmonary edema [42]. Clinically, a patient will present with NPPE with the following symptoms: dyspnea, progressive cyanosis, anxiety, increased work of breathing, excessive pink frothy secretions from the mouth, and cracks on auscultation [43]. NPPV is self-limiting, typically resolving in 12–24 h with nothing more than supportive care, including supplemental oxygen or CPAP if required. Consider reintubation and mechanical ventilation for a patient who cannot adequately oxygenate themselves despite supplemental oxygen [44].

18.6 Anesthesia-Related Mortality

Evaluation of perioperative mortality in children related to anesthesia is useful to evaluate what children are at higher risk and create better management strategies to improve the overall safety in the administration of anesthesia to

children. A meta-analysis by Gonzalez et al. noted the following risk factors associated with perioperative mortality. Higher rates of mortality were associated with developing countries compared to developed countries when comparing data from the same time frame [45]. Major risk factors were identified as age (newborns and infants less than 1 year of age are at greater risk), ASA III or greater, emergency surgery, general anesthesia, and cardiac surgery. In those children with coexisting comorbidities prior to surgery, complications related to airway management and cardiocirculatory events were accounted for majority of the causes of mortality [45]. A study by Lian et al. conducted a retrospective analysis of pediatric patient which were either admitted to ICU or died within 30 days postsurgery to develop a preoperative risk prediction score (PRPS) to predict the likelihood of postoperative ICU admission and/or the risk of pediatric perioperative death [46]. Similar risk factors associated with perioperative mortality which included age < 1 year old and patients classified as ASA III and above. Additionally, it was noted that patients with intraoperative SpO2 <90% were noted to be a significant independent risk factor. Additionally, it was noted that "unfasted" patients prior to surgery may be associated with emergent surgery. However, the authors mention that in their study, emergent surgery was not completely equivalent to unfasted patients. Therefore, they suggest that "unfasted" patient may be the risk factor [46].

18.7 Summary

Overall, complications can and do occur in any anesthetic procedures, but what one does to treat or prevent the complication is most prudent. A pediatric anesthetic case has the potential to develop into a catastrophic perioperative complication. Some complications include allergic reactions, postoperative nausea and vomiting, hypoxia, bronchospasm, laryngospasm, post-extubation stridor, negative pressure pulmonary edema, absorption atelectasis, emergence delirium, and cardiac arrest. All complications have the potential to be classified as mild, moderate, severe, or catastrophic. It is the anesthesiologist's knowledge and preparedness that will determine if the complication yields a mild, moderate, or severe result. The pediatric patient is vastly different from the adult in many forms from the anatomy to the physiology. Because of this the management and treatment can be different and more difficult. Take, for instance, the life-sustaining element of oxygen that can be too much for the neonatal human leading to retrolental fibroplasia and abnormal proliferation of fibrous tissue during eye development or absorption atelectasis causing drying of the mucosal and increase production of free radicals. The anesthetic gases used for inhalational induction can depress the myocardium and lead to vitamin B12 inactivation. Drugs used to induce immobilization can induce cardiac arrest or lead to an allergic reaction that can ultimately lead to cardiac arrest. The safe drugs used to treat anaphylactic complications, i.e., epinephrine, are themselves not without risk such as too much can lead to coronary vasospasm. The recommended dose is 0.01 mg/kg IV. Children have increase oxygen consumption leading to hypoxemia at a faster rate than adults. Mechanical ventilation must be optimized to the correct tidal volumes and peak inspiratory pressure; failure to do so can lead to hypoxemia, hypercapnia, or barotrauma. Even though bronchospasm and laryngospasm are frequently encountered adverse events, they can be catastrophic. The culprit can be light anesthesia, reactive airway disease, age of patient, and type of surgery. It can be managed by positive pressure, deepening the anesthesia, depolarizing neuromuscular-blocking agent, and epinephrine. Post extubation stridor secondary to mucosal trauma can be avoided with the use of appropriate-sized endotracheal tubes, minimizing the amount of airway manipulation and coughing on the tube. Treatments include dexamethasone, humidified air, and nebulized epinephrine. Postoperative nausea and vomiting, one of the more common complications, has four independent risk factors, and prevention methods include avoidance of known inducers and the use of low emetic potential anesthesia.

The pediatric airway in itself yields potential for complications. The occiput is larger making a difficult patient position, so it is recommended to place a shoulder roll to align the axis, and the tongue is larger making a difficult mask ventilation, so it is recommended to use an oral airway. When trying to intubate, the anatomical features that make it more challenging are that the larynx is higher, the vocal cords are slightly angled, and the epiglottis is U shaped. The use of the Miller blade for younger children and Macintosh for older children may make the intubation process easier.

18.8 Review Questions

1. The American Society of Anesthesiology Closed Claims Project revealed that catastrophic complications in pediatric anesthesiology were closely related to:
   A. Cardiovascular collapse
   B. Adverse respiratory events
   C. Anaphylactic reactions
   D. Improper drug administration

2. Hyperkalemic cardiac arrest in Duchenne muscular dystrophy and Schwartz-Jampel syndrome is associated with which of the following anesthetic agents:
   A. Sevoflurane
   B. Sugammadex
   C. Succinylcholine
   D. Sufentanil

3. Which of the following age groups listed below is associated with the highest risk of anesthesia related mortality?
   A. Neonates and infants less than 1 year of age
   B. Toddlers 1 to 3 years of age
   C. Children 3 to 8 years of age
   D. Children greater than 8 years of age

18.9 Answers

1. B – Adverse respiratory events
2. C – Succinylcholine
3. B – Toddlers 1 to 3 years of age

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Ambulatory and Office-Based Surgery

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_19

19.1 Introduction

The first ambulatory surgery centers in the United States began to appear in the 1950s [1]. Today ambulatory surgery has become a mainstay of healthcare delivery across the world. In the United States, only 20% of elective surgery occurs in an inpatient hospital setting with the rest occurring in an ambulatory facility [2]. Advances in minimally invasive surgical techniques and the pressure to control healthcare cost have driven the trend toward procedures being performed outside of the traditional hospital setting. Organizations such as the Society for Ambulatory Anesthesia (SAMBA) and the International Association for Ambulatory Surgery (IAAS) have formed to provide guidance and promote ambulatory surgery across the globe. The ambulatory and office setting continues to grow and will no doubt have an impact on every practicing anesthesiologist at some point in their career.

19.2 Definitions

Ambulatory surgery is a common phrase used today; however the definition can vary among different healthcare systems. The International Association for Ambulatory Surgery (IAAS) cofounder Tom W Ogg suggested the definition: "A surgical day case is a patient who is admitted for investigation or operation on a planned non-resident basis and who none the less requires facilities for recovery. The whole procedure should not require an overnight stay in a hospital bed." [3] With this guidance it is clear that the intent of ambulatory surgery is to manage the entire patient encounter within 1 day with the expectation of the patient returning to their prior place of residence. Office-based anesthesia is performing an anesthetic in a venue outside a traditional hospital such as an office that does not hold accreditation as either an ambulatory surgery center or hospital [4].

19.3 Facilities

A variety of arrangements exist for the provision of ambulatory surgery. Some facilities are integrated within a hospital to make use of existing personnel and services, while other arrangements make use of a freestanding ambulatory surgery center. The American Society of Anesthesiologists (ASA) offers guidelines for ambulatory anesthesia and surgery. Those guidelines are summarized in ▶ Box 19.1 [5]. They state that all ASA standard practices should be maintained and set expectations in regard to staffing. Additonally, it provides guidance as to patient care and record keeping. Government regulation and accreditation are done by agencies such as The Joint Commission, the American Association for Accreditation of Ambulatory Surgery Facilities, or the Accreditation Association for Ambulatory Health Care. Additionally individual states have developed regulations to ensure that safety and emergency protocols are in place.

Box 19.1 An Outline of ASA Guidelines for Ambulatory Anesthesia and Surgery

1. All ASA standard practices should be followed.
2. A licensed physician must be available at all times in person by phone until while patients are present.
3. The facility must be constructed and operated in a manner that complies with all local, state, and federal laws.
4. Staffing should consist of:
   - A. Professional staff
     1. Licensed physicians and nurses
   - B. Administrative staff
   - C. Housekeeping and maintenance staff
5. Minimal patient care should include:
   - A. Preoperative instructions and preparation.
   - B. An appropriate pre-anesthesia evaluation and examination to be performed or reviewed and verified by an anesthesiologist, prior to anesthesia and surgery.
   - C. An anesthesia plan developed with and accepted by the patient by an anesthesiologist.
   - D. Administration of anesthesia by anesthesiologists, other qualified physicians, or nonphysician anesthesia personnel medically directed by an anesthesiologist.
   - E. Physician responsibility for patient discharge.
   - F. Patients who receive other than unsupplemented local anesthesia must be discharged with a responsible adult.
   - G. Patients must be given written postoperative and follow-up care instructions.
   - H. Accurate, confidential, and current medical records.

Adapted from ASA Guidelines for Ambulatory Surgery [5]

19.4 Patient Selection

When choosing patients for ambulatory surgery, one must remember the expectation is for the patient to return to their prior living situation on the same day. With this in mind, a variety of medical and surgical factors should be considered. Surgery should be done with the expectation of no need for complex postoperative care or ongoing blood loss. Patients with a suspected or known difficult airway or unstable chronic medical conditions may be best served by having their procedure done at a hospital. Historically ambulatory surgery was provided for patients assigned to ASA physical status I or II. Currently it is common to see ASA III or IV patients in the ambulatory setting provided their comorbid diseases are optimized and stable. A retrospective review found no significant differences in unplanned admissions, unplanned admission rates, unplanned contact with healthcare services, or postoperative complications in ASA III patients undergoing ambulatory surgery when compared to ASA I or II patients [6]. Although more patients with an increasing number of comorbidities are being treated in ambulatory surgery centers, several conditions require special consideration.

19.5 Obstructive Sleep Apnea

Obstructive sleep apnea (OSA) is characterized by intermittent partial or complete airway obstruction during sleep. It is estimated that up to 14% of adult males and 6% of adult females suffer from obstructive sleep apnea [7], the majority of which may be undiagnosed [8]. It is often seen in obesity but can present in non-obese individuals as well. It is seen in children and adults. These patients have an elevated risk of morbidity in the perioperative period due to increased incidence of postoperative desaturation, respiratory failure, postoperative cardiac events, and elevated rate of ICU transfers [9]. Long-term exposure to intermittent hypoxia provides the physiologic basis for the increased risk of cardiovascular compromise [10].

In 2014 the ASA published updated practice guidelines for the perioperative management of patients with OSA. Some of the consensus agreements include [11]:

- Performing a physical exam prior to the date of surgery to examine the airway and consider factors such as neck size, tonsil size, tongue volume, and nasopharyngeal characteristics that may suggest undiagnosed OSA and if necessary warrant further work-up and optimization
- Factors such as OSA status, type of surgery, capabilities of the outpatient facility, and need for post-op opioids should be taken into account when determining if the procedure can be done on an ambulatory basis
- Local anesthetic and peripheral nerve blocks should be used when possible to minimize sedation and opioid use
- Patients should be extubated fully awake in a lateral, semi-upright, or other non-supine positions after full reversal of neuromuscular blockade

The use of a questionnaire such as STOP-Bang along with a physical exam has proven effective in identifying most patients at risk of OSA [12]. Patients with OSA can be safely treated in the ambulatory surgical setting; however they may have a higher likelihood of difficult intubation, have a greater requirement for vasopressors, and will potentially need more oxygen in the PACU [13], so the anesthesiologist should be prepared for this possibility in at risk patients.

19.6 Cardiovascular Disease

Approximately one in three adults (32%) in the United States has hypertension [14]. Hypertension is extremely common; however it should rarely be a reason for delaying surgery. In patients presenting the day of surgery with an elevated blood pressure and no evidence of end-organ damage, no difference in outcomes have been shown by actively treating vs delaying surgery for patient optimization [15]. Thus delaying a surgery to optimize a patient's hypertension is not likely to be of benefit. If patients are on beta-blockers, they should generally continue them on the day of surgery. Debate exists on the continuation of ACE inhibitors (ACEI) or angiotensinogen receptor blockers (ARBs) the day of surgery as they can be associated with refractory hypotension during

anesthesia. Low-level evidence exists that supports the withholding ACEI/ARBs the day of surgery to prevent hypotension [16]. A large cohort study however has shown no difference in hemodynamic characteristics, vasopressor requirements, or cardiorespiratory complications among patients who were or were not using ACEI during surgery [17]. The decision to continue or withhold ACEI/ARBs should be made on a case-by-case basis.

Determining a patient's preoperative exercise tolerance is vital as it is a good approximation of cardiovascular status and can help guide the need for further testing. It has been shown that patient self-reported exercise tolerance is a sensitive way of predicting cardiovascular perioperative complications with patients who state they can walk less than four blocks or two flights of stairs at the greatest risk [18]. This can help reduce the need for further formalized testing and serve as a quick measure for identifying patients at the highest risk. Other specific patient factors that have been shown to increase perioperative risk are a history of coronary artery disease, myocardial infarction, peripheral vascular disease, congestive heart failure, ventricular arrhythmia, dementia, Parkinson disease, and smoking equal to or greater than 20 pack years [18].

The American College of Cardiology (ACC) and the American Heart Association (AHA) task force on practice guidelines published an update in 2014 [19]. Patients with coronary artery stent placement in the previous 4–6 weeks are recommended to continue antiplatelet therapy for urgent, noncardiac surgery unless the risk of bleeding outweighs the benefit of prevention of stent thrombosis. If P2Y12 platelet receptor inhibitor therapy must be stopped, it is recommended to continue aspirin and to restart P2Y12 platelet receptor inhibitor therapy as soon as possible following surgery. For elective surgery it is recommended to delay surgery for 30 days post bare metal stent placement and 1 year post drug-eluting stent placement [19].

19.7 Malignant Hyperthermia

Malignant hyperthermia (MH) is a possibility anywhere volatile anesthetic agents or succinylcholine are used. The Malignant Hyperthermia Association of the United States recommends that facilities keep a minimum of 36 vials of dantrolene where any triggering agents may be deployed [20]. Some ambulatory centers will prefer to exclusively use total intravenous anesthesia and will only have succinylcholine on hand for emergency purposes. In this type of arrangement, it is still recommended to stock dantrolene should a MH event occur [20]. In the event MH is triggered in an ambulatory setting, initial efforts should be focused on dantrolene administration. Emergency medical services should then be contacted without delay to transport the patient to a medical center with all the capabilities to manage the event. The Malignant Hyperthermia Association of the United States, the Ambulatory Surgery Foundation, and the Society for Ambulatory Anesthesia have developed joint transfer guidelines for patients who develop acute MH in an ASC [21].

19.8 Preoperative Evaluation

Ideally the preoperative evaluation should be done with sufficient time in advance of the planned procedure to allow for additional testing and optimization should that be necessary. For young healthy patients, a telephone assessment may be appropriate [22]. In older patients more likely to have multiple comorbidities and social issues, a face-to-face assessment is advisable [23]. Routine laboratory testing is often not predictive of postoperative complications [24] and should be ordered with specific management questions in mind. In one study all preoperative testing was eliminated, and this resulted in no increased perioperative adverse events or readmission within 30 days [25]. This suggests many preoperative tests are unnecessary and only contribute to increase costs. In the ambulatory setting, preoperative testing should be done judicially as to not incur unnecessary delays.

19.9 Preoperative Fasting

The American Society of Anesthesiologists (ASA) guidelines for preoperative fasting allow a light meal up to 6 h prior to surgery and the consumption of clear liquids until 2 h prior to surgery [26]. In the European Journal of Anesthesiology 2011 guidelines for preoperative fasting, patients

Table 19.1 Summary of ASA preoperative fasting recommendations

Fasting time (h)	Food category	Example
2	Clear liquids	Water, fruit juice (no pulp), coffee, tea, carbonated beverages (no alcohol)
4	Breast milk	Breast milk
6	Light meal	Infant formula, nonhuman milk, toast
8	Heavy meal	Fried food, meat, high-fat foods

Adapted from ASA Guidelines for Preoperative Fasting [26]

should be encouraged to consume clear liquids until 2 h prior to surgery to avoid dehydration [27]. Patients should be directed to take their chronic medications with clear liquids the morning of surgery. The ASA recommendations for preoperative fasting are summarized in Table 19.1.

19.10 Premedication

19.10.1 Controlling Anxiety

Anxiety for many patients will begin as soon as they are scheduled for a surgical procedure. Up to 80% of patients may experience preoperative anxiety [28]. Attenuating a patients anxiety is a vital component of the overall patient satisfaction and can impact a patients overall cooperativeness with an anesthetic plan. An anxious patient may be more likely to prefer general anesthesia over regional techniques [29]. A visit with the patient by the anesthesia provider just before surgery has been shown to reduce patient anxiety [30]. The use of anxiolytic medication should be done with caution as longer-acting agents have the potential to prolong sedation and delay recovery [31]. A systematic review however found little evidence to support the idea that anxiolytic premedication delays discharge after day-case anesthesia [32]. The decision to administer anxiolytic drugs should be made on a case-by-case basis. Alternative anxiety reduction techniques such as allowing patients to listen to music have shown to be effective [33].

19.10.2 Preoperative Analgesia

Ambulatory patients may often be given various analgesic agents with the intent of decreasing postoperative pain or helping attenuate hypertension associated with tracheal intubation. Acetaminophen has shown the potential to reduce postoperative pain and opioid requirements when used as part of a multimodal pain control strategy [34]. Acetaminophen can be given orally preoperatively; however the duration of action is 4–6 h. For shorter cases this may be appropriate as plasma levels may still be therapeutic postoperatively. Intravenous acetaminophen administration intraoperatively has shown to consistently produce therapeutic plasma levels [35].

Opioids are commonly given in the perioperative period. The administration of fentanyl prior to tracheal intubation is often done to prevent acute elevation of blood pressure. The value of preoperative administration of opioids for attenuating postoperative pain is unclear. Administering controlled-release oxycodone prior to surgery has been shown in several studies to have no benefit in reducing postoperative pain and may increase incidence of nausea and vomiting [36, 37]. In 2016 the American Pain Society published guidelines on the management of postoperative pain. Recommendations include the use of multimodal analgesia that includes preoperative gabapentin or pregabalin, acetaminophen, or NSAIDs and the use of regional or neuraxial techniques where appropriate [38].

19.11 Intraoperative Management

19.11.1 Technique

Choice of anesthetic technique will be guided by multiple patient and local factors that at times may compete with each other. Ambulatory anesthetic goals are aimed at providing a rapid emergence with no or minimal postoperative nausea and vomiting (PONV) and maximum patient comfort that limits postoperative pain while not delaying discharge to home. In general the

anesthesiologist must choose between general anesthesia, regional anesthesia, local anesthesia, or some combination of the three. A meta-analysis comparing discharge time from an ambulatory surgery center between patients receiving peripheral nerve blocks, neuraxial technique, or general anesthesia showed no significant difference [39]. This would suggest that perceived variation in recovery times between the techniques is unfounded.

Some procedures will only be possible under general anesthesia. Other procedures may be possible via multiple types of anesthesia, and the decision on what technique to employ will involve consideration of patient factors along with surgeon preferences. Procedures that are suitable under local anesthesia may have an advantage of lower cost and shorter operating room time [40]. General anesthesia is a common choice of anesthetic technique and is often induced via short-acting intravenous induction agents, the exception being children or needle-phobic adults where inhalational induction with the volatile agent sevoflurane is performed. Propofol has properties that make it an appealing choice for IV induction in outpatient surgery. It is short acting allowing for a rapid recovery, is nonirritating to the airway, and can reduce postoperative nausea and vomiting [41]. Propofol however causes pain at the injection site and can induce dose-dependent apnea and hypotension after administration. Maintenance of anesthesia can be with a volatile agent or with IV anesthetics. Total intravenous anesthesia (TIVA) with propofol may provide an advantage of less PONV as compared to the use of volatile agents [42]. Inhalational agents such as sevoflurane and desflurane have low blood solubility that allow for rapid recovery and emergence; however they are associated with increased incidence of postoperative nausea and vomiting as compared to propofol [43]. Recovery from anesthesia maintained with propofol is comparable to anesthesia maintained by inhalational agents [41].

19.11.2 Regional Anesthesia

Regional anesthesia techniques such as peripheral nerve blocks and neuraxial techniques are commonplace in ambulatory surgery. It is not uncommon to see regional and general anesthesia combined. Regional anesthesia provides the benefit of reduced PONV and excellent postoperative analgesia. These benefits must be weighed against potential disadvantages. Regional techniques may be contraindicated in patients on anticoagulants, have a high failure rate if the practitioner is inexperienced, carry a risk of infection, and introduce patients to the risk of local anesthetic toxicity. Patients who receive peripheral nerve blocks may potentially be discharged from PACU sooner as compared with general anesthesia [44]. This is in contrast to neuraxial techniques that can potentially increase PACU discharge times [45]. The duration of action of lidocaine is appropriate for outpatient surgery; however it is avoided in spinal anesthesia due to the incidence of local anesthetic toxicity [46]. Bupivacaine and ropivacaine are alternative agents for spinal anesthesia; however their longer duration of action can make them less desirable in the ambulatory setting [47]. Intrathecal 2-chloroprocaine is a suitable alternative as it has shown to result in significantly faster discharge times as opposed to bupivacaine [48]. Bupivacaine when used at lower than typical doses and combined with an adjunct such as fentanyl has been successfully used in spinal surgery in the ambulatory setting [45].

19.12 Recovery from Anesthesia

Recovery is typically broken down into distinct phases. Standardized methods such as the Aldrete scoring system or the postanesthetic discharge scoring system (PADSS) are often employed to evaluate patients during their recovery from anesthesia. For efficiency the postanesthesia care unit (PACU) should be located in close proximity to the operating rooms. Generally patients have completed phase I of recovery when they are alert, oriented, able to maintain their airway, and hemodynamically stable. It is not uncommon for patients to emerge from the operating room and advance directly for phase II. Phase II consists of preparing the patient for discharge to home. Patients are often required to sit up unassisted or ambulate, tolerate oral intake, and void prior to completion of stage II. Common reasons for prolonged PACU stay include nausea and vomiting, pain, and drowsiness [49]. Having a plan in place to manage postoperative complications such as PONV and pain is vital to the efficiency of an ambulatory surgery center.

19.13 Postoperative Nausea and Vomiting

Risk factors for postoperative nausea and vomiting (PONV) include female sex, non-smoker status, use of postoperative opioids, and a prior history of PONV or motion sickness [50]. PONV incidence is increased following the administration of volatile anesthetic agents and opioids. Strategies that limit the use of such agents and a multimodal approach to analgesia should be employed whenever feasible. Various emetic pathways are thought to contribute to nausea and vomiting, and a variety of medications exist that are geared to act upon the receptors in these pathways. Many different guidelines have been published regarding the treatment and prevention of PONV [50, 51]. A study by Dewinter and colleagues has shown the use of a simplified algorithm effective in preventing and treating PONV [52]. The use of a simplified approach also makes implementation easier and increases compliance. This algorithm advocates the administration of two prophylactic antiemetics for men (dexamethasone + ondansetron or droperidol) and three prophylactic antiemetics for women (dexamethasone + ondansetron + droperidol) or two antiemetics (dexamethasone + ondansetron or droperidol) plus propofol TIVA. For treatment of PONV, ondansetron or/and droperidol is recommended. The details of the simplified algorithm are summarized in Table 19.2 [52]. This strategy resulted in a significant 33% decrease in the incidence of PONV. This approach may be appealing in the ambulatory surgery setting as postoperative nausea and vomiting is one of the most frequent complications encountered by patients who undergo general anesthesia [49].

Table 19.2 Summary of the simplified PONV algorithm

Men	→ 2 Antiemetics	→ 5HT3 antagonist or/ and first-generation antipsychotic
Women	→ 3 Antiemetics or 2 antiemetics + Propofol TIVA	→ 5HT3 antagonist or/ and first-generation antipsychotic
	Prophylaxis	*Therapy*

Abbreviated adaptation of the Simplified PONV algorithm proposed by Dewinter et al. [52]

19.14 Postoperative Pain Management

A plan for postoperative pain management should be in place prior to induction of anesthesia. Multimodal analgesia is the use of two or more analgesia agents targeting pain pathways at different levels. This approach has been shown to reduce opioid use and its associated side effects [53]. This should be of interest to those in the ambulatory setting as overreliance on opioids can lead to increased sedation and longer PACU times. While studies are ongoing to determine the optimal multimodal regimen, research has shown effectiveness at reducing opioid requirements. In particular the addition of NSAIDs or COX-2 inhibitors has shown to reduce opioid use when administered as part of a multimodal strategy [54]. The use of other agents such as gabapentin or pregabalin has been advocated by the American Pain Society [38].

19.15 Discharge

The focus should be patient safety when deciding to discharge a patient. Factors such as the patients living arrangement and home support should be taken into account prior to scheduling ambulatory surgery. Before returning home patients should be advised not to drive a motor vehicle or operate machinery for 24 h. Patients should be given written discharge instructions, and that is verbally communicated to the patient and to people who accompany the patient. Patients should be advised on a normal course of events during recovery and what to expect in regard to pain and dressing changes. Patients should be given information on how to contact a provider should questions arise and where to return should a worrisome event occur. Follow-up appointments should be made with the time and location of the said appointment provided in the written discharge information.

19.16 Office-Based Anesthesia

Office-based anesthesia refers to performing an anesthetic in an outpatient setting such as an office that does not hold accreditation as an ambulatory surgery center. Having a procedure done in the office is often convenient for the patient and surgeon. Costs associated with working in this setting are typically lower as opposed to an operating room providing potential savings to the patient [55]. Patient safety is especially important in the office setting. A closed claims analysis in 2009 determined that the severity of injury to patients undergoing anesthesia was greater outside of the operating room. Respiratory events from oversedation were the most common mechanism of injury [56]. Anesthesia providers should have all airway management and rescue equipment available on site.

Regulation and oversight are done by the individual states and requirements vary. Some states currently have no formal regulations. Organizations such as the American Association for the Accreditation of Ambulatory Surgical Facilities, the Accreditation Association for Ambulatory Health Care, and The Joint Commission provide guidance and necessary accreditation to office facilities. Anesthesiologists who will operate an office-based practice should become familiar with the laws and regulations that apply in their state.

19.17 Summary

Ambulatory and office-based anesthesia is becoming more prevalent for a multitude of factors. Decreased costs, ease of scheduling, and increased patient satisfaction all play a role. For the anesthesiologist working in the ambulatory setting, the technique of anesthetic delivery may require alteration to facilitate quicker recovery times with less incidence of PONV and better controlled postoperative pain control. A multimodal approach to pain management is increasingly becoming the standard of care. Proper patient selection is vital as patients with multiple comorbidities that are poorly controlled may be better served as an inpatient. A high level of proficiency in regional and neuraxial techniques is required as this is often employed in the ambulatory setting. Efficiency, prior planning, and coordination are key to minimizing PACU stays and avoiding prolonged discharge times. Finally the regulations that apply to the ambulatory setting are managed by individual states and may vary.

19.18 Review Questions

1. Are patients with obstructive sleep apnea (OSA) appropriate candidates for ambulatory surgery?

2. True or false: Preoperative benzodiazepines cannot be administered in ambulatory surgery due to prolonged postoperative recovery times.

3. If an ambulatory surgery center only administers anesthesia via total intravenous anesthesia (TIVA) with propofol, do they have to stock dantrolene?

19.19 Answers

1. Yes – Obstructive sleep apnea (OSA) patients present a unique challenge to the anesthesiologist, but that diagnosis alone does not preclude a patient for ambulatory surgery. Patients with OSA have an increased incidence of postoperative desaturation, respiratory failure, postoperative cardiac events, and elevated rate of ICU transfers [9]. With this in mind, careful consideration of the procedure to be performed, how well the patients OSA is currently managed, and expectations for postoperative pain should be taken into account prior to scheduling ambulatory surgery for a patient with OSA.

2. False – As many as 80% of patients may experience preoperative anxiety. Benzodiazepines are an effective anxiolytic. Longer-acting agents may not be appropriate; however shorter-acting agents like midazolam

should not be withheld solely over the concern for delaying discharge. Large-scale meta-analysis has not shown sufficient evidence that preoperative benzodiazepine administration delays discharge in ambulatory surgery [32].

3. Yes – Malignant hyperthermia is triggered by volatile anesthetic agents and succinylcholine. Even if a facility does not have volatile agents in stock, it is likely they will have succinylcholine on hand in the case of an airway emergency. Since succinylcholine is in the building and therefore could possibly be administered, dantrolene should be available should malignant hyperthermia be triggered [20].

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Remote Locations

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_20

20.1 Introduction

A remote anesthesia site generally refers to a location which is distant from the main operating room (OR) and may also be referred to as nonoperating room anesthesia (NORA). In contrast to an OR, remote locations are typically not designed to accommodate a patient undergoing a general anesthetic. These remote locations are typically designed for their intended purpose only (e.g., imaging) without considering the anesthesia-related aspects of a patient receiving anesthesia or the providers of the anesthetic. Anesthetizing patients in a controlled environment, with familiar equipment and readily available assistance, is an important factor to deliver safe anesthesia care. These principles may be compromised, when anesthesia providers are asked to provide anesthesia in sites remote from the traditional OR. The anesthesiologist is now frequently consulted to help manage patients with advanced congenital and valvular cardiac diseases and comorbidities such as chronic obstructive pulmonary disease, diabetes, renal failure, morbid obesity, and obstructive sleep apnea. Unique patient's characteristics such as inability to lie flat or difficult airway add to the already challenging anesthesia planning and conduction.

Cases performed outside of the OR are characterized by three distinct features:

1. The remote location, i.e., the procedure, does not take place in a typical OR.
2. Personnel performing the procedure for the most part are not surgeons but rather medical interventionalists or proceduralists, and the procedures and technologies used may be novel in one way or the other. Medical proceduralists are often highly specialized consultants with limited knowledge about the overall condition of their "referred" patients and are also uninformed about the practice of anesthesiology and relatively inexperienced in working with another "support" physician.
3. Many of these procedures are performed on patients deemed "too sick for surgery," and in some cases the patients are critical or unstable and therefore need advanced and specialized anesthesiology skills.

20.2 Why the Increased Need for Anesthesia in Remote Areas

The number of diagnostic, therapeutic, and interventional procedures performed outside of the OR environment has increased exponentially over the past 20 years [1–3]. Pino observed that by 2007, 12.4% of all anesthetic care in the United States was delivered outside the OR environment, mostly by non-anesthesiologists [4]. An explosion of technological advances, constraints on operating room time, the desire of patients for sedation and lack of recall, and a legitimate need for anesthetic care of certain patient populations such as pediatric and mentally challenged patients all contribute to the increase in popularity of anesthesia in remote areas. An aging population and the increasingly prolonged survival of patients with complicated disease states have changed both the complexity of the interventions performed and the acuity of the patient population. These cases involve nearly every medical specialty, generate volume and revenue equivalent to that of the OR, and are as demanding for anesthesiologists. Cases include everything from minor procedures to intense cardiac procedures requiring postprocedure care in the intensive care unit. The significant improvement in monitoring and the introduction of short-acting, fast emergence anesthetics have also contributed to the increase in cases done in remote locations.

20.3 Classification of Remote Locations

Remote locations share several design challenges. They belong to other departments, and the delivery of anesthesia is usually not considered in the design process. They are classified based on design, equipment, type of procedures performed, and specialties involved [5].

Remote locations may be classified as:

1. Locations not designed for the administration of anesthesia
2. Locations with fixed equipment
3. Subspecialty-specific rooms outside the main OR
4. Specialized diagnostic suites

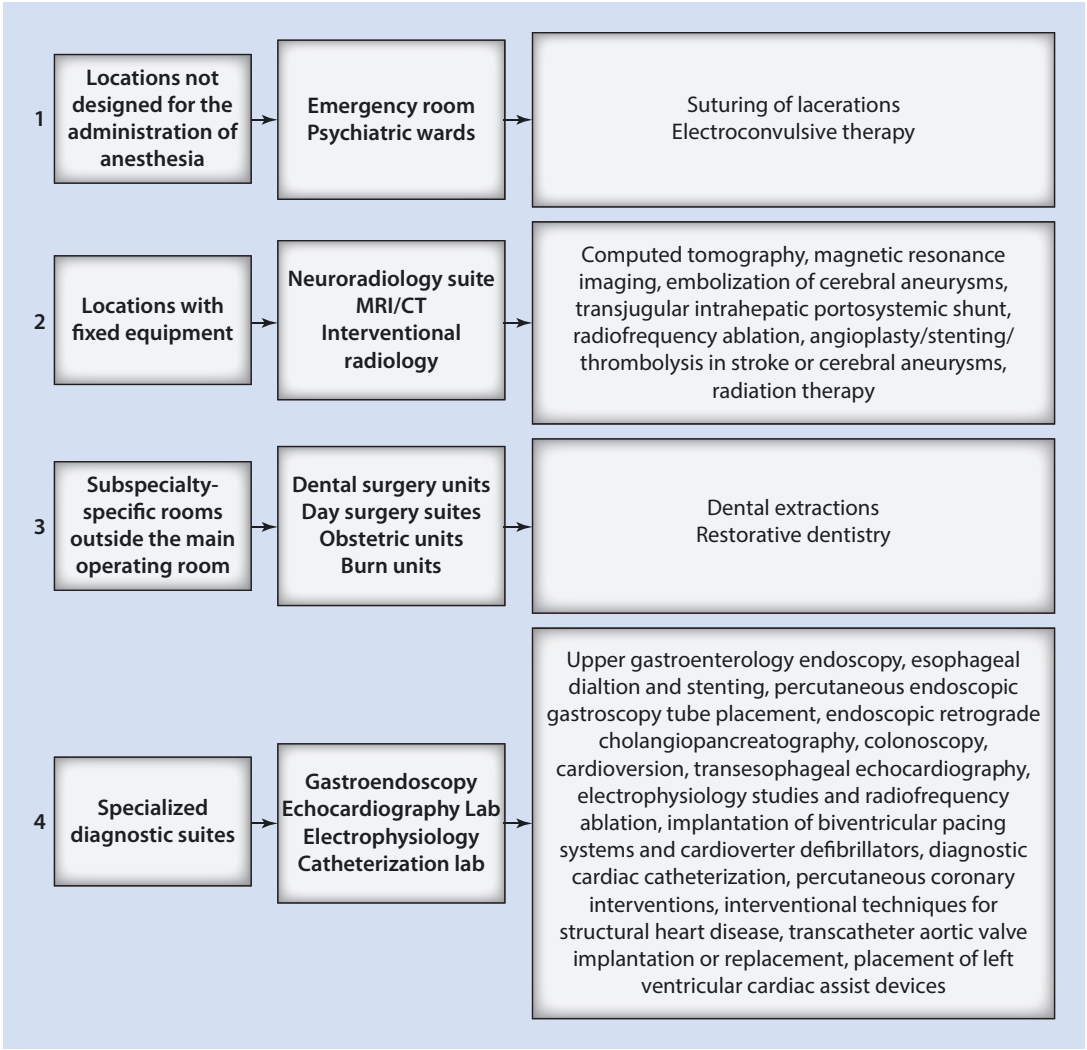

Fig. 20.1 Classification of remote locations

Examples of remote locations and procedure types are shown in Fig. 20.1. The standards of anesthesia care and patient monitoring are the same regardless of location. Remote locations have different safety concerns which may be related to the patient, procedure, and the environment.

20.4 Three-Step Approach to Anesthesia in a Remote Location

Adopting the three-step approach to anesthesia in remote locations helps to minimize errors (Fig. 20.2). There are several inherent problems

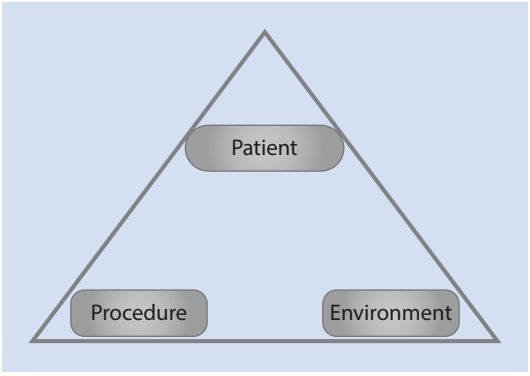

Fig. 20.2 The three-step approach to anesthesia in remote locations

related to the patient, the procedure, and the environment when providing anesthesia in remote locations. The anesthesiologist must establish what the procedure entails and how the procedure will be performed as well as the general health of the patient. The staff is unfamiliar with anesthetized patients and anesthesiology equipment. In most instances, there is lack of rigorous preprocedural check-in processes. There is inadequate anesthesia support, and anesthesiologists are far from colleagues and back up in the event of a crisis. Majority of procedures can be performed with moderate sedation and standard monitoring. For safe and effective anesthesia to be delivered in a remote location, the three-step approach—patient, procedure, and environmental factors—is a helpful guide [6, 7].

20.4.1 Patient Factors

The preoperative evaluation will give an indication on the general health and other comorbidities of the patient. However, it is highly likely that some patients scheduled for procedures in remote locations do not undergo a thorough preoperative evaluation. Most patients are admitted on the day of the procedure. The nil per os (NPO) status of the patient and an airway assessment are very crucial [8]. Several questions need to be asked: is the procedure expected to be painful? Can the patient lie flat and for how long? Is a motionless field required? Some procedures may elicit cardiovascular responses, and others may be associated with nausea and vomiting. It is also important to think of postprocedure care as most remote locations are not designed with a postanesthesia care unit to monitor the patient before being transferred.

20.4.2 Procedure

The anesthesiologist needs to understand the requirements of the procedure, its potential complications, anticipated duration, and the specific needs of the proceduralist. The anesthetic technique may need to be modified according to the type of procedure and its requirements. Familiarity with the procedure ensures that the necessary drugs, equipment, and monitoring devices are prepared [9]. The common procedures that may require anesthesiology services are listed in Fig. 20.1.

20.4.3 Environment

Remote locations are a less optimal environment for anesthesia delivery [9, 10]. Factors may include:

1. Hostile environment or design: These locations were often designed for other departments without considering whether anesthesia services would be needed. The environment is unfamiliar, and the room is cramped with unfamiliar equipment. The physical setup and the anesthesia equipment are often different from what are found in the OR, and the monitoring equipment may be inadequate. Since the proceduralist has the table controls, the procedure table or fluoroscopy equipment move frequently during the case without warning, and so the anesthesiologist must set up with this in mind, using long intravenous lines and breathing circuits.
2. Accessibility to the patient: Access to the patient by the anesthesia provider is often limited by diagnostic and therapeutic equipment such as the MRI scanners, fluoroscopes, or endoscopy towers.
3. Limited equipment and monitoring: Because these patients may require intense monitoring during the case, access to the patient is very important so that the anesthesiologist can quickly reach the patient in the event of an airway emergency, unstable hemodynamics, or patient movement. It should be remembered that all electrical equipment must be routinely checked by the bioengineering department before use in the procedure rooms to avoid such problems as electrocution and burns. Anesthesia equipment must undergo the same stringent checks as in the main OR.
4. Communication: Preoperative communication with the proceduralist is essential and must include contingency plans for emergencies and complications. The anesthesia provider must have an understanding of the procedure to provide optimum care.
5. Anesthesia assistance may be inadequate: Proceduralists and ancillary staff may be unfamiliar with the requirements for safe anesthesia care and how best to assist anesthesia providers when a difficulty is encountered. Away from the OR, help from anesthesiology colleagues in case of an

emergency may not be readily available. The location of resuscitation equipment should be noted and protocols developed with the local staff for dealing with emergencies, including cardiopulmonary resuscitation and management of anaphylaxis. Supplies and drugs may not be stocked, and equipment may not be well maintained or checked routinely.

6. Hazards and noisy environment: There are hazards unique to specific locations such as radiation in fluoroscopy and CT suites and the magnetic field in the MRI suite. In radiology suites, the electrophysiology lab, and the cardiac catheterization lab, exposure to radiation is always a concern. There is a need to protect both the patient and the anesthesia provider from the effects of ionizing radiation. Lead protecting aprons and thyroid shields may be worn for prolonged periods, which may lead to discomfort. An understanding of times and location of maximum exposure to radiation will help decrease risk to the staff. Noise generated by an MRI scanner during scanning may average 95 db in a 1.5 Tesla scanner. Protective earplugs need to be worn by the patient and the anesthesiologist.
7. Lighting may be inadequate: In radiology suites, for example, lighting may be dimmed to enhance images. The anesthesiologist must be exceptionally vigilant since complications may be missed with disastrous consequences.
8. Temperature regulation: Cold temperatures are maintained in most imaging suites to accommodate the sophisticated computer systems operating the imaging equipment. Because this makes it uncomfortable for the awake patient and the staff, heat conservation techniques and temperature monitoring need to be considered.

The American Society of Anesthesiologists (ASA) closed claims project is tasked with identifying major areas of anesthesia-related patient injury and developing strategies to improve patient safety [11–13]. Emerging patterns of injury from ongoing analysis of the ASA closed claims database have led to improved safety in anesthesia delivery in remote locations. As a result the ASA has developed standards of care for providing anesthesia in remote locations (ASA equipment requirements for remote locations are listed in Table 20.1) [14].

Table 20.1 ASA equipment requirements for anesthesia in remote locations

1	Reliable source of oxygen with backup supply, at least an E cylinder
2	Adequate suction
3	Scavenging system for wastage gases
4	Self-inflating hand resuscitator bag, adequate drugs, supplies, and equipment for the intended anesthetic care, standard ASA monitors, well-maintained anesthesia machine equivalent in function to that used in an operating room (if inhalational agents are used)
5	Sufficient electrical outlets with isolated electric power or electric circuits with ground-fault circuit interrupters (if anesthetizing area is deemed a "wet location")
6	Adequate illumination for anesthesia machine and monitoring equipment with battery-powered backup
7	Sufficient space to accommodate equipment and allow access to patient
8	Emergency cart with emergency drugs and CPR equipment
9	Adequate staff to support the anesthesiologist and reliable two-way communication for assistance
10	Anesthetizing area should be up to code with respect to building, safety, and facility standards
11	Postprocedure management in accordance with ASA Standards for Postanesthesia Care as well as equipment and staff appropriate for transport

American Society of Anesthesiologists Committee on Standards and Practice Parameters [14]

20.5 Standards of Care for Providing Anesthesia in Remote Locations

The ASA has also devised standards for basic anesthesia monitoring in remote locations. The anesthetic techniques used for procedures in remote locations range from monitored anesthesia care (MAC) to regional and general anesthesia. The choice of anesthetic depends on the patient's condition, the procedure involved, and

the anesthesiologist's level of comfort with and preference for a particular anesthetic. Specific procedure requirements may also determine the choice of anesthetic. It is often the choice of the proceduralist or based on standard protocol of the institution; however, the anesthesiologist must ensure that the best and safest technique for each patient is chosen.

The same level of care expected in the OR should be delivered in remote locations (Fig. 20.3). The ASA standards for basic anesthetic monitoring apply to all anesthesia care and are intended to encourage quality patient care. They apply to all general anesthetics, regional anesthetics, and MAC. The standards for basic anesthetic monitoring were approved by the ASA House of Delegates in 1986 and were last amended in 2010 and affirmed in 2015.

Standard I Qualified anesthesia personnel shall be present in the room throughout the conduct of all general anesthetics, regional anesthetics, and monitored anesthesia care. The objective of this standard is to ensure the presence of qualified anesthesia personnel at all times due to the rapid changes in patient's status during anesthesia.

Standard II During all anesthetics, the patient's oxygenation, ventilation, circulation, and temperature shall be continually evaluated.

Oxygenation Oxygen supply either from the wall oxygen or cylinder should be available to last for the duration of procedure. To ensure adequate oxygenation and avoid delivery of a hypoxic mixture when using an anesthesia machine, an oxygen analyzer with a low oxygen concentration limit alarm should be used to measure the concentration of oxygen in the patient breathing system. A pulse oximeter with a variable pitch pulse tone with a low threshold alarm audible to the anesthesiologist should be used as a quantitative method of assessing blood oxygenation. Adequate illumination and exposure of the patient are also necessary to assess color.

Ventilation Qualitative clinical signs of adequacy of ventilation such as chest excursion, observation of the reservoir bag, and auscultation of breath sounds are useful. Quantitative monitoring of the volume of expired gas is strongly encouraged. Continual end-tidal CO_2 analysis using a quantitative method such as capnography, capnometry, or mass spectroscopy should be in use from the time of endotracheal tube/laryngeal mask airway (LMA) placement until extubation or removal of LMA. When capnography is used, the end-tidal CO_2 alarm should be audible to the anesthesiologist and should have a device capable of detecting disconnection of components of the breathing system. During regional anesthesia as well as moderate to deep sedation, adequacy of ventilation using both qualitative clinical signs and monitoring of exhaled carbon dioxide is necessary.

Circulation To ensure adequate circulation, every patient should have an electrocardiogram continuously displayed from beginning of the anesthesia

Fig. 20.3 Typical OR setting

until preparing to leave the anesthetizing location, and arterial blood pressure and heart rate should be evaluated and determined at least every 5 min. Additionally, for every patient undergoing general anesthesia, circulatory function should be continually evaluated by at least one of the following: palpation of pulse, auscultation of heart sounds, monitoring of a tracing of intra-arterial pressure, ultrasound peripheral pulse monitoring or pulse plethysmography, or oximetry.

Body Temperature Body temperature should be monitored continuously when clinically significant changes in body temperature are intended, anticipated, or suspected.

In addition to the ASA monitoring standards, it is important to have appropriately functioning suction apparatus, appropriately sized airway equipment, and basic drugs needed for life support during an emergency. There should be open communication between the care teams. To underscore the importance of the dangers that can be encountered delivering anesthesia in remote locations, the joint commission on the accreditation of healthcare organizations (JCAHO) has also come up with hospital requirements for the administration of anesthesia (Table 20.2).

Table 20.2 JCAHO hospital requirements for administration of anesthesia

1	Administration of anesthesia by qualified and credentialed personnel trained to rescue a patient from general anesthesia
2	Continuous physiologic monitoring equipment during the procedure, availability of resuscitation equipment
3	Registered nurse involved in periprocedural care
4	Access and capability of administering intravenous fluids, medication, and blood products
5	History, physical consent, and discussion of risk, benefits, and alternatives with the patient or representative before anesthesia
6	Appropriate postprocedure care including monitoring, assessment, and discharge by a licensed practitioner
7	ASA standard guidelines for capnography

20.6 Types of Anesthesia in Remote Locations

The most common anesthesia delivered in remote locations is monitored anesthesia care [12] followed by general and regional anesthesia [11, 12].

Monitored Anesthesia Care MAC is a planned procedure during which the patient undergoes local anesthesia together with sedation and analgesia. MAC was the predominant anesthetic technique in remote location claims, occurring more frequently (50/58 vs 6%) than OR claims (Table 20.3). In a closed claims analysis comparing MAC with general and regional anesthesia, MAC claims were higher in older and sicker patients compared to general claims ($p < 0.025$), and more than 40% of the cases involved death or permanent brain damage similar to general anesthesia claims [15–18]. The patient's consciousness evaluation is of extreme importance during the surgical procedure performed with MAC. The ASA created the continuum of depth of sedation – a definition of general anesthesia and levels of sedation/analgesia. This was approved by the ASA House of Delegates October 1999 and last amended on October 15, 2014 (Table 20.4) [19]. MAC does not describe the continuum of depth of anesthesia, but rather it describes "a specific anesthesia service in which an anesthesiologist has been requested to participate in the care of a patient undergoing diagnostic or therapeutic procedure." [19]. Because sedation is a continuum, it is not always possible to predict how an individual patient will respond, hence the need for the presence of a trained anesthesia provider.

General Anesthesia This is a drug-induced loss of consciousness during which patients are not arousable, even by painful stimulation. The ability to independently maintain ventilator function may be impaired, and patients may require assistance in maintaining a patent airway, and positive-pressure ventilation may be required. Many remote sites may not have medical gas supply lines and gas scavenging systems that meet air exchange and electrical safety standards, making delivery of general anesthesia very risky. Adequate hemodynamic monitoring and the ability to obtain immediate qualified anesthesia assistance present potentially significant risks for the patients. Patients who have had a procedure under general anesthesia require

Table 20.3 Context-sensitive half-life of intravenous opioids and sedative-hypnotic drugs

Intravenous opioids	Elimination half-life	Context-sensitive half-life	Intravenous sedative-hypnotic drugs	Elimination half-life	Context-sensitive half-life
Fentanil	2–4 h	200min (6 h infusion), 300min (12 h infusion)	Propofol	4–23 min	3–18 min
Remifentanil	3–10 min	3–4 min	Ketamine	2–4 min	Similar to propofol
Alfentanil	111 min	50–55 min	Dexmedetomidine	2–3 h	4–250 min
			Etomidate	2.9–5.3 mins	Shorter than propofol
			Methohexital	4 min	
			Midazolam	1.7–2.6 min	
			Diazepam	20–50 min	
			Lorazepam	11–22 min	
			Thiopental	11 min	

Table 20.4 Continuum of depth of sedation

	Minimal sedation anxiolysis	Moderate sedation/ analgesia (conscious sedation)	Deep sedation/analgesia	General anesthesia
Responsiveness	Normal response to verbal stimulation	Purposeful response to verbal or tactile stimulation	Purposeful response following repeated or painful stimulation	Unarousable even with painful stimulus
Airway	Unaffected	No intervention required	Intervention may be required	Intervention often required
Spontaneous ventilation	Unaffected	Adequate	May be inadequate	Frequently inadequate
Cardiovascular function	Unaffected	Usually maintained	Usually maintained	May be impaired

Anesthesiologist [19]

expert recovery care. This may be provided either in the procedure room by appropriately qualified recovery staff or in the recovery room of operating rooms. In this latter situation, the availability of and familiarity with appropriate equipment during transfer should be verified prior to the procedure. In certain circumstances a patient may need to be ventilated in the postoperative period. The availability of an intensive care unit (ICU) bed should be confirmed prior to the procedure. It is ultimately the responsibility of the anesthesiologist to ensure that equipment, including the anesthesia machine, is functioning and that anesthetic drugs, as well as lifesaving emergency drugs, a difficult airway cart, defibrillators, and an assistant who can help in case of an emergency, are available [4, 5, 7, 9, 17].

Regional Anesthesia Regional anesthesia provides sensory blockade of a region without altering the normal anatomic features of the area. Nerve damage from regional anesthesia in remote locations was much lower than claims in the OR, likely

because less regional anesthesia is done in remote locations. In a closed claims analysis of all surgical anesthesia claims, regional anesthesia claims with death or permanent brain damage were less ($p < 0.01$) when compared to general and MAC claims [15]. Little has been studied about the use of regional anesthesia in anesthesiology practice at remote locations, and the reason for this is probably multifactorial in nature. Ultrasound-guided blocks require an entirely new skill set for practitioners and entail both a financial commitment for the cost of equipment and professional commitment to learn the techniques. The successful incorporation of peripheral nerve blocks into a practice requires a critical evaluation of the practice, looking for blocks that fill specific needs and choosing techniques and drug combinations that offer the highest likelihood of success. Ideally, the drugs selected for peripheral nerve blocks should have a rapid onset and excellent safety profile. The desired duration of action and degree of motor blockade should always be considered. A 20% intralipid emulsion infusion should be available to reverse local anesthesia toxicity of intravascular amide agent injection [20, 21]. Detailed information must be given to patients as to the duration and extent of the block, the need to protect the insensate limb, and the need for oral analgesic medications prior to the return of severe pain. Discussion of the post-block deficit with the surgeon and timely follow-up should be included as a plan for neurologic evaluation.

Intravenous Anesthetic Drugs Used in Remote locations Sedative-hypnotic drugs with a shorter duration of action and wider safety margins tend to be used in remote locations as part of a MAC technique. Subhypnotic dosages of intravenous (IV) anesthetics can be infused to produce sedation, anxiolysis, and amnesia and enhance patient comfort without producing perioperative side effects such as respiratory depression or postoperative nausea and vomiting (PONV). Additionally, it should provide for ease of titration to the desired level of sedation while providing for a rapid return to a "clear-headed" state on completion of the surgical procedure. For cardiac procedures, rapid reversibility of the sedative state may result in earlier extubation and a shorter stay in the ICU [22]. Intermittent bolus injections of sedative-hypnotic drugs (e.g., midazolam 1–2 mg, ketamine 0.25–0.50 mg/kg) can be administered, but continuous infusion techniques with propofol and dexmedetomidine are becoming increasingly popular for maintaining a stable level of sedation in remote locations. Benzodiazepines, particularly midazolam, are still the most widely used for sedation in remote locations to relieve situational anxiety during MAC cases. Careful titration in 1 mg increments every 5–10 min is necessary to avoid oversedation and respiratory depression. Propofol sedation offers advantages over the other sedative-hypnotics because of its rapid recovery and favorable side effects profile. A carefully titrated subhypnotic infusion of 25–75 mcg/kg/min produces a stable level of sedation with minimal cardiorespiratory depression and a short recovery period. Supplemental oxygen should always be provided when using sedative-hypnotic drugs. Propofol sedation can be supplemented with potent opioid and nonopioid analgesics. In comparing propofol and midazolam for patient-controlled sedation, midazolam was associated with less intraoperative recall. Low-dose ketamine infusion can be used for sedation and analgesia in remote locations without producing significant cardiorespiratory depression [23, 24]. Combining a rapid onset, short-acting sedative-hypnotics(e.g., methohexital, propofol) with a rapid short-acting opioid analgesic (e.g., alfentanil, remifentanil) are better suited for continuous infusion because of precise titration to meet the unique and changing needs of the patient [25]. This has facilitated the use of total intravenous anesthesia (TIVA) techniques in remote locations. The context-sensitive half-life has to be considered in choosing drugs for continuous infusion (Table 20.3). Because none of the currently available IV drugs can provide a complete anesthetic state without prolonged recovery times and undesirable side effects, a combination of drugs which provide hypnosis, amnesia, hemodynamic stability, and analgesia is appropriate [26–28].

Etomidate has minimal cardiovascular and respiratory depressant effects and is quite useful in high-risk patients. But pain on injection, excitatory phenomena, adrenocortical suppression, and a high incidence of PONV have limited its use [29]. Ketamine produces a wide spectrum of pharmacologic effects including sedation, hypnosis, analgesia, bronchodilation, and sympathetic nervous system stimulation [23, 24, 28]. The adverse cardiovascular, cerebro-dynamic, and psychomimetic effects of ketamine can be minimized by

prior administration of a benzodiazepine or a sedative-hypnotic such as propofol. New insights into the pharmacokinetics and dynamics of the IV anesthetics as well as the development of infusion pumps to facilitate IV drug delivery have greatly enhanced the use of TIVA techniques in remote locations. The shorter context-sensitive half-lives of the newer sedative-hypnotics make these drugs very useful for continuous infusions for the maintenance of anesthesia and sedation in remote locations [25–27].

20.7 Perioperative Complications in Remote Locations

The ASA closed claims database has provided insight into the nature of adverse events associated with anesthesia and sedation in remote locations. Bhananker et al. examined all surgical anesthesia claims associated with MAC compared to general and regional anesthesia. Close to half the claims were classified as preventable with better monitoring such as capnography and audible alarms [13, 30]. Oversedation resulting in respiratory depression was found to be an important factor in patients during MAC [15, 30]. ASA closed claims data found that events in remote locations were often judged as being preventable by better monitoring. Injurious respiratory events were significantly more common in remote location claims, with inadequate oxygenation/ventilation as the most common specific adverse event (Table 20.5).

The predominant anesthetic technique in remote location claims was MAC cases. Majority of the complications happened in the gastrointestinal suite followed by either cardiology or radiology. The severity of injuries was greater, and the proportion of death was almost double in remote location claims versus operating room claims. The anesthesia care was judged by the reviewers as substandard in a majority of remote location claims, and a large proportion of injuries were considered to be preventable by better monitoring. More patients suffered permanent brain damage and death in remote locations compared to operating room claims. Perioperative complications in remote locations may include:

- *Respiratory*:
  - Stridor
  - Wheezing
  - Coughing
  - Aspiration
  - Desaturation
  - Apnea greater than 15 s
  - Airway obstruction
- *Anesthesia-related complication*:
  - Inadequate anesthesia
  - IV-related complications
  - Unplanned intubation
  - Prolonged anesthesia
  - Secretions requiring treatment
  - Unintended deep level of anesthesia
  - Unplanned use of reversal agents
  - Unexpected need for bag-mask ventilation
  - Emergency sedation/anesthesia consultation required
  - Difficult intubation
  - Esophageal intubation
  - Lack of scavenging
  - Pain
  - Malignant hyperthermia
- *Cardiac*:
  - Cardiac arrest
  - Unexpected change in heart rate, blood pressure of 30%
  - Hypothermia
  - Agitation
  - Delirium
- *Gastrointestinal*:
  - Vomiting in a non-gastrointestinal procedure
  - Nausea and vomiting
- *Procedure-related complications*:
  - Cardiac tamponade
- *Death*

20.8 Location-Specific Catastrophes

20.8.1 Locations Not Designed for the Administration of Anesthesia: Psychiatry Wards and Procedure Rooms in Emergency Departments

Electroconvulsive therapy for patients with major depression, mania, certain forms of schizophrenia, and Parkinson's syndrome requires anesthesia and neuromuscular blockade to prevent physiological and physical trauma. Electroconvulsive therapy may be carried out in

Table 20.5 ASA Closed Claims Database Analysis in remote locations

ASA Closed Claims analysis remote location vs operation room											
	# of claims	Location with highest claims 1,2	MAC	Resp	Inadequate oxygenation/ ventilation	CVS	Equipment failure/ malfunction	Substan-dard care	Preventable by better monitoring	Permanent brain damage	Death
Metzner et al	87 vs 3287	1. GI suite 2. Cardiology	50 vs 6%	44 vs 20%	21 vs 3% $p < 0.001$	10 vs 16%	14 vs 13%	54 vs 37% $p < 0.01$	32 vs 8% $p < 0.001$	14 vs 10%	54 vs 29% $p < 0.001$
Robbertze et al	24 vs 1927	1. GI Suite 2. Cardiology and radiology	58 vs 6%	38%	33 vs 2% $p < 0.001$	13%	21%	63 vs 29% $p = 0.003$	25 vs 7% $p = 0.007$	8 vs 9%	54 vs 24%

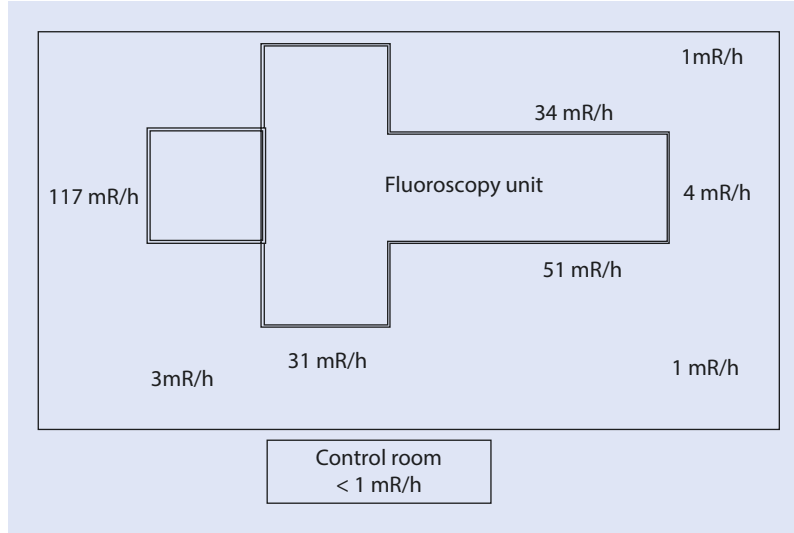

Fig. 20.4 Fluoroscopy safety

the psychiatry ward, and more recently most hospitals have moved it to the postanesthesia care unit (PACU) for safety reasons. The physiologic effects are a grand mal seizure, i.e., a tonic phase which lasts 10–15 s and a clonic phase of 30–50 s. The first reaction is a bradycardia and hypotension followed by hypertension, tachycardia, increases in ICP, intraocular and intragastric pressures, and 5–10 min of ECG changes. Anticholinergic pretreatment with glycopyrrolate/atropine is needed to prevent the transient asystole and bradycardia. An added advantage is the anti-sialagogue effects of the anticholinergics. Methohexital was once the drug of choice. But currently propofol, etomidate, and thiopental may also be used. Procedure rooms in emergency departments should have appropriate physiological monitoring systems to allow safe analgesia and sedation. Wall oxygen, suction and resuscitation equipment, drugs as well as adequate lightening are essential in these room. Capnography [30] and pulse oximetry should be available when procedures are done under deep sedation.

20.8.2 Locations with Fixed Equipment: Interventional Radiology/Neuroradiology/CT

Several procedures may be performed in the interventional radiology suite requiring anesthesia (Fig. 20.1). Procedures include embolization techniques (e.g., in the treatment of subarachnoid hemorrhage and portosystemic shunts) and intra-arterial thrombolysis (e.g., endovascular stenting). Transjugular intrahepatic portosystemic shunts are used to treat the complications of portal hypertension particularly variceal bleeding. Common procedures performed in the neuroradiology suite include embolization of vascular malformations and cerebral angioplasties. Some of the procedures may require rapid transition between deep sedation and an awake responsive state. As contrast media may be used, a history of a reaction to contrast media should be ruled out. Smooth emergence is essential, and it is important to avoid coughing and bucking by the patient. Access to the patient and to the patient's airway can be a challenge because of the fixed equipment which might be in the way. There is high exposure to radiation for both patient and the anesthesia provider (Fig. 20.4). Understanding the areas with the highest exposure to radiation in relation to the fluoroscopy unit is key to avoiding overexposure (Fig. 20.4) [31].

20.9 Magnetic Resonance Imaging

The area of interest must be close to the MRI coil, so patient positioning is very important. There is limited access to the patient's airway, and remote viewing of the patient might be necessary. The aperture is narrow, and obese patients may not fit into the MRI scanner (Fig. 20.5). If the anesthesiologist has to stay with the patient, it is a noisy environment, and hearing protection is key [32, 33].

Fig. 20.5 Radiology suite with fixed equipment

The American College of Radiology has defined four safety zones within MRI facilities. These zones are zones 1 through 4 and correspond to levels of increasing magnetic field exposure and hence a potential safety concern (Fig. 20.6).

- Zone 1: The magnetic field is less than 5 Gaus (0.5mT), and area is freely accessible to the general public.
- Zone 2: Is the interface between the unregulated zone and the strictly controlled zone.
- Zone 3: The RF magnetic fields are sufficiently strong to present physical hazard to unscreened patients and personnel.
- Zone 4: Synonymous with the MR magnet room. Has the highest and greatest risk, and all ferromagnetic objects must be excluded.

Understanding the zones is important to prevent harm to patients and personnel. Monitoring is a challenge in the MRI suite. Rapidly changing magnetic fields produce ST- and T-wave artifacts. If the ECG wires are in a loop, the magnetic field may heat the wires and leads leading to thermal injury [34].

Special considerations for monitoring include increased length of capnography and need for plastic components of blood pressure cuffs. Monitor pulse oximetry. Patients need to be induced in the holding area on an MRI safe stretcher and then transported to the MRI room. No metals should be taken into the room. Only MRI-compatible anesthesia machines and monitoring equipment should be used. Patient should be taken back to the holding area for emergence and extubation.

Inadequate sedation may result in patient movement and a failed study. Of particular importance, *never* take an oxygen cylinder into the MRI suite. Deaths have resulted as the cylinder is sucked into the magnetic coil. Never take a ferromagnetic metal into the MRI suite, and this includes laryngoscopes, scissors, stethoscopes, and mobile phones. In an emergency take the patient out of the MRI room. Do not take emergency equipment to the patient. Patients with mental disorders and pediatric patients may require deeper sedation or general anesthesia [32].

20.9.1 Subspecialty-Specific Built Room: Dental Surgery Units

Jastak et al. conducted a closed claim analysis of 13 anesthetic-related deaths and permanent injuries in the dental office setting between 1974 and 1989. Evaluation of intraoperative monitoring revealed a lack of vigilance. Hypoxia secondary to airway obstruction or respiratory depression led to all the deaths with the exception of one who survived with severe brain damage. Ten out of the thirteen cases were considered avoidable by appropriate patient selection, timely monitoring, and effective response to adverse occurrences [35]. Dental surgery units should have appropriate physiological monitoring systems, i.e., capnography, pulse oximetry, BP, and ECG monitoring to allow safe analgesia and sedation. Additionally, wall oxygen, suction, resuscitation equipment and drugs should be available.

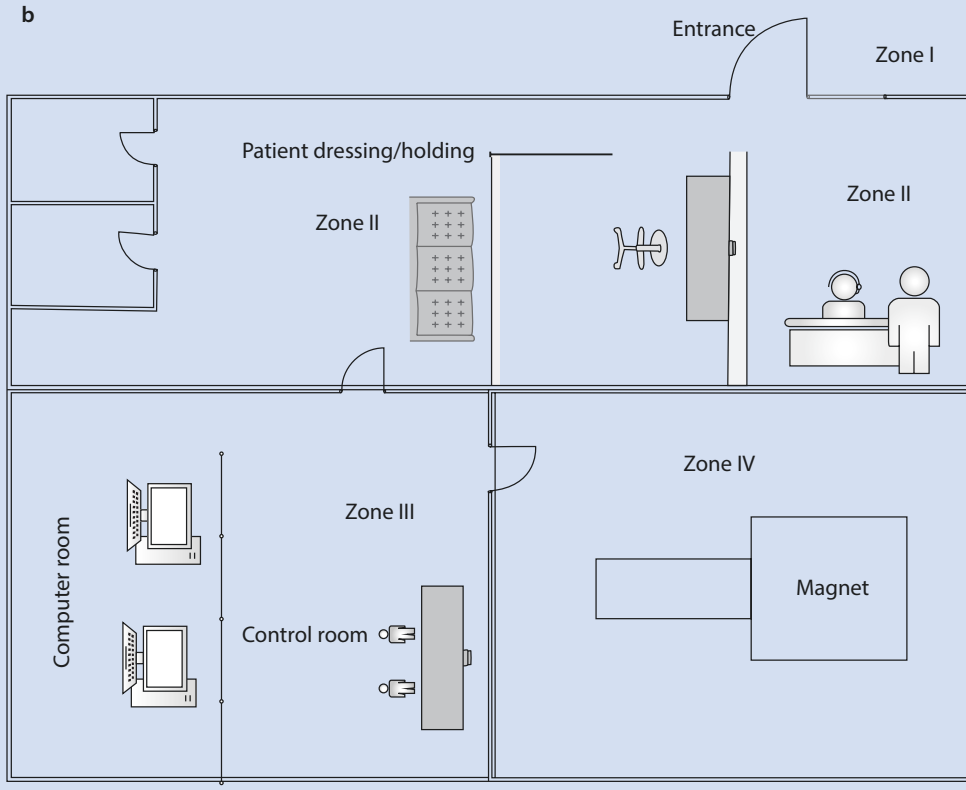

Fig. 20.6 **a** MRI suite. **b** MRI zones

20.9.2 Specialized Diagnostic Suites

20.9.2.1 Gastroendoscopy

More than half of claims from remote locations occurred in the gastrointestinal suite (Fig. 20.7) [11, 12]. Common procedures performed in this location include endoscopic retrograde cholangiopancreatography (ERCP), upper gastrointestinal endoscopy, and colonoscopy. General anesthesia with endotracheal intubation may be required if deep sedation is needed in the prone position [36].

Fig. 20.7 Endoscopy unit

20.9.2.2 Electrophysiology Lab/ Cardiac Catheterization Lab

The number of diagnostic and therapeutic interventions performed in electrophysiology (EP) labs has increased exponentially over the past 10 years (Fig. 20.8). This includes catheter-based electrophysiology studies and ablations as well as implantation of permanent pacemakers and transvenous cardioverter-defibrillator devices. The rate of major complications associated with catheter ablation procedures is less than 3%. Specific complication rates reported from a multicenter study of catheter ablation for supraventricular tachycardia include groin hematoma (3%), transient heart block or heart block not requiring a permanent pacemaker (2%), pericardial effusion (1.9%), complete heart block (1%), cardiac tamponade (0.6%), and transient hypotension (0.6%). Event rates for other complications were less than 0.4% [37–39].

For monitored anesthesia care, the preferred medications include short-acting opiates such as remifentanil and alfentanil [25]. Propofol is the most commonly used sedative-hypnotic. The anesthesia provider may need to lighten the anesthetic to modulate autonomic tone. Ketamine, which maintains sympathetic tone, may be used together with a propofol infusion [23, 24, 28]. Coughing as well as partial or total airway obstruction resulting in snoring or paradoxical abdominal motion can be problematic during intracardiac mapping. Catheter ablations for more complex arrhythmias, such as atrial fibrillation (AFib) or VT, typically take 4–8 h. These procedures often require a greater number of ablations (up to 100 or more ablative energy pulses) [37]. Advanced 3-D electro-anatomic mapping systems that require patients to remain motionless on the fluoroscopy table for the entire procedure are used. Patient motion may lead to distortion of the map, rendering it unusable; therefore, general anesthesia with paralysis may be the preferred anesthesia method during these procedures. Preferred anesthetic agents are those least expected to affect the autonomic nervous system, cardiac refractoriness, and intracardiac conduction especially during the post-ablation testing phase of the procedure. Propofol does not produce a significant prolongation of sinus node recovery time. Midazolam, alfentanil, propofol, and sevoflurane do not affect inducibility or maintenance of supraventricular tachycardia. The use of an esophageal temperature monitoring during catheter ablation for AFib is recommended. A luminal esophageal temperature probe is most accurate when it is advanced or withdrawn to position the thermistor tip in closest proximity to the ablation catheter the moment RF energy is delivered [40]. Frequent adjustment under fluoroscopic guidance may be required. This allows the anesthesia provider to alert the electrophysiologist of any sudden increases in intraluminal temperature (>0.2 °C) indicative of esophageal interaction during RF application. Every anesthesiologist involved in patient care in the EP lab should wear a dosimeter to track cumulative radiation exposure (Fig. 20.8). In a 2005

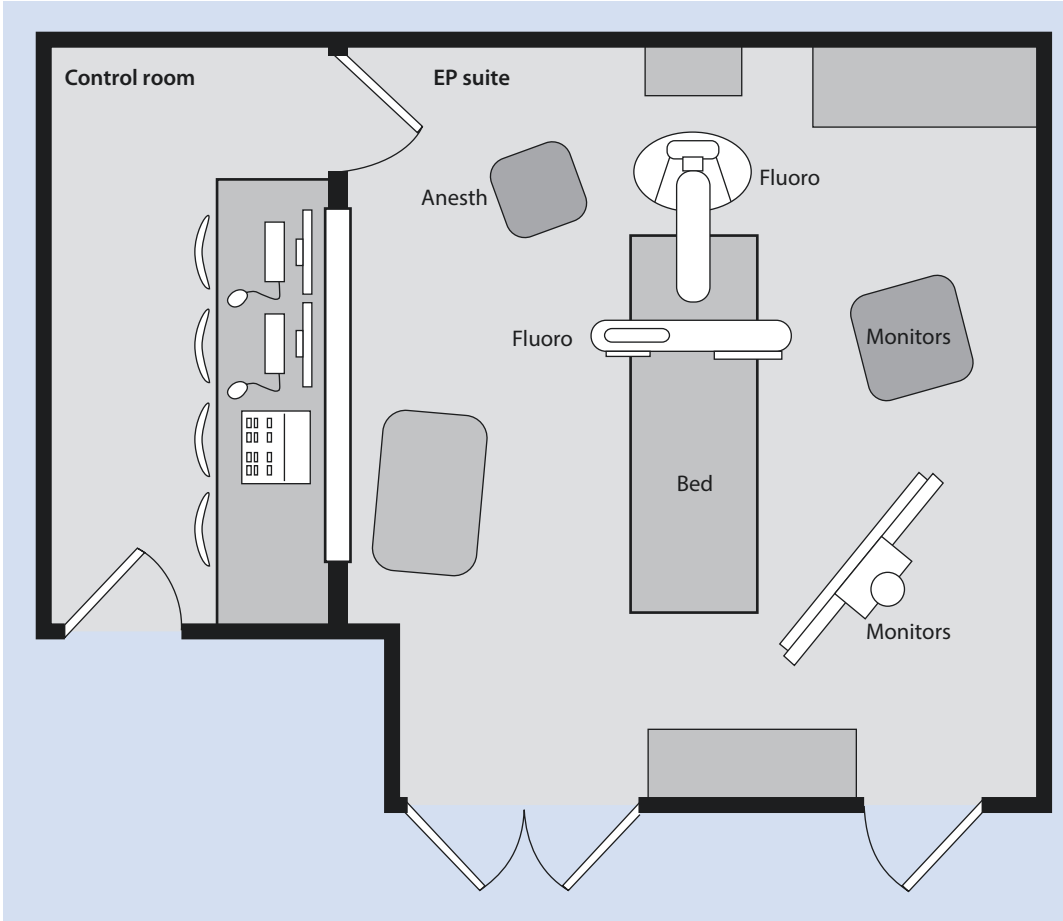

Fig. 20.8 Schematic courtesy of the Medical College of Georgia, used with permission

study, it was found that the aggregate radiation exposure for all members of the anesthesiology department doubled after the introduction of an EP lab [31]. The range of exposure levels was wide, making dosimeter tracking even more crucial.

20.10 General Principles of Anesthesia in Remote Areas

Several factors should be considered for safe delivery of anesthesia in remote locations.

A thorough preoperative evaluation is important to determine if it is safe for the procedure to occur in a remote location. Patient selection is very important and should not be overlooked. Understanding the procedure is very important, and having good communication with the proceduralist and his/her team is key.

Anesthesia-related complications as well as procedure-related complications should be considered. Take into consideration procedures that may involve significant blood loss. Consider the length of the procedure as well as supply and support functions or resources. The main operating room should be alerted in the event of a procedure-related complication which might require emergency surgery in the operating room. Cardiac procedures should only occur in remote locations where there is a cardiothoracic surgeon in house or on back up, should there be a need to take the patient to the operating room emergently. The operating room crisis checklists should be available in all remote locations where sedation and anesthesia are used [41, 42]. Keeping a record of the airway assessment and management, intraoperative events, and complications is important to guide the anesthesia team for any

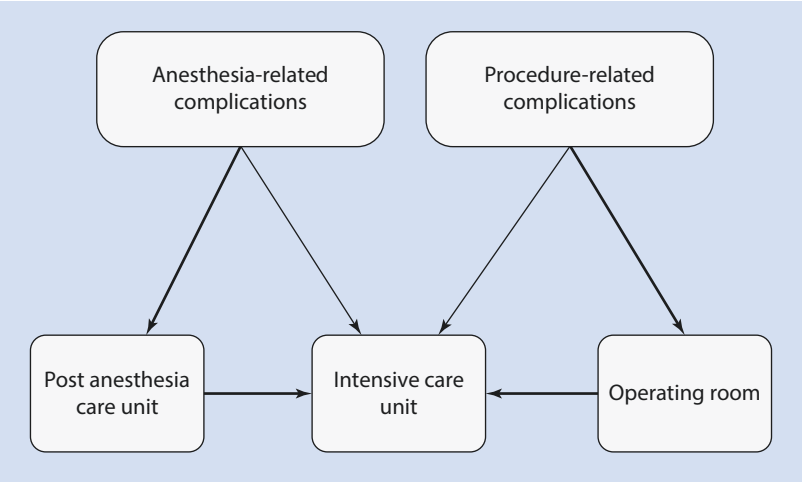

Fig. 20.9 Communication between the anesthesiologist and the proceduralist as well as the team in the remote location is important, first to understand the procedure and also to have a contingency plan in case of any adverse events

future procedures. Postprocedure recovery either in PACU or recovery area in the remote location or step-down unit or intensive care unit in the event of complications is important.

Communication between the anesthesiologist and the proceduralist as well as the team in the remote location is important, first to understand the procedure and also to have a contingency plan in case of any adverse events (Fig. 20.9). The anesthesiologist should play a role in planning any future remote locations as the increase in the number of cases performed in remote locations continues to grow. The anesthesiologist should also be a leader to ensure excellent patient outcomes.

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Equipment Problems

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_21

Key Points

- The pre-anesthesia checklist should be performed prior to patient care and when done correctly prevents the vast majority of patient injury due to equipment failure.
- Anesthesia providers should be aware of the common causes of equipment malfunction and should be competent in recognizing and addressing these issues.
- Simulation training is becoming an integral part of anesthesia provider training.

21.1 Introduction

As anesthesia care providers, our first duty is to provide patient safety. Modernization of anesthesia delivery equipment and monitoring, as well as improvements in provider training, has led to measureable improvements in patient safety and a decline in reportable adverse events due to equipment malfunction in the Anesthesia Closed Claims database. Anesthesia providers should be trained on the recognition and management of common equipment failures to reduce the risk of patient injury. Training should occur through a combination of studied learning, on-site training by shadowing experienced anesthesia providers, and simulation training to get a "run-through" of an emergency situation before it actually occurs in the clinical setting. Anesthesia providers should be competent in performing all aspects of the pre-anesthesia machine checklist, be aware of how to both recognize and manage common equipment problems and how to best prevent equipment malfunction from happening in the first place. Similar to flying a plane, vigilance in preparedness of anesthesia equipment malfunction leads to safer anesthesia care.

21.2 Anesthesia Machine Checklist

The first pre-anesthesia checkout (PAC) recommendation was developed in 1993 by the American Society of Anesthesiologists (ASA). At that time, the selection of anesthesia delivery systems was few, and their operation was largely the same. The twenty-first century has seen the evolution of the anesthesia machine to include new complex mechanical and electronic monitoring systems, making the task of conducting a thorough PAC challenging. Furthermore, one checkout procedure is no longer applicable to all anesthesia workstations. Variance in design among the manufacturers means that a PAC must be tailored to the individual machine. For these reasons, the ASA's updated pre-anesthesia checkout guidelines for 2008 aimed at creating general principles for all anesthesia delivery systems [1]. The idea was for individual anesthesia departments to take these principles and develop their own PAC that best utilized their resources so that a PAC could be performed consistently and expeditiously.

The role of the anesthesia department varies from institution to institution, but by and large, the anesthesia provider's role is expanding to include duties outside of the operating room. Because of their duties both in and out of the operating room, providers rely more heavily on ancillary staff to assist them with making sure anesthetics are delivered safely and efficiently. The 2008 PAC guidelines include ancillary staff such as anesthesia technicians and/or biomedical technicians in the pre-check process. The guidelines name 15 specific items that should be checked as part of a complete PAC. The responsibility of who may check the items depends on the complexity of the task and falls into one to four categories: provider, technician, technician or provider, or technician and provider. The ability to have both providers and technicians assist with the PAC adds redundancy to the process with the goal of reducing errors and patient harm [2].

The modern anesthesia machine is analogous to the smartphone. In both industries, manufacturers compete to improve existing machines and add new software and hardware to create a more user-friendly experience. For all the bells and whistles, a smartphone is guaranteed to perform a few basic universal functions. Similarly, all anesthetic machines must be able to supply medical gases (such as nitrogen dioxide and oxygen) mixed with anesthetic vapors through a positive pressure-generating ventilator that can safely dispose of expired gases through a scavenging system. There must also be a form of monitoring both the system and patient as well as a suction apparatus to clear the airway [1, 3]. These require-

ments are pervasive among anesthesia societies around the world and have been adopted and individualized by anesthesia departments [4–6].

As previously mentioned, ASA's 2008 PAC guidelines name 15 specific tasks that both anesthesia providers and technicians should perform to ensure the pre-check is complete. The following is a brief summary of those specific items. A PAC summary can be found in Table 21.1.

- Item #1: Ensure a self-inflating manual ventilation device (SIMVD), such as the Ambu Bag ™ (Ambu, Ballerup, Denmark), and backup oxygen source are both available and functioning. The ability to manually ventilate a patient is of utmost importance when there is an equipment failure. The Ambu Bag serves as a means to provide room air when needed. Additionally, an oxygen cylinder should be immediately available within the anesthesia care location and checked daily.
- Item #2: Confirm suction is adequate to clear patient's airway. Traditionally, suction is measured by allowing the suction tubing to attach to the hand or thumb. This method is dependent on the weight of the tubing itself. Reliable suction is able to support the total weight of standard tubing, which is about 6 feet.
- Item #3: Confirm the workstation is supplied by AC power and the backup battery is charged. Anesthesia machines run on AC power and have a built-in battery in case of power failures. Most machines have indicators showing which power source is being utilized.
- Item #4: Ensure appropriate patient monitoring and check corresponding alarms.

Table 21.1 PAC tasks to be completed daily or after a machine is moved or vaporizers changed

	Task	Responsible party
Item #1	Verify auxiliary oxygen cylinder and manual ventilation device (Ambu Bag) are available and functioning	Provider and tech
Item #2	Verify patient suction is adequate to clear the airway	Provider and tech
Item #3	Turn on anesthesia delivery system, and confirm that AC power is available	Provider or tech
Item #4	Verify availability of required monitors, including alarms	Provider or tech
Item #5	Verify that pressure is adequate on the spare oxygen cylinder mounted on the anesthesia machine	Provider and tech
Item #6	Verify that the piped gas pressures are ≥50 psig	Provider and tech
Item #7	Verify that vaporizers are adequately filled and, if applicable, that the filler ports are tightly closed	Provider or tech
Item #8	Verify that there are no leaks in the gas supply lines between the flowmeters and the common gas outlet	Provider or tech
Item #9	Test scavenging system function	Provider or tech
Item #10	Calibrate or verify calibration of the oxygen monitor, and check the low-oxygen alarm	Provider or tech
Item #11	Verify carbon dioxide absorbent is fresh and not exhausted	Provider or tech
Item #12	Perform breathing system pressure and leak testing	Provider and tech
Item #13	Verify that gas flows properly through the breathing circuit during both inspiration and exhalation	Provider and tech
Item #14	Document completion of checkout procedures	Provider and tech
Item #15	Confirm ventilator settings, and evaluate readiness to deliver anesthesia care (anesthesia time-out)	Provider

Standards of monitoring are clearly defined and include blood pressure, pulse oximetry, electrocardiography, capnography, and temperature. Monitors should clearly display these readings and have functioning alerts to make the anesthesia provider aware of changes.

- Item #5: Verify that the spare oxygen cylinder is adequately pressurized. The spare cylinder's valve should remain closed after checking. The type of machine (pneumatically powered versus electrically powered ventilators) dictates how quickly the oxygen will be used. An oxygen cylinder for a pneumatically powered ventilator may only provide 30 min of gas.
- Item #6: Verify that piped gas pressures are >50 psig. Gas arriving from a central source can fail. Ensure before the day begins that an adequate gas pressure is available.
- Item #7: Check vaporizer levels and secure filler ports. To prevent light anesthesia and recall, ensure the vapor levels are sufficient for the case. Machines equipped with low agent alarms will alert the provider to low vapor levels intraoperatively. If the machine does not have automatically closing filler ports, retighten the valves after refilling to prevent leaks.
- Item #8: Check for leaks in the gas supply lines. The flow of gas from the common gas outlet through the anesthetic vaporizers must be evaluated daily. Machines with automated leak tests are common but often do not include leaks at the level of the vaporizer. The automated test should be repeated for each vaporizer.
- Item #9: Test scavenging system function. The connections that remove used anesthetic gas from the patient prevent the gases from contaminating the patient and room. These connections should be checked daily. Some scavenging systems use positive and negative pressures to protect against pressure fluctuations in the breathing circuit. This more specialized task can be completed by a technician.
- Item #10: Calibrate the oxygen monitor and check low oxygen alarms. The monitor should be calibrated to read 21% for room air. Test by setting the alarm to sound at a higher oxygen concentration than 21% while sampling room air.
- Item #11: Verify carbon dioxide absorbent is not exhausted. Absorbent often turns a characteristic color indicating that it has been desiccated. Other method to test for CO_2 rebreathing is by checking the capnography. The inspired CO_2 concentration (FiCO2) should read <4.
- Item #12: Breathing system pressure and leak testing. The complete circuit must be tested to ensure that adequate pressures can be generated during both manual and mechanical ventilation and that the APL valve can relieve pressures during manual ventilation. Automated processes now evaluate for leaks and the compliance of the circuit, which adjusts the volume delivered by the ventilator.
- Item #13: Verify that gas flows properly through the breathing circuit during both inspiration and expiration. Leaks through unidirectional valves are too slight to be detected visually. A technician can assess for valve incompetence, but this would be too cumbersome to perform daily. Instead, capnography can detect backflow through a valve.
- Item #14: Document completion of checkout procedures. Documentation helps the provider keep track of checkout tasks and serves as a record should any adverse events occur.
- Item #15: Confirm ventilator settings and evaluate readiness to deliver anesthesia care. This is analogous to a "time-out" in which the anesthesia provider can confirm that all the proper tasks have been completed and the machine is ready to deliver the correct anesthesia to the correct patient. It protects against errors caused by pressure or haste.

The ASA created these recommendations as a guideline for anesthesia providers to suit their own practice. They form the backbone of safe anesthesia practice for which the provider should make a daily effort to fulfill.

21.3 Anesthesia Machine: Perils and Pitfalls

Gas delivery systems have advanced tremendously from what was first used in the nineteenth century's famed Ether Dome at Massachusetts General Hospital. The father of anesthesia's, William T.G. Morton, 1846 device was a simple glass bulb containing an ether-soaked sponge

with two openings – one with a mouthpiece for inhalation and the other a valve to bring in room air. As Fig. 21.1 shows, gas delivery has become much more sophisticated and monitored. The system is also now more complex with multiple connections, mechanical components, and electronics, which increases the chance of equipment failures.

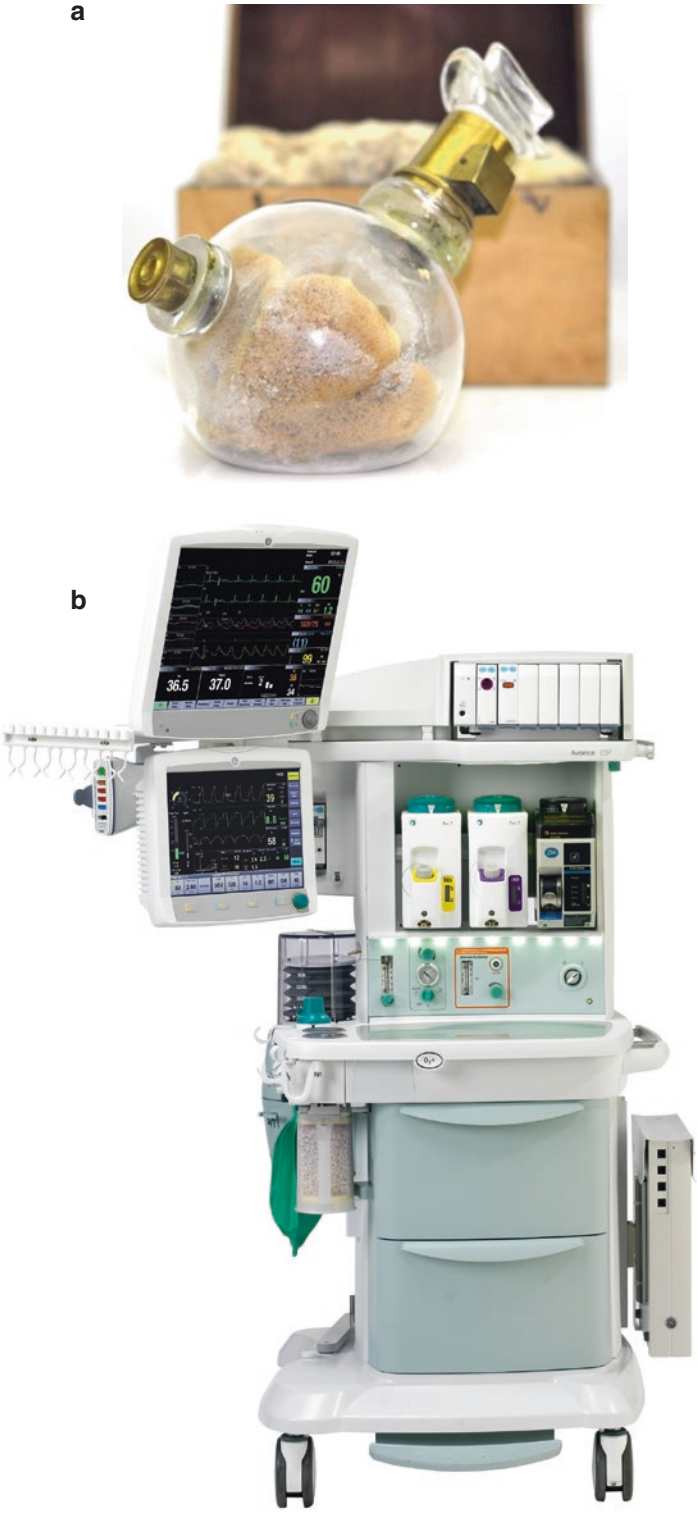

Fig. 21.1 Comparison of Morton's etherizer **a** to the most recent GE Avance workstation **b**

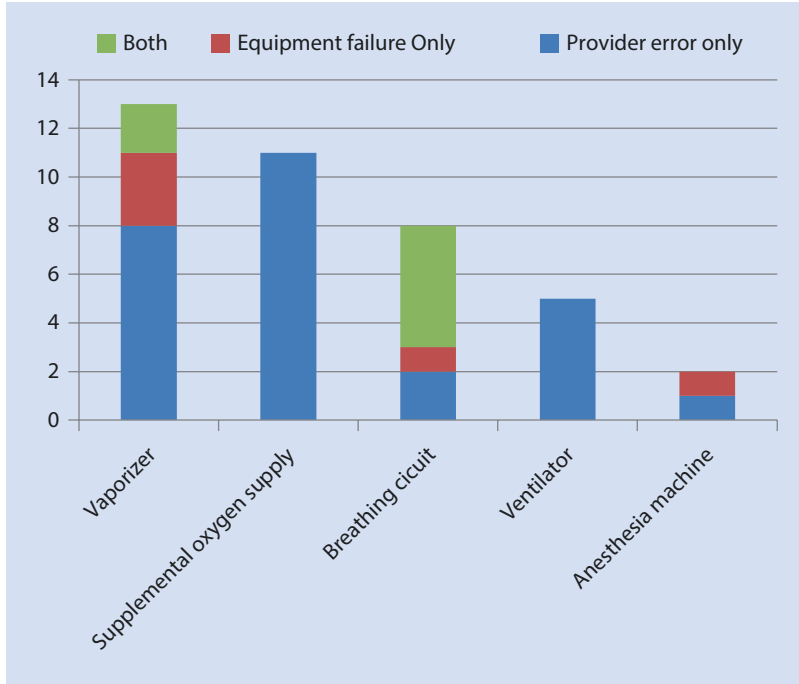

Fig. 21.2 Adverse anesthetic outcomes involving equipment. (Data from the 2013 Closed Claims Analysis Update by Mehta et al.)

An equipment failure is defined as an unexpected malfunction of a device, despite routine maintenance and previous uneventful use. Equipment misuse is defined as incidents originating from human fault or error associated with the preparation, maintenance, or deployment of a medical device. Furthermore, equipment misuse was nearly three times more common than equipment failures in a 1997 analysis of closed insurance claims by the ASA [7]. Despite this, Caplan et al.'s study concluded that only 2% of the 8496 claims dating to 1985 were related to equipment issues. Most other claims were due to other factors like difficult airway, sudden changes in vitals, etc. Trending these claims through the decades shows that anesthesia equipment claims decreased as a proportion of general anesthesia claims over time [8]. These equipment issues were separated into five categories: breathing circuit, ventilator, vaporizer, gas tank, and anesthesia machine (Fig. 21.2). A fundamental knowledge of the perils and pitfalls inherent with each component of the gas delivery system can help the provider identify equipment failures intraoperatively.

21

21.3.1 Breathing Circuit

The plastic disposable circuit that attaches to the machine is the tip of the iceberg when it comes to the anesthetic breathing system (ABS). Much of the ABS components lie underneath the surface. The multiple mechanical components and connections that make up the ABS are all sources for failure and misuse. Disconnections, blockages, leaks, valve malfunctions, and carbon dioxide absorber failures can lead to patient injury. Caplan et al.'s [7] survey showed that disconnections were the most frequent incidents, while obstruction of the expiratory limb can be the most rapidly injurious. Obstruction of the expiratory limb through a mechanical distortion or a blocked valve backs up pressures into the lung quickly leading to barotrauma. The most recent update of claims from 1990 onwards listed eight breathing circuit incidents with four being from obstruction and no claims due to disconnections [8].

21.3.2 Ventilator

The mechanical ventilator frees up the anesthetist's hands from manually ventilating and allows for the provider to focus attention elsewhere when needed. Unfortunately, because the ventilator is so automated, the provider may forget important steps to ensure the ventilator is working properly. As a result, ventilator misuse is far more common than ventilator equipment failure [9]. Turning on the ventilator may seem intuitive; however, there

are multiple clinical scenarios in which the ventilator may accidently be left off. In fact, the four ventilator claims from the most recent report were all due to provider failure to turn on the ventilator [8]. Some examples include after position change, upon transfer of an intubated patient from the ICU to the OR, after discontinuing cardiopulmonary bypass, and after placement of a chest tube. Other common ventilator misuses by a provider include inappropriate settings for tidal volume or respiratory rate, inappropriate pressure limits, inappropriate inspiratory-expiratory ratio setting, failure to reset fresh gas flow leading to increased tidal volumes, and deactivating or inappropriate use of the ventilator and threshold pressure alarm limit (TPAL) alarms. The ventilator is also subject to equipment failures. Troubleshooting issues with ventilator should include a check of the bellows, as there may be a hole or poor seal between the bellows and casing.

21.3.3 Vaporizers

The agent analyzer provides the concentration of vaporized agent that is inspired by the patient. It is factory calibrated and should be within 10–15% of the vapor concentration dial setting. Vaporizer discrepancies occur when the agent analyzer reads differently than the dial setting on the machine [10]. Common problems that result in an inappropriately increased vaporized agent concentration lead to overdose or potentially lethal doses of anesthetic agent. Overfilling the vaporizing chamber with liquid agent spills liquid agent into the bypass. The fresh gas is meant to bypass the vaporizer; however, it comes in contact with the spilled liquid agent, thus resulting in inappropriately high concentrations. Additionally, the "pump effect" may also raise the agent concentration without adjusting the dial. When back pressures are applied to the breathing circuit, such as with intermittent positive-pressure ventilation, the anesthetic vapor may get pushed back through the bypass and mix with fresh gas. This effectively increases the vapor output. Alternatively, the vaporizer may provide too little anesthetic agent, typically as a result of provider misuse. The most common outcome in the claims update was light anesthesia ($n = 14$) and overdose ($n = 3$) [8]. These claims were instances of the vaporizer not being turned on, failure to notice the vaporizer was empty, incorrect positioning or missing components, and vaporizer malfunction.

21.3.4 Supplemental Oxygen Supply

A spontaneously breathing patient in the immediate postoperative period should receive supplemental oxygen to correct hypoxemia associated with recovery from anesthesia and surgery. Unfortunately, provider error has accounted for all of the claims in this category [8]. Improvised techniques to deliver oxygen without proper tubing or mask were most common. Situations such as these events often result in barotrauma and pneumothorax. Additionally, mislabeled or misread gas tanks may lead to serious injury if another gas is mistaken for oxygen, such as carbon dioxide.

21.3.5 Anesthesia Machine

Anesthesia machine breakdowns do not typically result in significant adverse events. A proper anesthesia checkout should identify any machine failures before the case begins. For intraoperative failures, a backup machine should be on standby for emergencies. The anesthesia provider may be required to manually ventilate the patient while awaiting functioning equipment.

The categories described above should provide an adequate survey of the equipment failures and equipment misuses encountered on a daily basis. It requires an anesthesia provider to be ever vigilant to safeguard against his or her own omissions and errors as well as factors outside of his or her control.

21.4 Patient Injuries

In April of 1982, ABC's 20/20 aired an episode entitled "The Deep Sleep: 6,000 Will Die or Suffer Brain Damage." It would become a watershed moment for the practice of anesthesia. Not surprisingly, in the few years following the episode's release, the anesthesia community intensified their focus on patient safety. Organizations such as the ASA Committee on Patient Safety and Risk Management and the independent Anesthesia Patient Safety Foundation were formed to reduce

morbidity and mortality. The ASA Closed Claims database, created in 1985, collects closed malpractice claims for review so that sources of technical failure and human error can be identified. Rather than using resources to fight for tort reform, leaders in the 1980s began analyzing litigation as a way to improve the specialty. Anesthesiology is now considered to be one of the leading specialties in addressing patient safety [11].

For all the steps taken to ensure safety, adverse events do still occur that result in injury and occasionally death. Adverse events run a wide spectrum in anesthesia, ranging from oral injuries to peripheral nerve injuries to death and major disability [12]. Whether these events are the fault of the provider, the equipment, or the anesthetic itself is difficult to delineate. A recent study of gas delivery equipment claims found that provider error alone constituted the majority of claims (68%), while equipment failure accounted for a smaller portion (13%) and provider error with equipment failure made up the last 18% [8].

Of the 6022 claims reviewed by Mehta et al. in their closed claims update, only 0.2% involved equipment failure. Injuries associated with vaporizer malfunctions included light anesthesia with patient awareness and anesthetic overdose resulting in brain damage. Failure of the breathing circuit also commonly resulted in death/brain damage secondary to hypoxia. There was one reported case of a machine leak leading to hypoxia and cardiac arrest in a pediatric patient. There were no equipment failures associated with the supplemental oxygen supply and ventilators.

The drawback to only analyzing malpractice claims for patient injury is that less severe adverse outcomes may never end up as litigation. A large German quality assessment project attempted to standardize self-reporting by forming a list of 63 pitfalls, events, and complications (PECs) and defined five degrees of severity based on the outcome of each PEC [13]. Their report concluded that PECs caused by technical equipment was rare (0.07%), had no fatal outcomes, and were generally less severe.

In summary, equipment failures are often recognized by providers before injury occurs and subsequently go unreported. Therefore, those failures that are missed or that the provider had no control over tend to be more catastrophic resulting in death or brain injury.

21.5 Management of Anesthesia Equipment Failure

Anesthesia providers should display competency in the management of a variety of equipment failures. Development of this competency should occur during training through self-study, shadowing experienced anesthesia care providers, and simulation training. Significant improvement in provider training and equipment design has led to greater patient safety over the past several decades, and as a result litigation claims have seen a dramatic decline [8].

First and foremost, it is imperative to have a SIMVD and alternative oxygen source to deliver oxygen to the patient in the event of equipment failure ([8, 14–16].

21.5.1 Breathing Circuit Problems

Mehta et al.'s closed claims update revealed that 9.6% of critical incidents under anesthesia occur due to circuit leaks [8]. In these instances, a low-pressure alarm should notify the provider of the problem. Most instances are due to low pressure between the circuit and the patient, such as a circuit disconnect. However, the leak could be due to malfunction from the patient, such as an endotracheal tube (ETT) cuff leak, all the way to the machine, including the ventilator bellows, CO2 canister, vaporizer, flow sensor, or oxygen pipeline [16]. If a leak occurs, start at the patient and work backward to the machine to inspect for the source.

The first problem encountered may be a circuit leak due to ETT cuff tear. Alarms that may sound include the low-pressure alarm and the capnometer alarm. A leak may be detected by administering a breathing and hearing leak around the ETT. While troubleshooting, administer 100% FiO2 by manual ventilation. Check the pilot balloon for proper inflation, reinflate the cuff, and if the leak remains, exchange the ETT. This may be performed by simply removing the faulty ETT or placing a cook catheter to perform tube exchange. Moving toward the machine, a circuit disconnect or tear in the circuit tubing may be the reason for a low-pressure leak. Inspection of the circuit may reveal the disconnect or defect, and the circuit should be

repositioned or replaced [14]. Circuit leaks may also occur due to disconnect of the gas sampling line.

Obstruction in any given part of the breathing circuit may also occur and prevent inadequate oxygen delivery during anesthesia. Again, troubleshooting an obstruction should begin at the patient and work backward toward the machine. The anesthesia provider may be alerted by the high peak airway pressure alarm or capnometer alarm. Begin by auscultating the patient's lungs to rule out bronchospasm (treat with bronchodilator), pneumothorax (may require chest tube placement), or main stem intubation (reposition the ETT). The ETT should be suctioned to rule out mucous plugging or any other obstruction in the ETT. Kinking of the ETT may require replacement of a fresh ETT [14].

Circuit obstructions due to manufacturing defects have been reported [17]. Obstruction may also occur due to stuck inspiratory or expiratory valve or at the APL valve [8]. Inspect the valves for free movement during inspiration and expiration; consider changing the valves if residue is present. Consider placing a fresh circuit if concern for circuit obstruction due to kinking, secretions, or defective circuit exists.

Incidences of both circuit leaks and obstruction have been reported due to problems with the CO2 absorbent canister. Circuit leaks may occur if the canister is not properly seated, in which case the provider should be alerted by the low-pressure and capnometer alarm. Alternatively, obstruction may occur at the CO2 canister due to blockage from absorbent granules or a broken canister [18]. The CO2 canister should therefore be inspected for a leak due to improper positioning or obstruction due to any source, respectively.

Similarly, failure may occur at the level of the gas scavenging system. Fresh gas flows should be evaluated, conduits should be inspected, and obstruction should be evaluated for due to kinking, occlusion, or problems with the vacuum control or relief valves [16].

21.5.2 Ventilator

Failure to simply turn on the ventilator after induction, position changes, cardiopulmonary bypass, etc. may result in patient harm. Ventilator alarms should sound; however, these may be silenced. Ventilator settings should be confirmed and appropriate for the patient (neonate, pediatric, or adult settings) to ensure appropriate volume and pressure is being delivered [8]. If issues with the ventilator arise, manual ventilation should be performed until the issue is resolved.

21.5.3 Vaporizer

Failure to turn on or fill the vaporizer may result in light anesthesia; both of these issues are easily corrected. If vapor overdose is suspected, the patient should be ventilated with 100% oxygen until the end-tidal agent is appropriate and the vaporizer should be changed. If a leak is determined to be originating from the vaporizer, it should be inspected to ensure the caps are tightly sealed, O rings are appropriately positioned, and the vaporizer is properly seated [8, 14, 16].

21.5.4 O2 Supply

Significant patient harm may result due to misuse of oxygen supply equipment. If alarm malfunction is suspected, consider recalibration of the oxygen sensor or replacement with a fresh oxygen cell. If an issue exists with the main gas supply (suspicion of gas line crossover or failure), disconnect the anesthesia machine from the central supply, and turn on the backup oxygen tank located on the back of the anesthesia machine. Again, ventilating with a free standing oxygen tank may be necessary while troubleshooting occurs. Supplemental oxygen delivery materials should only be used as their manufacturer intended; improper use of oxygen delivery tubing, masks, nebulizers, or wrong gas tanks has resulted in significant patient harm [8].

21.5.5 Anesthesia Machine

If machine failure is suspected, the device should be removed from the patient care location and evaluated by a biomedical technician or other appropriate personnel.

21.6 Plan for Machine Failure

The best plan for anesthesia equipment failure is prevention. Equipment failure may be costly, with patient safety at risk, procedural delays, and added expenses for additional supplies and personnel [16].

Prevention begins with a complete machine check, realizing that due to variation in available anesthesia equipment, it is not possible to rely on one universal PAC. It is well established that simply performing the automatic self-test is incomplete and may miss a variety of equipment problems [17–19]. There are several recurring themes in the literature regarding closed claims from anesthesia equipment problems. First, it is imperative that a SIMVD and alternative oxygen source are present and functioning. Second, any steps in the pre-anesthetic machine checklist not automatically performed by the machine must be performed by the anesthesia provider, i.e., incorporating a "test lung" into the circuit, as well as performing the low-pressure leak test with each vaporizer on (Table 21.2).

Simulation training has been shown to expose knowledge gaps in dealing with equipment malfunction, as anesthesia technicians often perform a bulk of equipment maintenance and troubleshooting. Mudumbai et al. tested anesthesia trainees by presenting them with a scenario where a pipeline crossover existed between the central oxygen and nitrous dioxide. While most trainees recognized low FiO2 delivery, most did not recognize the elevated FiN2O. These exercises are important and again stress the necessity to switch to manual ventilation with an alternative oxygen source when central supply oxygen problems arise [15]. Similarly, Waldrop et al. simulated a number of scenarios involving anesthesia equipment failure for anesthesia trainees. They found that provider skills varied widely; however, senior residents performed better than their junior counterparts [14]. Approaching these situations through simulation rather than entirely during patient care, where seconds truly count, allows for better anesthesia provider training, self-evaluation, thorough feedback, and measurement of progress over time.

21.7 Review Questions

1. Your capnography tracing, which a moment ago displayed a normal capnogram with an $ETCO_2$ of 32, now reads zero. The low-pressure alarm sounds. What is your first step?
   A. Call for help.
   B. Silence the alarm, O_2 saturation is 100%.
   C. Check the CO2 canister.
   D. Check the patient circuit for a disconnect.

Table 21.2 PAC tasks to be completed prior to each procedure

	Task	Responsible party
Item #2	Verify patient suction is adequate to clear the airway	Provider and tech
Item #4	Verify availability of required monitors, including alarms	Provider or tech
Item #7	Verify that vaporizers are adequately filled and, if applicable, that the filler ports are tightly closed	Provider or tech
Item #11	Verify carbon dioxide absorbent is fresh and not exhausted	Provider or tech
Item #12	Perform breathing system pressure and leak testing	Provider and tech
Item #13	Verify that gas flows properly through the breathing circuit during both inspiration and exhalation	Provider and tech
Item #14	Document completion of checkout procedures	Provider and tech
Item #15	Confirm ventilator settings and evaluate readiness to deliver anesthesia care (anesthesia time-out)	Provider

2. Which of the following is true regarding the pre-anesthesia checklist?
   A. The ASA checklist is updated regularly and applicable to all anesthesia delivery machines.
   B. Anesthesia providers must perform several steps manually for completion.
   C. Machines with automated checklists will perform the entire recommended check.
   D. Both anesthesia providers and technicians should perform each step in the checklist.

3. Which of the following is the leading cause of patient harm due to anesthesia equipment issues?
   A. Provider error
   B. Provider error and equipment malfunction
   C. Equipment malfunction
   D. None of the above

21.8 Answers

1. D – The anesthesia provider may be alerted to a circuit leak by both the capnography and low-pressure alarms. When a leak occurs, the provider should place the patient on 100% FiO_2 and inspect for the source of the leak starting at the patient and working backward toward the machine. Common causes include ETT cuff leak, circuit disconnect, and CO_2 or vaporizer malposition. Silencing of patient alarms leads to delays in recognition and management of equipment failure. If initial troubleshooting does not resolve the issue, the patient should be oxygenated with a SIMVD and alternative oxygen source, and the provider should call for additional help.

2. B – ASA Recommendations for Pre-Anesthesia Checkout Procedures is meant to merely serve as a template for organizations to develop their own facility-specific pre-anesthesia checklists. The automated check does not fulfill all of these checkout procedures, and there are several steps that must be performed manually to fully ensure proper function. The checklist is divided into tasks that should be performed by the anesthesia provider, technician, and both.

3. A – Provider error is cited in a majority of anesthesia closed claims related to equipment problems, with most occurrences happening in the absence of equipment failure. One-third of these claims could have been prevented by a proper pre-anesthesia checkout.

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Perioperative Medication Errors

Blas Catalani, Steven Boggs, and Ezekiel Tayler

C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_22

sola dosis facit venenum
"The dose makes the poison"
Paracelsus (1493–1541)

22.1 Introduction

There has always been a necessary balance in medicine between the principles of diagnosis and treatment. However, the resources required to achieve such a balance are constantly changing. While the applied elements of medical diagnostics continue to evolve scientifically, the selection and delivery of a particular treatment regimen still require a human touch. Accordingly, at its most fundamental level, the successful delivery of a specific therapeutic intervention and the prevention of error require administration of the correct medication in the correct dose via the correct route at the correct time to the correct patient. These fundamental steps are made increasingly difficult by the ever-expanding diversity and variable potency of medications available to practitioners.

To appreciate the magnitude of medications use in the United States, data from the Centers for Disease Control and Prevention (CDC) [1] shows that:

- From 2011 to 2014 the percentage of persons:
  - Using at least one prescription drug in the past 30 days: 48.9%
  - Using three or more prescription drugs in the past 30 days: 23.1%
  - Using five or more prescription drugs in the past 30 days: 11.9%
- Among physician office visits (2015):
  - Number of drugs ordered or provided: 3.7 billion
  - Percent visits involving drug therapy: 76.2%
  - Most frequently prescribed therapeutic classes: analgesics, antihyperlipidemic agents, antidepressants
- Among emergency department visits (2014):
  - Number of drugs ordered or provided: 317.6 million
  - Percent of visits involving drug therapy in emergency departments: 79.6%
  - Most frequently prescribed therapeutic classes: analgesics, antiemetic or antivertigo agents, minerals, and electrolytes

Annually in the United States, an estimated 7000 deaths result from preventable medication errors [2]. The Network for Excellence in Healthcare Innovation (NEHI) calculates that there are over 3.8 million medication errors on inpatients each year [3], and the cost of these errors is approximately $4.2 billion annually [4]. Lahue and colleagues [5] estimate that inpatient preventable ADEs associated with injectable medications increase the annual US payer costs by $2.7–5.1 billion and average $600,000 in extra costs per hospital.

The sheer number of prescribed medications administered worldwide leads to the large capacity for errors in administration. In the United States alone, the total number of dispensed medical prescriptions has grown annually from 3.953 billion in 2009 to 4.453 billion in 2016 [6]. Even with six sigma performance (an error rate of 3.4 defects per million opportunities), medication errors would still occur in 1309 cases with the aforementioned US prescription data in the setting of pharmacy-regulated processes for dispensing medications. Even in such a regulated environment, it is unlikely that six sigma performances could be obtained. Additionally, this data does not account for medication administration within hospitals which shifts perspective to highlight the overall volume of medications administered and underscore the obstacle to eliminating medication errors.

It is important to note that the probability that an error will occur is influenced substantially by the quality of the handoff of care between providers [7]. The error rate increases as the total number of patient care handoffs between providers increases [8]. This informs an appreciation for data reflecting the incidence of perioperative medication errors. Staender and Mahajan estimate the overall incidence of minor events or complications during anesthesia to be 18–22%, while the incidence of severe complications is approximately 0.45–1.4%, and mortality occurs at a rate of 1:100,000 anesthetics [9]. Nanji et al. reported 5.3% of medication administrations during 277 operations involved a medication error and/or an adverse drug error (a rate consistent with previous studies) and of those errors, 79.3% were preventable [10]. These errors have also been found to be (unsurprisingly) higher among anesthesia providers with less experience (e.g., trainees) [11].

In evaluating the perioperative medication error rate, one must recognize the limitations of the data and identify likely barriers to comprehensive reporting of medication errors. The most prominent barriers include lack of awareness on the part of the provider that they have committed an error, an insufficient (or total lack of a) reporting infrastructure, fear of punishment for self-reporting a medication error (regardless of patient outcome), and provider apathy.

22.2 What Is a Medication Error?

To give some structure to an analysis of medication errors, we must first define certain terms.

MEDICATION: A "medication" is a product that contains a compound with proven biological effects, plus excipients or excipients only. A medication is administered as a placebo, to prevent disease, to diagnose illness, to modify physiological function, to treat a disease, or to induce and maintain anesthesia [12].

ERROR: Pertinent definitions for "error" describe an act of unintentional deviation from truth or accuracy that may be committed through ignorance, deficiency, or accident and fails to achieve what should be done. Importantly, an error may produce something by mistake [13].

MEDICATION ERROR: Ferner and Aronson (2006) emphasize that "medication errors" are failures in the treatment process that leads to, or has the potential to lead to, harm to the patient [14].

When a medication error occurs along, the "continuum of medication use" must be defined. Accordingly, medication errors can occur during the following time periods on this continuum:

- Manufacturing
- Compounding
- Prescription (i.e., medication selection by a provider)
- Transcription (i.e., actual writing of a prescription by a provider)
- Distribution/dispensing (i.e., obtaining the medication by the patient; e.g., pharmacy fills a prescription)
- Administration (i.e., delivery to the patient's body; e.g., IV, PO, PR, IM, SQ, TD, topical, SL)
- Monitoring following administration

22.3 How Is a Medication Error Classified?

Many methods of categorizing and stratifying medication errors have been proposed. When considering how to classify drug-related events, there are two constructs one can use to categorize medication errors (ME), adverse events (AE) and adverse drug reactions (ADR).

Option 1: Ackroyd-Stolarz et al. (2006) propose a simplified system which separates drug-related problems (DRPs) into those which are associated with injury and those which are not [15] (Fig. 22.1).

Option 2: Aronson and Ferner formulate a system with medication errors (MEs) which do not cause adverse events (AEs), AEs that are not reactions to medications and each possible permutation including adverse drug reactions (ADRs) [12, 14] (Fig. 22.2).

In both models, it is emphasized that "near misses" and events that do not cause actual injury are not to be minimized, as they may be harbingers of defective systems and can be used to prevent adverse events in the future.

Option 3: The Agency for Healthcare Research and Quality (AHRQ) describes a series of categories into which a medication error can be classified but does not utilize the familiar ME/ADE/ADR terms. Instead, it describes scenarios that exemplify the error category being described [16] (Table 22.1).

In all cases, further classification of the actual cause of the error can and must be made. Ferner and Aronson go so far as to delineate the psychological origins of an error and differentiate between "mistakes," "slips," and "lapses" on the part of the provider [12, 14] (Fig. 22.3).

22.4 Perioperative Medication Errors and Anesthesiology

From the perspective of anesthetic practice, medication errors beyond provider control must be discounted (e.g., manufacturing, compounding). In turn, emphasis must be placed on types of medication errors which occur with greater frequency in the perioperative environment. The circumstances in which a patient and anesthesia provider encounter one another create a role

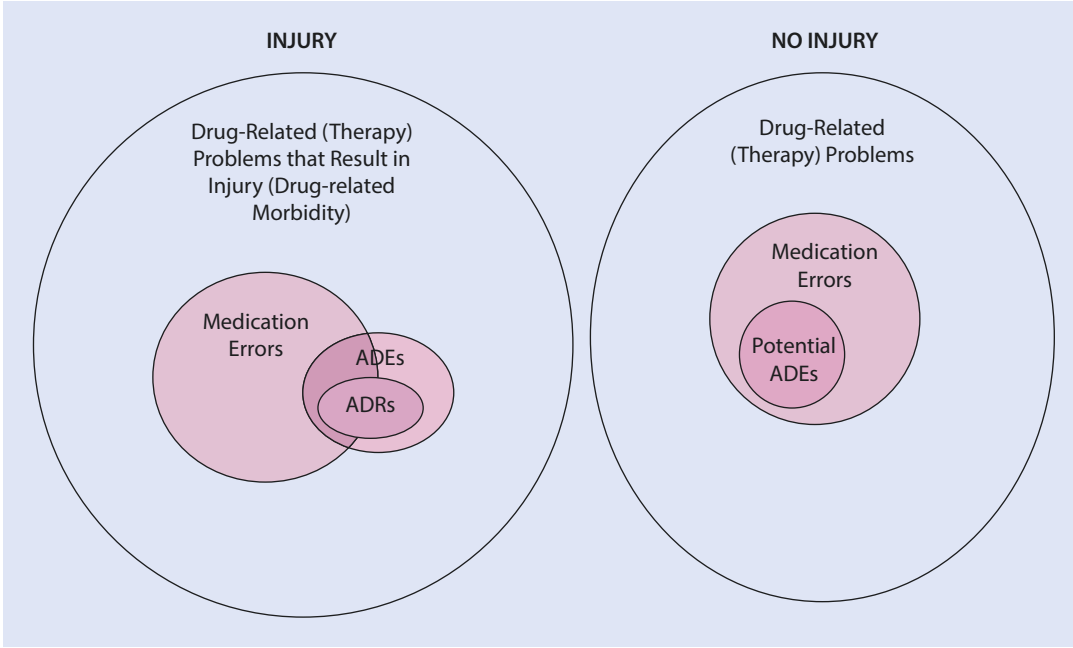

Fig. 22.1 Relationships between the different types of problems associated with medication use. All of the shaded circles are also considered to be medication misadventures. Drug-related morbidity is always the result of some DRP; however, only some DRPs result in injury. All medication errors are classified as ADEs when injury occurs, but it is still important to distinguish between medication errors and ADEs for the purpose of this diagram because not all ADRs result from medication errors. (Above Figure (Fig. 22.1 per caption) from Ackroyd-Stolarz et al. 2006. PMID: 17138513 ▶ https://www.ncbi.nlm.nih.gov/pubmed/17138513)

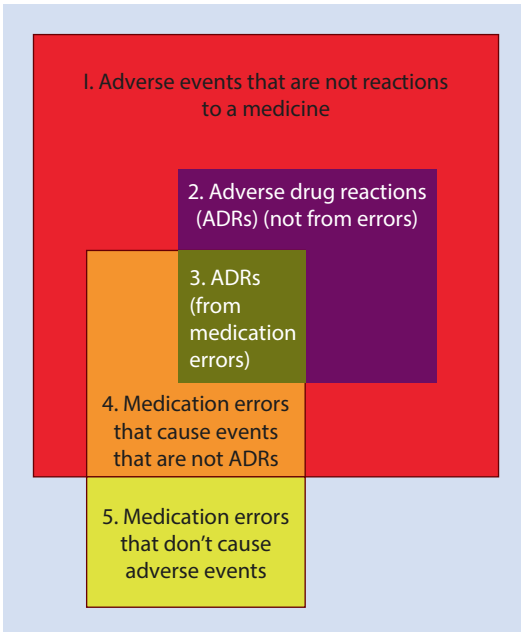

Fig. 22.2 A Venn diagram showing the relation between adverse events, adverse drug reactions, and medication errors; the sizes of the boxes do not reflect frequencies of the events illustrated. (Figure 22.2 from Aronson 2009 PMID: 19594526 (sourced by Aronson from a collaboration article: Ferner and Aronson [14], PMID 17061907))

for those providers that is singular among practitioners in that they may draw up, dilute and administer medication without the participation of an intermediary pharmacist, nurse, or the patient themselves.

For the purposes of consistency between specialties and patient care environments, the terminology related to medication errors as a function of the occurrence on the aforementioned "continuum of medication use" must be redefined in terms of the provision of anesthesia:

- "Prescription" of a medication by an anesthesia provider (MD, CRNA) will refer to the *decision* to treat a patient circumstance (e.g., elevated blood pressure) with a particular medication (e.g., nitroglycerin).
- "Distribution/dispensing" will refer to the actual *procurement and manipulation* of a medication (e.g., picking up a medication vial and drawing into a syringe).
- "Administration" will continue to refer to the actual *delivery* of the medication to the patient (e.g., into the IV line, onto/into the patient's skin/muscle/membranes, etc.).

Table 22.1 AHRQ categories of medication error classification – MATCH toolkit for medication reconciliation. (Agency for Healthcare Research and Quality (▶ http://www.ahrq.gov/professionals/quality-patient-safety/patient-safety-resources/resources/match/matchtab6.html))

Category	Description	Example
A	No error, capacity to cause error	NA
B	Error that did not reach the patient	NA
C	Error that reached patient but unlikely to cause harm (omissions considered to reach patient)	Multivitamin was not ordered on admission
D	Error that reached the patient and could have necessitated monitoring and/or intervention to preclude harm	Regular release metoprolol was ordered for patient instead of extended release
E	Error that could have caused temporary harm	Blood pressure medication was inadvertently omitted from the orders
F	Error that could have caused temporary harm requiring initial or prolonged hospitalization	Anticoagulant, such as warfarin, was ordered daily when the patient takes it every other day
G	Error that could have resulted in permanent harm	Immunosuppressant medication was unintentionally ordered at one-fourth the dose
H	Error that could have necessitated intervention to sustain life	Anticonvulsant therapy was inadvertently omitted
I	Error that could have resulted in death	Beta-blocker was not reordered postoperatively

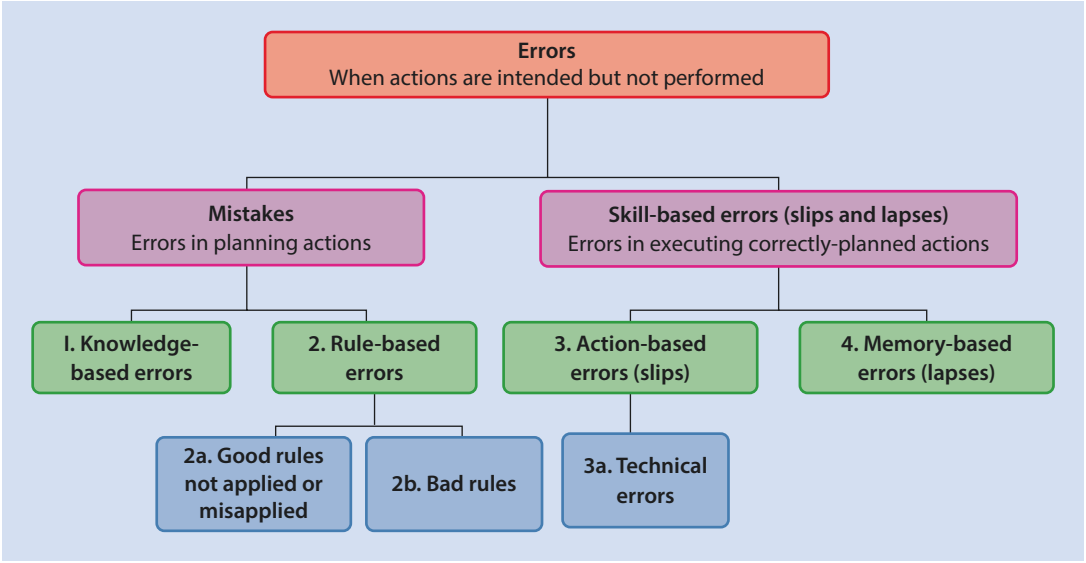

Fig. 22.3 The classification of medication errors based on a psychological approach. (Figure 22.3 from Aronson 2009 PMID: 19594526 (sourced by Aronson from a collaboration article: Ferner and Aronson [14], PMID 17061907))

- "Transcription" will refer to *documentation* of a medication administration (and thus must be placed after the administration event in the perioperative care setting).
- "Monitoring following administration" will continue to refer to continual evaluation of the patient after drug administration for desired effect and/or adverse drug effects/reactions (ADEs/ADRs).

22.4.1 Taxonomy of Anesthesia-Related Medication Errors (Fig. 22.4)

22.4.1.1 Perioperative (Pre-/Post-op) and Intraoperative (Operating Rooms and Labor and Delivery)

Prescription (decision)-related medication errors in the perioperative setting are largely due to one of three inciting events:

- Treatment without consideration of patient factors (e.g., failure to recognize patient drug allergies when deciding to treat; failure to perform a comprehensive medication reconciliation)
- Improper dosage of the correct medication (e.g., selection of milligram/mg dosing where micrograms/mcg are indicated)
- Improper duration of action for desired effect (e.g., treatment of acute/short-lived derangements with long-acting medications and vice versa):
- **Prevention strategy:**
  - Performing a comprehensive preoperative medication reconciliation
  - Electronic medical record (EMR) alerts to draw provider attention to relevant patient contraindications or drug minutiae
  - Proper forethought/planning to ensure the most appropriate medications that are available

Medication errors related to *distribution/dispensing (procurement/manipulation)* can result from:

- Failure to dilute properly (e.g., phenylephrine, insulin)
- Sound-alike medications (dopamine vs. dobutamine)
- Look-alike (phenylephrine vs. ephedrine) (Fig. 22.5)
- Similar-colored labeling (even on prepackaged medications) (Figs. 22.6, 22.7, and 22.8)
- **Prevention strategy:**
  - Tall-man lettering (DOPamine vs. DOBUTamine)
  - Pharmacy preparation of prepackaged, prelabeled syringes, or any infusions needed
  - Pharmacy placement of ALERT labels on look-alike, sound-alike medications (refer to Fig. 22.4)

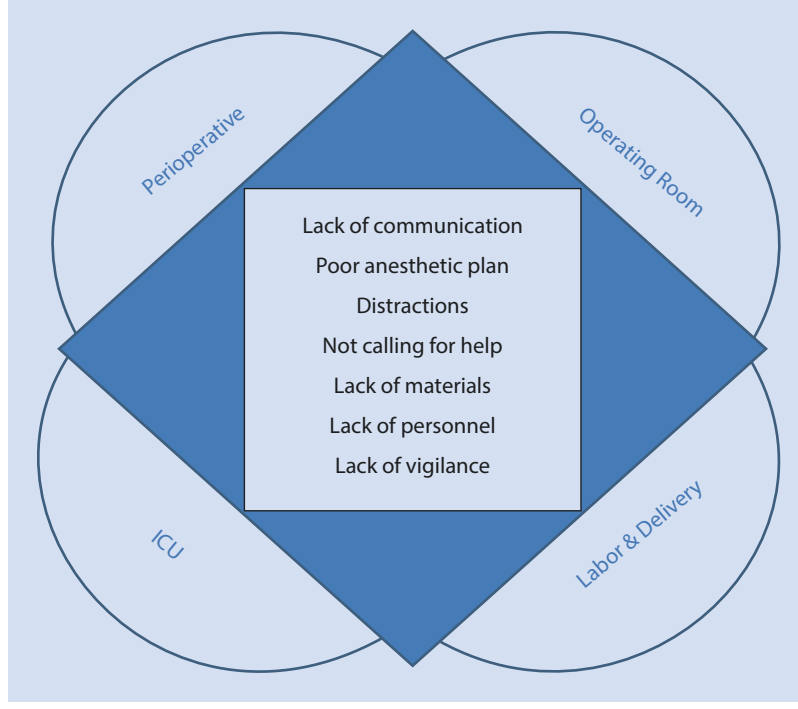

Fig. 22.4 Key elements of perioperative care and common circumstances that may lead to an anesthetic "error". (Image courtesy of Dr. Ezekiel Tayler)

Fig. 22.5 Look-alike labeling within the same drug class. (Photo courtesy of Dr. Blas Catalani)

Fig. 22.6 Look-alike labeling between two entirely different medications. (Photo courtesy of Dr. Blas Catalani)

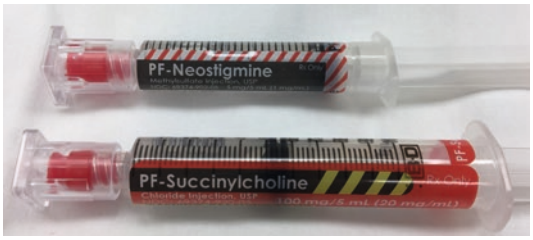

Fig. 22.7 Another example of look-alike labeling between two entirely different medications this time with the same volume despite different syringe sizes. (Photo courtesy of Dr. Blas Catalani)

- Bar code scanning with computer confirmation of medication prior to opening of vials/drawing up drug into a syringe

Administration (delivery)-related medication error occurs in all three phases of perioperative care (pre-, intra-, postoperative) when providers fail to consistently adhere to what the AHRQ refers to as the "five rights" [17] – administration of the:

- Right medication, in the
- Right dose, at the
- Right time, by the

Fig. 22.8 Look-alike vial sizes and cap colors with minor differences in labeling between entirely different medications. (Photo courtesy of Dr. Blas Catalani)

- Right route, to the
- Right patient
- **Prevention strategy:**
  - Adherence to the "five-right" confirmation protocol
  - Reducing perioperative distractions
  - Multiple patient identifiers (wristbands, time-out protocols)

Lastly, errors related to *transcription (documentation)* can result in myriad ADRs due to absent, incomplete, or inaccurate documentation leading to:

- Repeat dosing of recently dosed medication (with or without ADEs)
- Subsequent overdose (e.g., narcotics, antiemetics) or sustained/potentiated effects (e.g., paralytics, antihypertensives) of certain medications
- **Prevention strategy:**
  - Computerized/electronic medication administration record (eMAR) to facilitate review of administered medications across multiple venues (pre-, intra-, post-op)
  - Bar code scanners linked to eMAR
  - Timely documentation of medication administrations by provider

22.4.1.2 Intensive Care Unit (ICU)

Unless specifically boardcertified in care critical care, the presence of an anesthesiologist within the intensive care unit (ICU) may be segregated

into transporting patients to and from the unit for surgical procedures, emergent situations (e.g. airway management), or acute pain management. The nature of anesthesia care is focused on the management of sick and debilitated patients. Accredited anesthesiology residency programs mandate 4 months of critical care exposure [18] for this reason. The ICU is a dynamic environment with multiple layers of healthcare providers, which opens the door to numerous potential errors. With more variables in the system, medical errors in the ICU have been well documented [19–22]. As a consultant walking into such an environment, an anesthesiologist should have a good understanding of the inner workings of the ICU and who to speak with when questions arise.

Meticulous attention must be made to the types of drugs infusing into the patient and to which lines they are infusing. Once the patient leaves the ICU, the anesthesiologist is responsible for the types of drugs administered and the routes in which they flow. All medications should be accounted for prior to leaving the ICU and documented upon arrival to the OR if actively infusing. Physicians and nurses must anticipate and prevent foreseeable events. As an example, patients should not be discharged from the ICU with vasoactive medications that could run out during transport. In an elevator or other location, this could lead to a cardiac arrest or anoxic event due to hypotension. Another error could involve a patient on total parenteral nutrition. Failure to check glucose levels and to administer insulin therapy throughout a case could result in hypoglycemia and seizure activity without clinical manifestation if paralytics are used. When it comes to management of invasive lines/catheters, vigilance is essential. Connecting an intravenous catheter (IV) to an existing thoracic epidural would have disastrous consequences.

Upon returning a patient to the ICU after an OR procedure, a proper sign-out should occur directly between the anesthesia provider and both the ICU attending for medical/surgical issues and the ICU nurse assigned to care of the patient. In particular, a review of all medications actively infusing, identification of the lines into which they are infusing, and notation of any recent bolus medications (e.g., paralytics, analgesics, etc.) should be discussed. It is imperative that drug concentrations are noted and that the ICU knows what they are. They may have to obtain different concentrations of drugs to ensure compatibility with the ICU pumps and protocols, so that pumps can be programed correctly. Unfamiliar concentration parameters (e.g., mcg/kg/min vs. mg/min vs. cc/hr) and/or improper pump settings can confuse management among the staff. The opportunity should be given to the receiving care team to have all questions answered prior to the departure of the anesthesia provider from the ICU. At the end of a long, challenging surgical and anesthetic case, there is a strong tendency to have a hasty sign-out. However, less than full sign-out can lead to future errors in patient management and outcome.

In an emergent situation, despite any chaos surrounding a patient, one should seek out a nurse, resident, or physician responsible for the patient and ask about drug allergies, the cause of current medical condition(s), and any knowledge of difficult airway issues from the past. A perfect example of an attempt to prevent a non-error adverse drug reaction is the selection of a non-depolarizing paralytic (NDP) agent over succinylcholine in an airway emergency. A decision to use a NDP over succinylcholine could ostensibly prevent the potential ADR of succinylcholine-induced hyperkalemic cardiac arrest; most patients in the ICU have been immobile for some period of time leading to the proliferation of extrajunctional acetylcholine receptors. Fortunately, with the introduction of sugammadex, this decision can be made more liberally in institutions that have this medication that has been relatively newly released in the United States. The principle holds, however, that sometimes a question that takes 15–30 s to answer can mitigate catastrophic consequences.

If a hospital utilizes an acute pain service (APS), then an ICU could be the site for the placement of innumerable types of pain control regimens. ICU nurses may not be credentialed to manage epidurals, ketamine infusions, or nerve block catheters, so orders and management for such interventions may fall solely on the anesthesiologist. Aside from giving the wrong dosage and/or incorrect medication to a patient, there are many system breakdowns that can occur while managing an APS. Many providers will allow for the consulting physicians to enter orders, but these orders must be checked against existing order sets. A patient in severe chest pain who receives a thoracic epidural or continuous peripheral nerve block catheter may not need a patient-controlled

analgesic (PCA) anymore, or it need only be continued at a much lower dose. If the PCA is not addressed, respiratory depression (or arrest) could occur. Nerve catheter sites should be checked daily, and communication with the nursing staff about their existence should occur routinely. Additionally, nurses may not know the signs/symptoms of local anesthetic toxicity or location of lipid emulsion. If a paging system or other route of communication is not set up by the APS, harm could be brought to the patient without any notification of the APS. It is important to take ownership of the patient, medications, and devices to provide competent and safe care.

22.5 Summary

The scope of perioperative care is vast, and, consequently, the potential for medication errors to occur in these areas is likewise extensive. There are numerous primary attendings, consulting physicians, fellows, residents, nurses, medical students, and support personnel all caring for patients whose clinical complexity ranges from simple procedures to those with the most complex multifactorial, surgical, and medical diseases. With all of the possible interactions, the potential for errors is significant. To distill all of the lessons in this chapter, communication is the fundamental key to reduce ADRs. It is more important to ask twice than act once. The consequences of perioperative medication errors, according to Wahr et al., "require that vigorous attempts be made to assess vulnerabilities in medication safety that exist in our operating rooms" [23]. It is imperative that healthcare providers involved in "continuum of medication use" continue strive for continual reduction in the rate of medication error occurrence and thereby improve patient outcomes.

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Physiologic Monitoring: Technological Advances Improving Patient Safety

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_23

23

Key Points

- The ASA has established guidelines for basic monitoring of four parameters during anesthesia: circulation, ventilation, oxygenation, and temperature.
- The standard ASA monitors provide no way to measure certain aspects of the circulatory system such as preload, afterload, contractility, cardiac output, stroke volume, etc.
- The gold standard for measuring cardiac output is thermodilution. While standard measurement requires a PA catheter, newer methods such as pulse contour analysis have allowed minimally invasive technologies to proliferate.
- Transesophageal echocardiography (TEE) is a helpful tool for real-time interpretation of cardiac function. TEE is the single most sensitive tool for monitoring wall motion abnormalities. Its major drawbacks are availability and the learning curve required for proper use.
- Depth of general anesthesia (DGA) monitoring extrapolates frontal lobe electroencephalogram data to quantify the level of consciousness. While data is limited, DGA has been shown to be useful in certain patient populations.

Case

A 52-year-old male with a past medical history including nonalcoholic steatohepatitis, end-stage liver disease, hyperbilirubinemia, coagulopathy, and hypertension undergoes orthotopic liver transplantation. After the patient is anesthetized, radial and femoral arterial lines, a central venous catheter, and TEE probe are placed for intraoperative monitoring. Rather than place a Swan-Ganz catheter, the anesthesiologist decides to use the new FloTrac system the hospital has just purchased.

The new liver is reperfused, starting the neohepatic phase. Vasopressor requirements increase. Consistently, the FloTrac reads very low values for cardiac output. Unaware that the FloTrac is inaccurate in low-resistance pathologies like cirrhosis and in hemodynamically unstable patients, the anesthesiologist decides to give more volume. After four additional liters of crystalloid and blood products, the cardiac output improves, but the central venous pressure rises significantly.

Suddenly, the patient's blood pressure drops precipitously. Transesophageal echocardiography is begun, revealing a grossly enlarged right ventricle that appears hypokinetic. The left ventricle seems normal to slightly enlarged. The patient goes into cardiac arrest. Compressions begin. After 30 min of ACLS, the patient expires.

Afterward, the surgeon asks the anesthesiologist what happened.

"Enlarged right ventricle – um, probably a PE," says the anesthesiologist. "And to think, I even used our new FloTrac device."

Autopsy is negative for pulmonary embolism. The patient died from right heart failure.

23.1 Introduction

Monitoring the patient during the perioperative and intraoperative periods is the essential role of the anesthesia provider. Technological advances in anesthetic monitoring over the past several decades have made delivery of anesthesia considerably safer [20]. As a result, the American Society of Anesthesiologists has established guidelines recommending standard monitoring of oxygenation, ventilation, circulation, and body temperature. Monitoring oxygenation requires use of variable-pitch pulse oximetry and quantification of oxygen delivery in the fresh gas flow. Ventilation is either assessed qualitatively or via capnography if an advanced airway is in place. Circulation is monitored via electrocardiogram and blood pressure measurements. Temperature can be measured anywhere in the body without a specified location. These are minimum standards, and the complexity of the case will dictate using more advanced clinical tools capable of measuring more variables, with finer precision, in time-sensitive fashion, using the least invasive means possible [2].

Especially over the last decade, physiologic monitoring technology has expanded well past

the confines of standard ASA monitors to become a major industry. In fact, the global market for anesthetic monitoring devices was valued at $820 million in 2014 and is forecast to balloon to $1.61 billion by 2020 [22].

With the vast array of products on the market, it is essential that the modern anesthesiology provider familiarize him or herself with these products, their indications, and potential pitfalls. To avoid the impracticality of discussing every product on the market, this discussion is limited to more of the common physiologic monitors available: advanced cardiac monitors and depth of general anesthesia monitors. Proper implementation of these devices may help prevent myriad clinical disasters.

23.2 Basic Science

23.2.1 Circulation

The circulatory system operates analogously to an electrical circuit. Cardiac output (CO), blood pressure (BP), and systemic vascular resistance (SVR) correspond to current (*I*), voltage (*V*), and resistance (*R*), respectively. Accordingly, Ohm's law:

$$V = I \times R$$

can be adapted to [5]

$$\mathrm{BP} = \mathrm{CO} \times \mathrm{SVR}$$

For purposes of calculation, BP = mean arterial pressure (MAP) − central venous pressure (CVP).

$$\mathrm{MAP} - \mathrm{CVP} = \mathrm{CO} \times \mathrm{SVR} / 80$$

CO is the product of heart rate (HR) and stroke volume (SV). The latter is dependent on preload, afterload, and contractility. The coefficient, 80, in the above equation is to adjust for the proper units [18]. As stroke volume is dependent on preload, afterload, and contractility [46], a more complete picture of the circulatory system is therefore expressed:

$$\mathrm{MAP} - \mathrm{CVP} = \mathrm{HR} \times \mathrm{SV}$$
$$\{\text{preload, afterload, contractility}\} \times \mathrm{SVR}$$

Using standard ASA monitors, MAP is measured with conventional oscillometric or invasive blood pressure monitoring, and HR can be determined from EKG. However, CVP, preload, afterload, contractility, and SVR are not typically measured. In the event of sudden hypotension with no change in heart rate, standard monitoring therefore leaves several variables unaddressed [1].

23.2.2 Ventilation

Ventilation is the movement of air during respiration, the purpose of which is to deliver extrinsic gas (oxygen, anesthetic, etc.) into the circulatory system via the alveoli. Modern anesthesia machines will automatically quantify respiratory rate, tidal volumes, and minute ventilation. Capnography (CO2 monitoring) serves as a confirmation of gas exchange at the level of the alveolus [29]. More subtly, capnography also confirms ongoing perfusion of the tissues, as CO2 is the essential byproduct of metabolism. However, capnography measured via end-tidal CO2 (PETCO) varies from arterial CO2 (PaCO2) because of dead-space ventilation. Furthermore, PETCO can be affected by changes in tidal volume, respiratory rate, fevers, hyper- or hypocatabolic state, pulmonary emboli, cardiac output, inadequate CO2 reabsorption, and sampling error [28].

23.2.3 Oxygenation

Oxygenation is the measure of oxygen delivery (DO2) to the tissues. Essential components of this process are:

1. Delivery of oxygen-rich fresh gas flow
2. Adequate ventilation to deliver this oxygen to the alveoli
3. Diffusion of alveolar oxygen into the blood stream
4. Uptake of dissolved oxygen by hemoglobin
5. Transport of hemoglobin to the tissues via convection
6. Diffusion of oxygen bound to hemoglobin from the capillary to cell in sufficient quantity to meet metabolic demand [45]

Standard monitoring measures this process at only two locations: the delivery of fresh gas at the level of the machine (1) and pulse oximetry (5).

23.2.4 Temperature

Despite being a standard ASA measurement, there is no standard location recommended for taking the patient's temperature. This can be problematic as temperature can vary by several degrees based on location of measurement. Temperature independently affects immune function, clotting, metabolic rate, and blood chemistry. Further, the complications of hypothermia can include increased risk of cardiac morbidity, coagulopathy (and thus risk of transfusion), delayed wound healing, and prolonged hospitalization [36].

23.2.5 Depth of General Anesthesia (DGA)

While the ASA has no guideline on monitoring anesthetic depth, modern anesthesia machines utilize mass spectrometry to measure the inspired and expired concentrations of anesthetic gas. These values are compared to the mean alveolar concentration (MAC), the average expired gas concentration that will prevent 50% of patients from moving to a surgical stimulus, to determine anesthetic depth. However, what MAC value guarantees unconsciousness, recall, or lack of movement varies by individual [3]. Accordingly, more advanced techniques seek to avoid anesthesia awareness by measuring depth of general anesthesia (DGA). These technologies focus on frontal lobe EEG and auditory evoked potential analysis. These modalities are increasingly becoming routine measures for DGA [9].

23.3 Advanced Cardiac Monitoring

Cardiac output (CO) can be used to calculate stroke volume (SV) and systemic vascular resistance (SVR) based on parameters already measured via standard ASA monitors (HR and MAP) and equations previously elucidated: SV = CO/HR and SVR = CO/(MAP − CVP). HR can be easily determined from ECG, plethysmograph, or arterial line. MAP is measured throughout every case via cuff or arterial line. Technology has been developed to accurately determine CO in clinical situations because of the extra clinical information this data point can provide [46].

23.3.1 Thermodilution

First described by Fegler in 1954, "thermodilution" measures CO by analyzing changes in local blood temperature following the bolus of cold solution [14]. Injecting fluid (usually 10 cc of either cooled or room temperature solution) into the proximal port of a pulmonary artery catheter momentarily alters the blood temperature in the right atrium. With each cardiac cycle, the cooled bolus is diluted into the remainder of the blood volume until no further temperature deviation is present. When graphed over time, the area under the temperature change curve is inversely proportional to the CO [25].

The CO can be calculated using the Stewart-Hamilton equation:

$$Q = \frac{V \times \left(T_b - T_i\right) K_1 \times K_2}{T_b\left(t\right) dt}$$

where

Q = cardiac output

V = volume of injectate

T_b = blood temperature

T_i = injectate temperature

K_1 and K_2 = corrections for specific heat and density of the injectate and for blood and dead-space volume

$T_b(t)\ dt$ = area under the curve of temperature change over time [25].

While this calculation is considered the gold standard of cardiac output calculation, some considerations arise:

1. Placement of a Swan-Ganz catheter is required [16].
2. Quantity and speed of injection should be constant for serial measurements.
3. CO varies with respiration, so it is recommended that measurements be taken at the same phase of the respiratory cycle.
4. The basic assumptions of thermodilution can be undermined by severe tricuspid regurgitation, an intracardiac shunt, or other IV fluid entering the heart at the same time [27].
5. While cold solution (0–4 °C) elicits a better measurement than room temperature solution, colder temperatures may induce bradycardia and cause a decrease in cardiac output [23].

23.3.2 Continuous Cardiac Output (CCO)

A modified pulmonary artery catheter developed by Edwards Lifesciences measures cardiac output on a continuous basis. Relying on the same scientific principles as thermodilution, these catheters use imbedded copper filaments to heat a small portion of blood in the right ventricle. The resultant temperature change is recorded by a thermistor at a more proximal point on the catheter [24]. Advantages to using this technique include the automatic data generation and the avoidance of repeated fluid boluses into the heart, as these boluses carry the risk of infection and over time alter the patient's blood volume. Although thermodilution is considered the clinical gold standard, CCO has been adopted at many institutions because of its ease of use and reliability. Studies have shown that CCO technology correlates well to manual thermodilution methods [21].

23.3.3 Pulse Contour Analysis

In 1904, Erlanger and Hooker introduced the principle that CO is proportional to arterial pulse pressure. Pulse contour analysis takes this idea further, analyzing the shape of the arterial waveform and area under its systolic portion as corollaries to CO. As each systolic ejection of the heart is analyzed, SV can be determined beat to beat. When multiplied by HR, the CO can be determined [24].

The major advantage of pulse contour analysis is its minimally invasive profile. Namely, a pulmonary artery catheter is no longer required to measure cardiac output. This technology therefore avoids the potential complications associated with the PA catheter: infection, cardiac arrhythmias, breakage or knotting of the catheter, and trauma to or even rupture of the pulmonary arteries [13]. The devices that rely on pulse contour analysis utilize an arterial line, either in isolation or in conjunction with a venous cannulation site [16].

Since cardiac output is determined exclusively from the shape of the arterial waveform, a high-fidelity signal must be assured. An overdamped or underdamped signal will render the remainder of the analysis unreliable [24]. Cardiac arrhythmias (e.g., atrial fibrillation) can also cause unreliable results. Severe aortic insufficiency will also cause overestimation of CO. If an intra-aortic balloon pump (IABP) is present, CO will be overestimated – as the inflation of the pump will be erroneously factored into the HR – and the stroke volume created by the pump will be included in the measurement [21].

As SV varies with the phases of the respiratory cycle, the important variable of stroke volume variation (SVV) can be introduced. SVV is defined as the percentage change in SV between its relative maximum and minimum within the respiratory cycle. SVV has been validated as an indicator of patient fluid responsiveness. In general SVV < 10% indicates a patient unlikely to benefit from fluid administration. In contrast, SVV > 15% indicates a patient who would likely benefit from fluid administration [11].

23.3.3.1 PiCCO System

The pulse index continuous cardiac output (PiCCO) system utilizes both transpulmonary thermodilution and pulse contour analysis to calculate cardiac output. It requires both central venous and arterial cannulation. Thermodilution is used for calibration of the device, which must be done every 8 h. A cold fluid bolus is injected into a central line. Temperature changes are detected by a thermistor attached to a specially designed arterial line (usually placed in the femoral artery). Once calibrated, continuous cardiac output is then calculated based on pulse contour analysis [16]. In addition to cardiac output, the PiCCO system calculates global end-diastolic volume, intrathoracic blood volume, and extravascular lung water, global ejection fraction, contractility, and SVR [24].

PiCCO has been studied extensively and found to correlate well with traditional thermodilution in most cases. Its use is less reliable in aortic aneurysms, severe valvulopathies, during periods of rapid temperature change, and with the use of an IABP [16, 21].

23.3.3.2 LiDCO System

The lithium dilution cardiac output (LiDCO) system uses a variation of thermodilution, measuring dilution of lithium rather than changes in temperature. Lithium is injected into a central or peripheral vein, and its concentration is detected in a peripheral arterial line [11]. Two versions exist: LiDCO *plus* and LiDCO *rapid*. With LiDCO *plus*, lithium is used to calibrate the system, which

needs to be done every 8 h, similar to PiCCO [21]. LiDCO *rapid* doesn't rely on lithium thermodilution and instead uses a nomogram with which to calculate CO. It is an uncalibrated system most used perioperatively to trend SV values [1].

Both LiDCO systems utilize a variation of pulse contour analysis called "pulse power analysis." Rather than calculating the area under the arterial waveform, the power of every beat is extrapolated from the waveform itself. A key assumption is that, following correction for compliance and calibration, power and flow have a linear relationship. Once calibrated, the LiDCO system calculates CO, SV, SVV, and pulse pressure variation (PPV) on a continuous basis [35]. Like SVV, PPV is a useful indicator of volume responsiveness [16].

Beyond the limitations common to pulse contour/power analysis (e.g., IABP, poor arterial waveforms), LiDCO *plus* devices have more finite limitations secondary to lithium. LiDCO *plus* should not be used for patients <40 kg, in patients already taking lithium, or in the first trimester of pregnancy [1, 16]. High levels of nondepolarizing neuromuscular blockers in the bloodstream may cause the electrode to drift, necessitating recalibration [21]. Additionally, testing requires the withdrawal of 3–4 cc of blood per use, which in critically ill patients may be inadvisable [11].

Major advantages to both LiDCO systems compared to PiCCO are it is less invasive (no CVC required), its algorithm is somewhat more resistant to dampening, and it does not require fluid boluses. However, the variables measured are fewer, and it relies on an electrode to detect lithium ion which must be replaced every 3 days [16].

While most validation studies have shown a good correlation between LiDCO *plus* and traditional thermodilution, two studies have found an unacceptable difference between the two modalities in the context of cardiac surgery. Conversely, SVV and PVV data derived from LiDCO *plus* has been shown to be clinically reliable in practice [21].

23.3.3.3 FloTrac System

The FloTrac system (Edwards Lifesciences) utilizes pulse contour analysis as its method to determine cardiac output and only requires a peripheral arterial line. Unlike PiCCO and LiDCO *plus*, FloTrac does not need to be calibrated. Rather, its calculations are based on a database of patient characteristics preloaded into every machine. The FloTrac determines stroke volume by analyzing the arterial waveform at 2000 different data points. The arterial waveform is sampled every 20 s to generate with new results [24]. CO is determined by the equation:

$$CO = PR \times SDBP \times \chi$$

PR = pulse rate
SDBP = standard deviation of 2000 arterial data points in relation to pulse pressure
χ = An individualized conversion factor [19]

Pulse rate differs from heart rate in that the system only considers fully "perfused beats," i.e., beats with a full systolic wave, automatically eliminating PVCs or other poorly perfused cardiac contractions [12].

The individualized conversion factor, χ, is based on the patient's characteristics (age, gender, height, weight) and waveform characteristics (e.g., skewness, kurtosis) which are used to estimate vascular compliance [24].

It is important to note that FloTrac has been noted to perform poorly when measuring patients in certain situations. Unacceptable performance has been shown in studies including patients at extremes of vascular tone such as patients with cirrhosis undergoing liver transplant, septic shock, or hemodynamic instability requiring large doses of vasopressors [6]. In a 2014 meta-analysis, Slagt et al. found improvement in the accuracy of the technology with subsequent generations, though up to 30% bias in the latest generation. FloTrac was also found to be particularly inaccurate in patients with sudden changes in vascular tone [41].

One reason for the unreliability of the technology during hemodynamic instability is the placement of the device. While a peripheral arterial line allows for minimally invasive analysis, radial arterial lines can be subject to constriction when vasopressors are being used in large doses or in hemodynamically unstable situations [39]. Consequently, cardiac output can be greatly underestimated in these patients.

23.3.4 Transesophageal Echocardiography (TEE)

Transesophageal echocardiography is a subject large enough to fill books of its own. However, the

modern anesthesia provider will need to be familiar with TEE and its applicability in clinical situations. What follows is a quick review of the major benefits of quick TEE analysis in terms of the information this modality can provide about a patient's hemodynamic status. TEE allows for visualization of all four chambers of the heart simultaneously in real time. It can be used as an instant means to evaluate wall motion abnormalities, ejection fraction, volume status, pulmonary emboli, contractility, valvular abnormalities, intracardiac thrombi, and intracardiac shunts, and cardiac output [33].

TEE is the most sensitive means of detecting wall motion abnormalities, as they can be visualized directly [10]. Of all the standard views, the trans-gastric short-axis view allows for easiest visualization of wall motion abnormalities, as the distributions of all three (left anterior descending, left circumflex, and right) coronary arteries can be seen simultaneously [33].

Ejection fraction can be estimated in the trans-gastric mid-papillary short-axis view, by fractional area change (FAC). FAC is the percentage change in the left ventricular end-diastolic area (LVEDA) compared to the left ventricular end-systolic area (LVESA):

$$\mathrm{FAC} = \frac{\mathrm{LVEDA} - \mathrm{LVESA}}{\mathrm{LVEDA}} \times 100\%$$

Note that FAC is based on area and is therefore not equivalent to ejection fraction but rather correlated to ejection fraction. A normal value for FAC is >35%. Additionally, ejection fraction may be directly measured by Simpson's method of discs. While the method will not be fully explained here, it involved simultaneous examination of the LV in X-plane, i.e. two views, 90 degrees apart from one another. These views together allow for estimation of volume via addition of ellipsoid, longitudinal discs [8].

Volume status can be determined by gross examination of the ventricles. While quantitative measurements exist, most volume measurements are purely qualitative, determined by examination of the ventricles to determine if they seem "empty" or "full." An empty ventricle would appear hyperdynamic, with a high ejection fraction and low end-diastolic volumes [33].

TEE is unique among modalities as it can confirm the existence of thromboembolisms via non-invasive means. Pulmonary emboli can be visualized directly using the mid-esophageal ascending aorta short-axis or upper esophageal aortic arch short-axis views. From the mid-esophageal four-chamber view, the RV would appear grossly dilated with wall motion severely decreased. Accordingly, the LV volume should appear decreased [33]. McConnell's sign is preserved RV apical contraction in the setting of RV free wall akinesis and is associated with PE. However, a recent study found sensitivity and specificity of 70 and 33%, respectively. Accordingly, it should be used with caution [7].

CO can be calculated using TEE. A calculation of stroke volume is made by measuring the flow through the left ventricular outflow tract (LVOT), which is commonly chosen because it maintains its dimensions during systole. First, in the mid-esophageal long-axis view, the diameter of the LVOT (LVOTd) is measured. Second, in the deep trans-gastric long-axis view, pulsed wave Doppler is taken through the left ventricular outflow tract, creating a flow wave. The area of this wave, called the velocity time integral (VTI), is then measured. The VTI represents the distance traveled in one beat by a red blood cell and is expressed as a distance (cm). This is multiplied by the area of the outflow tract to create a cylindrical column of fluid, representing stroke volume. Cardiac output is then determined by the following equation [34]:

$$\mathrm{CO} = \mathrm{HR} \times \pi \left(\mathrm{LVOTd}/2\right)2 \times \mathrm{VTI}$$

23.4 Depth of General Anesthesia (DGA) Monitoring

As discussed in a previous chapter, anesthesia awareness is a rare but damaging situation. What constitutes awareness is different for each patient and can range from quick moments of recall to periods of pain. The anesthesia provider has historically used "responsiveness" as a measure of anesthetic depth: whether a patient moves to stimulus, exhibits a change in vital signs, etc. [37]. However, if given a paralytic medication, an awake patient may remain completely still while undergoing great distress. Additionally, fluctuations in vital signs can be masked by vasoactive medications (e.g., β-blockers) that are commonly given as

part of the anesthetic technique. Because of the severe consequences for both patient and provider of an awareness event, DGA monitoring, if validated, would provide discernible benefit [26].

What constitutes consciousness is a difficult question that has flummoxed philosophers and scientists for centuries. Although the molecular pathways of anesthesia's effects on the brain have been established, no monitor exists which can determine in binary fashion whether a patient is conscious [15]. Rather, monitors of anesthetic depth have thus far relied on measurable outputs of brain activity. Unlike the heart, lungs, liver, etc., whose activity can be measured in discrete metrics, the brain works in a subtler way that is less amenable to quantification [37].

23.4.1 EEG Devices

The most reliable and scientifically sound data comes from measuring the brain's electrical activity, the electroencephalogram (EEG). Anesthesia's effects on a patient's EEG have been definitively characterized. As one increases the depth of anesthesia, the pattern exhibits a high-amplitude and lower-frequency pattern. Beta waves become less frequent, while alpha and delta waves appear more commonly. As depth increases further, bursts of alpha or beta waves become separated by periods of low-amplitude or isoelectric activity, termed burst suppression. At its most profound, anesthesia can create a totally isoelectric EEG [37]. Because this pattern has been established, most products measuring anesthetic depth on the market today utilize technology that interprets EEG data.

23.4.1.1 BIS Monitor

First introduced in 1992, the bispectral index (BIS) monitor analyzes the EEG of a patient's frontal lobe to produce a numerical score representing anesthetic depth. A four-lead EEG is placed on the patient's forehead to monitor frontal lobe activity. The waveform measured is then examined by an algorithm that examines amplitude, frequency, and phase of certain aspects of the wave. The precise algorithm used is proprietary. A score from 0 (no brain activity) to 100 (an awake patient) is produced, with the ideal anesthetic depth being characterized in the range of 40–60. BIS was developed using a data based on patient EEG's of known anesthetic depth. These tracings were then visually discriminated to give the spectrum on which the numerical score is based [31].

The validation of BIS as a clinical tool has been controversial, with studies coming up with conflicting results. A 2014 Cochrane meta-analysis found BIS monitoring helps prevent awareness in high-risk populations when compared with using clinical signs but found no difference in using BIS in comparison with monitoring end-tidal gas concentrations [30]. However, other studies have studied outcomes with BIS and found only limited indications for its use [26, 43]. One recent study found BIS to be inferior to monitoring end-tidal gas concentrations in critically ill patients [4].

Of all the DGA monitors, BIS is the oldest, most clinically tested, and most adopted. As a result, BIS has become the standard by which all other DGA monitors have been assessed. This does not mean BIS is the "gold standard" DGA monitor. No methodology for assessing the "best" DGA monitor has been validated. BIS simply has the most data with which to assess its use [26].

23.4.1.2 Entropy Monitor

On the market since 2003, the entropy DGA monitor relies on the assumption that as depth of anesthesia increases, the entropy (or chaotic nature) of EEG waveform decreases. Therefore, the regularity of brain activity is used as a proxy for anesthetic depth. Unlike other EEG monitors, entropy produces two scores: state entropy (SE) and response entropy (RE). SE is a numerical score (0–91) which is based on EEG. RE (on a scale of 0–100) is based on both EEG and EMG. The difference between the two numbers is supposed to denote the action of the forehead muscles, which is detected, but not accounted for, in BIS measurements [42].

23.4.1.3 Narcotrend

Introduced in 2001, the Narcotrend monitor is a three-electrode EEG placed on the patient's forehead. The EEG is analyzed with the depth of anesthesia classified using a six-letter system: A (awake) to F (profound anesthesia) with E representing the ideal state for surgery. Like BIS, Narcotrend was developed based on a database of patients at certain anesthetic depths. The respective EEGs were visually discriminated to create the scale on which the score is based [38, 42].

As one of the most studied monitors, a number of clinical conclusions can be made about Narcotrend. Only Narcotrend and BIS have enough clinical studies behind them to demonstrate clinical utility in some patients. Additionally these two technologies are the only DGA monitors to be routinely used in children. Compared to BIS, Narcotrend is more resistant to interference from EMG based on its algorithm [26].

23.4.2 Auditory Evoked Potential (AEP) Monitors

An auditory evoked potential (AEP) is the evoked response of the brain to repeated auditory stimuli as measured by an EEG. Middle latency auditory evoked potential (MLAEP), taken 10–100 ms after the signal, represents the earliest cortical response to an auditory stimulus. Amplitudes and latencies of AEP signals have been shown to correlate to anesthetic depth. An AEP is less prone to artifact that an EEG, which would yield theoretical benefit to this modality. While these technologies have been developed for commercial use, studies demonstrating their clinical utility have been limited [40]. However, one study found the new AEP/2 monitor to perform poorly compared to BIS in pediatric populations [17]. In contrast other studies have demonstrated that use of AEP can improve the titration of drugs, decrease the incidence of postoperative nausea and vomiting, and shorten recovery room stays [32, 44].

23.5 Conclusion

Advanced physiologic monitors for use in anesthesia are a billion-dollar industry that only continues to expand. These monitors are necessary for diagnostic purposes when problems occur that cannot be identified by "standard" ASA monitors. Choice of when to use these monitors depends on the patient's history and the procedure planned.

Cardiac output monitoring allows extrapolation of numerous hemodynamic variables and can be measured by increasingly noninvasive means. The gold standard for measuring cardiac output is thermodilution, where cold solution is injected into the heart. The temperature deviation created is measured over time, with the area under the curve inversely proportional to the cardiac output. Despite being the most reliable means of measuring cardiac output, standard thermodilution requires a pulmonary artery catheter and injection of outside fluid bolus and only provides incremental data.

Continuous cardiac output monitors are specialized pulmonary artery catheters that use thermodilution principles but without an external fluid bolus. Instead of cold injectate, a copper wire incrementally heats upstream fluid. The technology takes measurements automatically and more frequently but is not truly "continuous" as each measurement takes time to derive. Continuous cardiac output still requires a pulmonary artery catheter, which carries its own unique complication profile.

Pulse contour analysis is a means of measuring cardiac output solely by analyzing the wave form of an arterial line. PiCCO and LiDCO require calibration utilizing central venous cannulation, with LiDCO further requiring the use of lithium, which limits its clinical applicability. FloTrac systems do not require calibration and can be used solely with an arterial line. All pulse contour systems require a high-fidelity wave form that is not damped. Further, intra-aortic balloon pumps, aortic insufficiency, and the use of vasopressors can affect the analysis. FloTrac software has been shown to be inaccurate in hemodynamically unstable patients as well as those with abnormal physiologic profiles such as cirrhosis.

Transesophageal echocardiogram is a useful, clinically validated monitor that allows visualization of the heart and measurement of key parameters. Quantitative measurements of cardiac output, valvular abnormalities, and ejection fraction can be obtained by trained practitioners. Qualitative analysis of filling volumes, wall motion abnormalities, emboli, effusions, and contractility can be made in real time by less experienced users. The major limitations of TEE are the cost of the technology and the training required by the anesthesiologist to interpret the data. While complications have been reported including thermal and physical injury to the esophagus, the incidence is very low. Further, the absolute contraindications to TEE are limited.

Depth of general anesthesia (DGA) monitoring uses electroencephalograms to extrapolate levels of consciousness, the goal of which is to prevent anesthesia awareness. Most monitors on the market today use frontal lobe analysis to pro-

duce a numerical score denoting consciousness. A range is designated to indicate the "adequate" depth of anesthesia. While this technology has not been shown to be cost-effective in every case, frontal lobe monitoring has been shown to help prevent awareness in total intravenous anesthetics and situations where the level of anesthetic gas needs to be minimal (e.g., hemodynamic instability, trauma). Auditory evoked potentials measure the response of the brainstem to sounds delivered through headphones. While the technology has been shown to correlate to anesthetic depth, it is not commonly used in practice today.

23.6 Review Questions

1. Which of the following is not a component of standard ASA monitoring?
   A. Pulse oximetry
   B. Temperature
   C. ECG monitoring
   D. Anesthetic depth
   E. Oxygen content of fresh gas

2. Which of the following TEE views allows for simultaneous visualization of the distributions of each of the three major coronary arteries?
   A. Mid-esophageal long-axis view
   B. Mid-esophageal two-chamber view
   C. Trans-gastric mid-papillary short-axis view
   D. Deep trans-gastric long-axis view
   E. Trans-gastric two-chamber view

3. Which of the following numerical values would be consistent with adequate anesthetic depth using BIS monitoring?
   A. 1
   B. 11
   C. 21
   D. 31
   E. 41

23.7 Answers

1. C – Anesthetic Depth. While technology exists to measure brain activity as a proxy for consciousness, the ASA does not include these devices as part of basic monitoring for an anesthetic.

2. C – Trans-gastric mid-papillary short-axis view. This view allows for visualization of the left and right ventricles in cross section, allowing for examination of the major coronary distributions. None of the other views can achieve this.

3. E – 41. BIS is measured on a scale of 0–100, with 0 representing maximum anesthetic depth and 100 correlating to an awake patient. The target range for general anesthesia is 40–60.

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Quality of Care in Perioperative Medicine

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_24

24

24.1 Introduction

Clinical performance in healthcare has become increasingly scrutinized as pressures mount to contain costs and increase quality of care. Quality of care has become a focus of hospital committees, insurance providers, government agencies, and healthcare providers. The discipline of quality of care is focused on the tracking, analysis, and reduction of errors so as to ensure improved patient outcomes while containing cost.

Improvement in the quality of healthcare is fundamental to the integrity of anesthesiologists and other physicians. In the perioperative environment, collecting data on processes and outcomes as well as eventual evaluation of this data may ensure a culture of safety and provision of quality care. Collaborative efforts by the healthcare team in the operating room are important to this process, as well as multidisciplinary efforts to assure the quality of care throughout a patient's hospital course. Finally, protocols and evidence-based programs should be developed and enforced to assure the best practice medicine for delivering the best possible quality of care.

24.2 History of Patient Safety and Quality Efforts

The medical specialty of anesthesiology has been a model for patient safety and, in turn, quality of care [1]. The consistency of safety is fundamental to the improvement of quality in perioperative medicine. Patient safety and quality of care in anesthesiology have been influenced by the early development of industrial quality and in the establishment of quality standards in medicine and hospital management.

The history of industrial quality of Japanese products was revolutionized by two American men following World War II between 1950 and 1960. In a remarkable implementation of program and culture, two men from the United States, W. Edwards Deming and Joseph M. Juran, helped transform the industrial quality of Japanese products. Deming and Juran were largely credited for what many would later refer to as the "Japanese post-war economic miracle." While most Japanese products had always been competitive in price, the quality was well known to be inferior. Juran has been called the father of quality, and Deming is most well known for his 14 points which started the total quality management movement [2]. They helped transform the Japanese production of goods by shifting the focus of quality improvement upstream toward the scrutiny of the system and processes.

Deming was an engineer, whose 14 points and system helped identify any aberration or flaw within a process and removed deficiencies one at a time. His 14 points are as follows: constant improvement of product, adopt the new philosophy, cease dependence on inspecting the end product to accomplish quality, build long-term relationships with trust and loyalty, train while on the job, improve processes constantly and endlessly, key leadership to supervise production, encourage positive morale with no fear in the culture, interdepartmental barriers must be broken down to streamline collaboration, eliminate quotas but rather inspire with leadership, allow every worker to indulge in the pride of his own workmanship, install the ability for employees to attain self-improvement and continuing education, and exhort the entire workforce to accomplish transformation within the company. These 14 points were fundamental in improving the quality of Japanese products, aiming for the goal of delivering what the customer wants with precision and consistency. In Deming's analysis of the system, he sought to identify individual impairments, removing them one by one. At the time this was a paradigm shift; process was improved upon rather than attempting to fix individual workers.

While Deming and Juran introduced the concept of industrial quality improvement, the medical community has also sought methods to improve quality of healthcare. The need for quality of care in healthcare can be traced back to Dr. Ernest Codman in 1910. A surgeon from Boston, Dr. Codman sought to track patient outcomes by utilizing an "end results system" to help identify adverse outcomes and clinical errors. He established the first mortality and morbidity conference at the Massachusetts General Hospital in Boston after joining Harvard Medical School faculty to help identify errors and prevent harm in the delivery of healthcare. The morbidity and mortality conference program has been adopted in clinical departments throughout the world as a mainstay of quality and safety. His interest in patient outcomes and quality in healthcare leads to the formation of the American College of

Surgeons and the Hospital Standardization Program. The American College of Surgeons continued to lead the initiative in improving quality of healthcare, and by 1917, they developed the Minimum Standards for Hospitals. In this, hospital visits and inspections were required to receive certification by the American College of Surgeons.

One of the first collaborations in healthcare-related efforts toward quality of care was the development of the Joint Commission on Accreditation of Hospitals. It was formed in 1951 in a partnership between the American Medical Association, the American Hospital Association, the Canadian Medical Association, and the American College of Physicians [3]. The goal and mission of the Joint Commission on Accreditation of Hospitals have been to "continuously improve health care for the public, in collaboration with other stakeholders, by evaluating health care organizations and inspiring them to excel in providing safe and effective care of the highest quality and value." With the passage by Congress, in 1965, of the Social Security Amendments, hospitals that were accredited by the Joint Commission on Accreditation of Hospitals were now eligible to participate in Medicare and Medicaid programs. As of 2017, the Joint Commission inspects and qualifies over 21,000 healthcare facilities and programs as the oldest and largest accrediting body in the nation.

As leaders in industrial quality improvement discovered, many in the field of anesthesiology also found that the greatest strides in quality improvement are accomplished through establishing a culture and system of constant quality improvement. This was a shift in the approach to providing medical care for most clinicians, as the focus is often on one patient at a time. Creating a system to provide an improvement in outcomes for an entire cohort of patients only began to take shape in the twentieth century. Dr. Avedis Donabedian was one of the first physicians to put this together in 1966. In *Evaluating the Quality of Medical Care*, Dr. Donabedian distilled the quality of medical care into providers, the delivery of care, and the clinical outcomes [4]. He defined a model that could help quantify, analyze, and improve the quality of care.

In 1983, the American Society of Anesthesiologists formed the ASA Committee on Patient Safety and Risk Management in response to rising medical malpractice insurance premiums. This subsequently leads to the formation of the Anesthesia Patient Safety Foundation in 1985, which was an independent foundation that was initially funded by the ASA. The formation of the APSF was the vision of Dr. Ellison C. Pierce, Jr., Chairman of Anesthesiology at Harvard Medical School and President of the ASA [5]. The goal of patient safety and reduction of preventable anesthetic accidents was formally addressed by the organization through newsletters, investigations, and organized safety programs. As a result of pursuing safety and quality of care, anesthesiologists began to see their malpractice premiums decrease and were applauded by the Wall Street Journal in 2005 for this initiative as a profession [6].

Since the formation of the Anesthesia Patient Safety Foundation, the quality and safety in the field of anesthesiology have improved for a multitude of reasons. The development of improved and diverse patient monitoring devices and pharmacological advances in anesthesiology have aided practitioners in providing better care. Pulse oximetry, advanced ventilators, capnography, fiber-optic endoscopes, video laryngoscopes, and ultrasound are just a few of the many technological advances in the field of anesthesia which have improved quality and safety. Pharmacologic anesthetics with faster onset and offset, less hemodynamic effects, and less overall side effects have also contributed greatly to the safety and quality in anesthesiology. The American Society of Anesthesiologists established a standard of care for monitoring a patient while utilizing an anesthetic. The ASA Standards for Basic Anesthetic Monitoring, first defined in 1986, has helped ensure that only qualified anesthesia personnel are properly monitoring ventilation, oxygenation, temperature, and circulation [7]. Many revisions and consensus statements have helped refine these standards over the years, and this has served as a universally accepted standard of monitoring for anesthesia providers.

Many of the previously described organizations and institutions as well as a plethora of others were developed around the ideas of W. Edwards Deming, Dr. Ernest Codman, Dr. Ellison Pearce, and Dr. Avedis Donabedian. Quality of care in medicine is a very complex system, and the necessity for providing safety and quality only continues to increase in a system with constrained resources and little margin for error. Individual medical professionals as well as large healthcare networks have important roles in delivering quality healthcare in our complex healthcare system.

24.3 Approaches to Quality Improvement

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24.3.1 Evaluation and Management of Adverse Outcomes

The prevention of adverse events requires a thorough understanding of the processes and practices, a comprehensive reporting of adverse events, and a collaborative effort to analyze and strategically revise processes to prevent further harm. With so many safety mechanisms in place and conscientious medical providers, adverse events are often the result of many independent errors that align to allow for harm to take place.

Before adverse events can be reduced, they must first be identified. With negative consequences, personal shame, lack of confidence in the system, poor education regarding quality initiatives, and concern of implicating others, often times adverse events are under reported [8]. In fact, physicians are the least likely to self-report any adverse events [9]. Especially in "near miss" situations where no harm actually occurred, clinicians are even less likely to report these events. The World Health Organization defines adverse events: "An event or circumstance, which could have resulted, or did result, in unnecessary harm to a patient" [10]. It is clear that it is of great importance to capture "near miss" events as opportunities to serve as an additional data point to help guide safety and quality policy. Reported adverse events occur at a rate of between 5.3 and 10.7% of patients in the hospital according to ICD billing codes that indicate adverse events [11]. Despite under reporting, there is a great opportunity to investigate adverse events, analyze, and strategically devise ways to reduce the risk of further adverse events.

A system of detecting of adverse events should be in place so that medical providers are not the only source of reporting. Electronic medical records, routine peer review, pathology reports, incident monitoring, and medicolegal resources should be utilized to help identify adverse events. Tracking "near misses" should also be in the framework of adverse event reporting. Industrial quality control systems have demonstrated that when "near misses" and minor adverse events are tolerated, a higher rate of catastrophic events can ensue [12]. Systems need to be adequately tailored to capture incidents and events for the unique features of each organization and practice. Some of the features of an incident reporting system that may be helpful include a system that is easy to access, an option of anonymity, secured data, an ability to organize and analyze data easily, and the ability to produce reports [13].

Latent errors are often the difference in what might cause an adverse event to occur. While human errors may be a component of the root cause, discovering latent errors is ultimately the goal of analyzing adverse events. The Joint Commission on Accreditation of Healthcare Organizations has developed a policy with respect to the analysis of adverse events, requiring a root cause analysis of all adverse events that affect patients [14]. Root cause analysis can be a laborious endeavor, and it may be difficult to quantify the results of these studies. The adverse event trajectory can be best described through models including the Swiss cheese models [15] and bow tie diagrams [16].

In the Swiss cheese model, a set of parallel barriers to prevent harm exist within a system. In order for an adverse event to actually occur, holes due to errors or system failures must occur on every cascading barrier level. The layers of Swiss cheese must then align in an unfortunate manner such that the fail-safe mechanisms are unable to prevent an adverse event. While the Swiss cheese model may aid in patching up some of these barriers or perhaps even implementing a new layer, effort should also be given toward creating systems to anticipate and recover from such adverse events if they occur with frequency.

Often used in industrial quality systems and most notably nuclear power plants, bow tie diagrams may be of some benefit in preventing adverse events in healthcare [16]. A bow tie diagram centers around an adverse event that may occur. On the left side of the diagram, all risks and preventive measures are listed. On the right side of the diagram, all possible adverse events and recovery options and outcomes are listed. The bow tie diagram has great potential for not only preventing adverse events but minimizing damage or recovering from adverse events once they occur. The bow tie diagram is most significant in this discussion for describing the importance of a recovery plan in the event of an adverse event.

The Institute for Safe Medication Practices has a nine-level strategy to reducing errors, ordered from the lowest to highest strength and reliability:

(1) suggestions to be more careful or vigilant, (2) education and information, (3) rules and policies, (4) reminders and checklists, (5) redundancies, (6) standardization, (7) automation and computerization, (8) forcing functions, and (9) fail-safes and constraints [17]. Suggestions can be helpful in a motivated culture of healthcare providers and are likely the easiest practice to employ. Suggestions to be more careful or vigilant are also the least effective because any inherent latent factor is not considered, and dissemination and effectiveness of suggestions are widely variable. Education and information can be helpful, motivating with a greater understanding of the overall benefit of a modification of practices. This method relies on the individual provider and can lose effectiveness over time unless routinely enforced. Rules and policies improve the protection of the overall system by providing a legal framework for the conduct of an organization. It is less effective on the individual level because it is often hard to keep track of all of the rules and policy details. Reminders and checklists are often utilized in the operating room through time-out procedures and have been very successful in the aviation industry. Providers who routinely perform checklists and reminders must always be vigilant against fatigue and inattentiveness that may present during repetitive tasks. Redundancies help reduce error in a greater extent, providing an extra barrier that must be errant according to the "Swiss cheese model" previously described. While not a guarantee against error, redundancies reduce them greatly. Standardization of processes is an important tool in reducing errors. A consistent standardized team who follows a standardized approach is much less likely to make an error because of the familiarity and simplification of variables. Automation and computerization are some of the greatest tools in modern healthcare to protect patients from harm. Mechanisms such as barcode scanning prior to medication administration protect a patient from errors such as wrong dose, wrong medication, or wrong patient. Compliance with automation and computerization safety systems is mandatory, and any deviation from the process must be immediately addressed. The best and strongest level of error reduction strategies is in fail-safe and constraint systems. In these systems, there is not any possibility that a patient would experience harm. An example of one of these systems is the anesthesia machine that is equipped with a proportioning system that prevents any delivery of a final inspired oxygen concentration of less than 21%.

Adverse events are most often the unfortunate result of latent errors within a system and human error. The identification of adverse events is the first step toward reducing risk through effective incident reporting systems. Next, the adverse event should be analyzed with a root cause analysis, illustrating where the faults may lie in a Swiss cheese model or bow tie model. Appropriate interventions that range from suggestions to fail-safe and constraint systems should be applied.

24.3.2 Quality Management

A strong and responsive quality management program is essential to the optimal functioning of perioperative services. Patient satisfaction, patient safety, surgical excellence, and overall operating room efficiency are difficult to ensure without such a process in place [18]. Anesthesiologists are considered the physician specialists to address operating room management and patient safety in the perioperative setting and should be quality management leaders in these areas. An effective quality management program will increasingly be valued in an era of reimbursement that is based not only on volume but also on outcome.

Developing a quality management program requires departmental support from the highest level of authority. A quality management officer should be selected and enjoy the full support of senior leadership such that all providers are expected to acknowledge adverse outcomes and remain committed to the process of quality improvement. The role and work of the officer should be respected as an integral part of the department's functioning.

Supporting a quality management officer should be a committee, comprised of members representing the various stakeholders in a group or department. Anesthesiologists, CRNAs, AAs, nurses, and trainees should constitute the committee and work together to define performance metrics. Importantly, the stakeholders should be not only of a diverse selection of clinical representatives from different departments but also of a wide sampling of experience inclusive of senior members and junior members. Metrics can be thought of as "top down" or "bottom up." That is, top-down metrics are those

already collected through CPT/ICD coding as well as quality measures required by programs such as the Surgical Quality Improvement Project. Bottom-up metrics include sentinel events or adverse outcomes [19]. Both metrics are important to overall quality management and require the support of providers, nursing, hospital IT, and/or the billing department. Additional measures of quality should be established through the committee process in partnership with all stakeholders.

The first step in organizing a quality management project is to begin harvesting pertinent data in a top-down approach. In the age of electronic medical records, many data points are already collected en masse. Requesting data from technical support specialists and the medical informatics department can yield a great deal of information. A patient's ASA physical status classification, comorbidities, admitting diagnosis, length of stay, pain scores, vital signs, and a plethora of other information may be extracted from the electronic medical record. Another valuable source of data may be in the billing information. Data collected in the billing information includes the ICD code, length of operation, age, sex, ASA codes, procedures, and more. Organized data may have already been collected through other departments such as through a nursing quality management project. It may be worthwhile to inquire surgical colleagues and nurses about any overlapping quality management projects. In addition to hospital projects and collaborative quality management programs, many quality management projects are designed to help improve performance on Consumer Assessment of Healthcare Providers and Systems (CAHPS) scores and Surgical Care Improvement Project (SCIP) scores. Finally, the quality management team may find it best to collect data directly. Creating a form, questionnaire, or poll standardizes the data collection process and may deliver information not available in any of the aforementioned methods.

The valuable data that has been collected must be translated into useful reports through careful analysis. Sorting out the most pertinent data points is one of the most skillful requirements in analyzing the data. Retrospectively analyzing data can be difficult to perform without incurring certain biases; however identifying trends and linking causal relationships should be attempted. A medical statistician may be employed to assist with the complex calculations and production of charts or reports.

In reporting quality management measures, reports can be based on individual anesthesiologists or at the aggregate system level and may have varying levels of privacy in reporting. For the individual provider, it can be helpful to report compliance and performance as compared to the average. For example, a particular provider may have pain scores or patient satisfaction scores that are significantly worse than the average provider. This type of report may be shared confidentially with each provider, as this may be a very sensitive issue. In preparing such reports, the data should be risk adjusted as some anesthesiologists may care for a more difficult or easier population. Other types of reports for individuals may include adverse events such as perioperative complications. Again, these reports should be shared with the provider with sensitivity. On an aggregate level report, the responsibility should be shared by the entire hospital or group. These reports may be shared with the hospital, the group, or may even be compelled to share publicly. Handwashing compliance reports or central line infection reports are familiar quality management reports that occur in many hospitals these days to help encourage healthcare workers to take all precautions to improve on these metrics. As more information becomes available to the public, there are often quality measures that become accessible [20]. The Joint Commission or Medicare Physician Quality Reporting System may require certain quality measures to be reported. In the eyes of the public, the confidence in providers can be unwittingly challenged and often due to poor reporting. The quality management team should ensure that any publicly reported data is as best risk adjusted as possible, which may invariably be flawed [20, 21].

The "bottom-up" approach to quality management addresses unusual events, adverse outcomes, and sentinel events. Self-reporting of these adverse events is often low as clinicians may fear medicolegal consequences, insult to their reputation, perceived disruption in the patient-physician confidence, or lack of confidence in benefit of reporting. Further, near miss events are even less reported. Communicating a well-known alert system protocol for reporting incidents along with a responsive quality management team can greatly improve reporting. Once an incident is reported,

it must be addressed in an expeditious manner. If there is concern that a practice is unsafe or may cause imminent harm to a patient, there should be a system in place for immediate review of protocols. All other incidents should be addressed according to priority of severity. Low-level incidents should be reviewed on a monthly basis in a quality management committee. It should be determined whether there is a pattern of practice that may lead to further adverse events and what changes could be implemented. The quality management committee should communicate with hospital risk management regarding adverse events that could result in a legal predicament.

A quality management team and officer are important to the success of quality improvement in the perioperative setting at any hospital. Success of the individual provider and the perioperative team depends on the consistency of safety and performance assured by the quality management team. In "top-down" and "bottom-up" approaches, the refinement of outcomes and reduction of adverse events can be simultaneously accomplished.

24.4 Review Questions

1. Which of the following are reasons that physicians may not report adverse events?
   A. Medicolegal consequences
   B. Professional reputation
   C. Lack of confidence in quality management system
   D. Disruption of patient confidence
   E. All of the above

2. Utilizing a "top-down" approach to quality management includes all of the following *except*:
   A. Collecting data from electronic medical records and billing information
   B. Identifying adverse events
   C. Creating quality management reports for the hospital and individual providers
   D. Analyzing performance metrics with medical statisticians

3. According to the Institute for Safe Medication Practices, which of the following is the strongest strategy level to reduce errors?
   A. Reminders and checklists
   B. Rules and policies
   C. Standardization
   D. Fail-safes and constraints
   E. Suggestions to be more careful or vigilant

24.5 Answers

1. E

2. B

3. D

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Professional Liability

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_25

Call out box

Anesthesiologists are leaders in the arena of patient safety yet still practice in high-risk environments, which can increase the likelihood of malpractice lawsuits. Regardless of appropriate quality care and a focus on patient safety, poor patient outcomes may be unavoidable. Medical malpractice litigation is unfamiliar territory for many physicians. Knowledge of medical malpractice in anesthesia and professional liability insurance are essential in helping protect an anesthesiologist's practice, license, and personal finances from certain legal threats. Policies have been developed and task forces established to investigate significant trends in previously uninvestigated complications, and professional liability claims are frequently reviewed and published by the Anesthesia Closed Claims Project to help physicians ensure patient safety and quality improvement. This chapter highlights major aspects of professional liability in anesthesia, focusing on background information, basic definitions, key concepts, examples, and resources.

25.1 Introduction: Professional Liability Related to the Practice of Anesthesiology

Over the last several decades, advances in the field of anesthesiology relating to devices, techniques, clinical practice, and drugs have greatly improved patient outcomes through a noticeable reduction of anesthesia-related injuries. Additional support of the American Society of Anesthesiologists (ASA) to demonstrate proactive approaches to patient safety with the ASA Closed Claims Project, the Anesthesia Patient Safety Foundation, and the Foundation for Anesthesia Education and Research has allowed the practice of anesthesia to remain a patient-centered profession focused in continually improving patient safety. Better patient outcomes have resulted in a decrease in the average cost of professional liability insurance premiums. However, despite these advances, the field of anesthesia remains a high-risk environment still susceptible to significant events resulting in morbidity and death. Regardless of appropriate quality care and improved patient safety, poor patient outcomes may be unavoidable with physicians facing possible medical malpractice claims. Medical malpractice litigation starkly contrasts the practice of medicine and is unfamiliar territory for many physicians. Understanding the nature of these claims and precautions to safeguard against liability prepares physicians to address a claim or lawsuit while maintaining their license and practice.

The following chapter provides a brief review of professional liability in anesthesia, focusing on background information, basic definitions, key concepts, examples, and resources.

25.1.1 Background on Medical Responsibility and Origins of Medical Malpractice

The concept of medical responsibility is more than 4000 years old, dating back to the time of Babylonian kings and Roman law. The Code of Hammurabi dating back to 2030 BCE provided that "If the doctor has treated a gentlemen with a lancet of bronze and has caused the gentleman to die, or has opened an abscess of the eye for a gentleman with a bronze lancet, and has caused the loss of the gentleman's eye, one shall cut off his hands." [1]. Documentation of legal responsibility for medical wrongs also existed under Roman law and was later incorporated into English common law (following the Norman Conquest of 1066). English common law, from which US medical malpractice law derives, provides a framework for, and the history of, medical malpractice decisions [1]. An early medical malpractice case held that both a servant and his master could sue for damages against a physician who had treated the servant and worsened his sickness by employing bad medicine [1]. The law applicable to medical malpractice continued to evolve, and, in 1532, formal opinions of healthcare workers were required in every case of violent death—a prelude to requiring medical expert testimony to establish the standard of care in negligence claims [2]. In the United States, medical malpractice claims started to appear in the 1800s [3]. Interestingly enough, prior to the 1960s, medical malpractice lawsuits were uncommon in the United States [4]. Today, lawsuits filed by patients alleging malpractice by a physician are relatively common and have greater influence on medical practice than ever before [5].

25.1.2 Statistics on Medical Malpractice

In 1986, to improve healthcare quality, the Congress and the Department of Health and Human Services established the National Practitioner Data Bank (NPDB) to centralize data related to medical malpractice claims. If a malpractice claim payment is made on the behalf of a healthcare provider, then federal law mandates that this information be reported to the NPDB. Since 1990, this data demonstrates a decrease in the overall number of reports of malpractice payments but an increase in payment size even after accounting for inflation. According to NPDB data, in 2005, anesthesia-related cases accounted for 3.3% of all reports with the median payment of $200,000. From incident to payment, malpractice cases take approximately 3–5 years to resolve [6]. Of note, amounts and frequency of malpractice payments vary significantly by state owing mainly to differences in state law.

25.2 Medical Malpractice

Legally, medical malpractice refers to professional negligence, which requires an injured patient to prove that poor quality medical care resulted in injury and that the injury is related to the physician's bad actions. A medical malpractice claim is a creature of state law in the United States, with subtle variations across states in the elements of the cause of action and potential differences in the standards of care, burdens of proof and production, and limitations on types and amounts of damages that a successful plaintiff can recover. To prove negligence, the patient's claim must address four key elements:

1. Duty
2. Dereliction (i.e., breach) of the duty
3. Direct cause
4. Damages

All four elements must be proven by the patient-plaintiff to win a medical malpractice case against the defendant-anesthesiologist.

25.2.1 Duty of Care

Legal duty is based on the notion that each person has a responsibility or obligation to provide acceptable care to others. Due to the nature of their occupation and by oath, physicians are obligated to provide reasonable and acceptable care to all their patients. A duty of care only exists when a doctor-patient relationship has been established. This is the easiest element for a patient-plaintiff to prove. For example, once an anesthesiologist sees a patient preoperatively and agrees to provide anesthesia care, a doctor-patient relationship is formed, and a duty of care exists. Some other examples of general duties include performing an appropriate patient examination, consultations with physician specialists, maintaining medical records, obtaining an informed patent consent, and adhering to privacy and other laws [7].

After the doctor-patient relationship is established, the anesthesiologist must treat the patient within the standard of care. The standard of care does not have a uniformly agreed definition and varies from state to state, making it ripe for litigation. Some state courts take into account location and how another physician may treat a patient in similar circumstances. Other state courts apply a national standard, meaning an anesthesiologist is held accountable based on the reasonable and prudent actions of other anesthesiologists in the nation and how they would address a similar circumstance. Therefore, it is not sufficient for an anesthesiologist to act in good faith or in accordance with the norms of their specific region or current hospital or institution. Most jurisdictions use a national standard of care, while a minority of courts use a locality standard. In some cases, more than one standard of care could exist. The standard of care imposed by the court with jurisdiction over a particular medical malpractice case could even be determined by a group of respected physicians. Because of these disparities, the presiding court will often establish the applicable standard of care after hearing testimony from expert witnesses and then making a legal determination that will be applied to the facts of the particular case.

25.2.2 Dereliction

Dereliction is known more commonly as *breach of duty*. A judge presiding over a medical malpractice case may also rely on the testimony of medical expert witnesses to help determine whether the defendant-anesthesiologist failed to meet the applicable standard of care. Based on the testimony

accepted by the judge and the facts of the case, if the court finds the defendant-anesthesiologist at fault for an omission or a failure to act within the standard of care, then the plaintiff-patient will have established a breach of duty.

25.2.3 Direct Cause

The third element of the cause of action is determining whether the defendant-anesthesiologist caused the plaintiff-patient's injury. Specifically, the question is whether the physician's breach of duty is the *proximate cause* of the patient's injuries. Proximate causation is one of a number of types of causation under the law and is determined by answering two questions: (1) Would the injury have occurred if not for the action by the defendant-anesthesiologist (also known as "but for cause") and (2) did the harm caused by the defendant-anesthesiologist contribute substantially to the plaintiff-patient's injuries despite other factors. If the answer to both of these questions is yes, then the court may find that the plaintiff-patient has satisfied the causation element of the medical malpractice claim by proving that the defendant-anesthesiologist's act or omission is the cause of the injuries.

Ordinarily, the patient-plaintiff bears the burden of proof for all elements of a medical malpractice case. However, in some cases, especially anesthesia malpractice cases, the anesthesiologist defendant may have to prove that they did not cause the harm. This shift in the burden of proof from patient to physician may occur in after the patient has shown that the physician had exclusive control of the thing (e.g., anesthesia) that caused the injury even though there is no evidence that the physician is negligent. It is based on the legal doctrine of res ipsa loquitur, Latin for "the thing speaks for itself." It is invoked when a plaintiff establishes a rebuttable presumption that the physician was negligent and without the negligence, the injury would not have occurred. Under the care of anesthesiologists, anesthetized patients lack awareness of surroundings and inability to fully prevent or protect themselves from injury; therefore, this doctrine is more likely used in anesthesia malpractice cases versus other types of malpractice claims [7]. In this case, an anesthesiologist needs to demonstrate that the injury would have occurred in typical circumstances in the absence of negligence while also proving that he or she was not negligent.

25.2.4 Damages

The last element of a medical malpractice cause of action is damages. A plaintiff-patient who fails to prove that they suffered damages as a result of the injuries caused by a physician's breach of duty cannot recover from the defendant physician. In the simplest terms, there are three types of damages: punitive, general, and special. Punitive damages are reserved for defendant-anesthesiologists whose negligence is determined to be willful or reckless. General damages include pain and suffering, which are considered to be damages that directly result from the injury caused by the physician. Special damages are those that arise as a consequence of the injury and are reasonably foreseeable, such as medical expenses and opportunity costs (sometimes referred to as consequential damages). In jury trials, the jury decides on the amount of the medical malpractice damage award, which typically correlates with the severity of the injury and to the degree of which the defendant-anesthesiologist is found to be negligent [7–10]. Each year in the United States, nearly 60,000 medical malpractice claims are filed, and about 30 percent result in damage awards to the plaintiff [11].

25.3 Reducing Risk of Claims and Medical Errors

Undesirable patient outcomes occur in any field of medicine. According to some studies, patients are less likely to sue a healthcare provider when the patient perceives the provider as caring, communicative, honest, and appropriately apologetic [12, 13]. Unfortunately, there is a lack of consensus on the optimal response to a medical error. After a full disclosure and a carefully crafted apology, patients and their families may be less likely to sue for damages [14]. Routine use of full disclosure after a medical error is controversial, however, due to the potential for unintended medicolegal consequences [15]. In response, some states are adopting "apology laws," which make apologies inadmissible as evidence of provider wrongdoing, to encourage communication after adverse outcomes. In response to medical error and undesirable outcomes, clear communication with co-workers is paramount and provides a clear establishment of the adverse event circumstances

and key happenings, in addition to thorough documentation that limits speculation or conjecture, such as providing non-conflicting narratives and imparting the full truth [6]. Finally, risk management personnel should be consulted in regard to medical error concerns and adverse events.

25.3.1 Meeting the Standard of Care

Vigilance in meeting the standards of care such as ensuring informed consent, consistent, and detailed documentation and exercising empathy with patients can reduce likelihood of malpractice claims.

25.3.1.1 Informed Consent

Informed consent must be obtained prior to any procedure with the anesthesiologist including an adequate explanation of the procedure, possible alternatives, and associated risks. The patient must indicate an understanding of the aforementioned procedure and risks and then provide consent for treatment. Since anesthesia comes with risks separate from surgery, anesthesiologists should obtain consent separately from surgeons. Patients should have enough time to decide to either accept or refuse treatment. If the patient is unable to give informed consent or given reasonable amount of time to process the information provided, then a legally recognized surrogate may decide for the patient. Surrogates may include next of kin or legal appointments. When in doubt about the ability of a surrogate to provide informed consent, first consult with hospital or clinical risk management personnel.

25.3.1.2 Medical Records and Documentation

All healthcare providers should keep meticulous documentation of patient encounters. Medical documentation becomes the patient's narrative. Any information not included in that narrative, in effect, did not happen in the eyes of third parties (including experts, judges, and members of juries). Therefore, it is essential for anesthesiologists to make notes of any pertinent events in a patient's medical record.

Anesthesiologists assuming a supervisory role in the management of anesthetists may be faced with vicarious liability in which the anesthesiologist assumes responsibility for the omissions or actions of his or her subordinates. Thorough documentation of the anesthesiologist's presence during key and critical periods as well as recording communication of anesthetic plans with subordinates provides a strong narrative in reducing liability risk. Failure to meticulously document these situations is not only bad practice, it also creates an opening for patient-plaintiff attorneys to insinuate that inadequate supervision existed [6].

25.4 Lawsuits: What to Expect

The stages of a medical malpractice claims generally are as follows:

- Stage 1: Injury or death
- Stage 2: Attorney consultation
- Stage 3: Investigation
- Stage 4: Medical expert consultation
- Stage 5: Service of process and commencement of the action by filing the case
- Stage 6: Discovery
- Stage 7: Settlement or trial

Of note, the aforementioned stages of a medical malpractice lawsuit vary slight state by state.

During the initial stages, a lawyer and patient must determine if the doctor-patient relationship existed and gather evidence to prove the elements of the case (refer to the four D's of medical malpractice). After the plaintiff's attorney gathers information, he or she will likely contact a medical expert. If the case has legal merit and is financially viable, then the plaintiff may approach the physician prior to filing a complaint or will formally commence the action by filing the complaint with the court and serving the defendant(s) with a summons and complaint detailing the allegations and the damages sought. At the same time, or immediately following commencement of the action, the parties are entitled to conduct discovery (inspections, document requests, interrogatories, requests for admissions). This discovery period is often followed by a period of negotiation, which may lead to a settlement or the parties will proceed with a trial, although the parties are free to negotiate and settle at any point in time during the litigation and are often encouraged by judges to schedule time to resolve matters as soon as possible to avoid incurring expenses, inconveniencing litigants, and burdening the court system.

25.5 Countersuits

Countersuits (claims made by a defendant against the plaintiff in the original action) often appear to provide the only plausible means of legal recourse by a defendant physician against a plaintiff patient and may be tempting for some who feel they are the target of a malicious or harassing lawsuit by a patient or their representatives. However, the likelihood of success in a countersuit is quite poor. In a successful countersuit, the healthcare provider must prove the patient had malicious intent when filing a lawsuit in the first place.

25.6 Psychological Impact and Effect on Practice

The legal process can be lengthy and disruptive. As a result, this can lead to trauma with personal and emotional sequelae [16, 17]. Specifically, medical malpractice stress syndrome (MMSS) bears resemblance to post-traumatic stress disorder (PTSD) and occurs after a healthcare provider is sued. MMSS typically manifests as anger, inability to concentrate, or irritability among many others [18]. Some physicians may choose to self-medicate during this process leading to substance abuse problems that may affect the day-to-day operations thereby compromising patient care [18]. Therefore, it is imperative the physician accused of malpractice seeks support, reflects on career positives, maintains hobbies, and engages the legal process by participating actively in his defense. These actions might allow a healthcare provider to avoid internalization of negative feelings and possibly mitigate stress secondary to litigation.

Closed claims database

In 1985, the closed claims database was developed by the ASA to study anesthesia-related injuries resulting in medical malpractice claims. Notable trends include decreasing surgical anesthesia claims but increasing acute and chronic pain management claims [19]. The following are common groups of claims in the database: death, 34%; nerve damage, 16%; brain damage, 12%; and others, 38% [12]. Notably, monitored anesthesia care (MAC) is associated with the highest incidence of death and permanently disabling injury. Among obstetric anesthesia claims are maternal death, 22%; newborn brain damage, 20%; and headache 12% [19].

25.7 Conclusions

Anesthesiologists should carry medical malpractice insurance to protect personal assets from potential lawsuits. While litigation can be highly stressful for physicians and their families, increased knowledge, understanding, and documentation processes can be useful tools. Methods to minimize the risk of liability should be added to the anesthesiologist's armamentarium. Generally, it is agreed that effective communication as well as obtaining informed consent preoperatively and practicing within the standard of care as determined by peer review are important tools used to minimize the risk of liability. Additionally, adequate documentation and an appropriate response to a medical error or a bad outcome may further decrease the chances of a lawsuit.

Recommended Resource for Further Reading

Resource	Brief description
Manual on professional liability: An informational manual compiled by the ASA Committee on professional liability (► http://monitor.pubs.asahq.org/article.aspx?articleid=2435869&_ga=2.231724316.225485226.1498174565-2045035840.1495231300)	An in-depth manual written by the ASA in 2010 that details specific information about professional liability in anesthesia while providing checklists and additional resources
Additional resources	
National Practitioner Data Bank ► https://www.npdb.hrsa.gov/	
Anesthesia closed claims project ► http://depts.washington.edu/asaccp/welcome-anesthesia-closed-claims-project-its-registries	

25.8 Review Questions

1. Which of the following concepts are included in the definition of malpractice?
   A. Duty
   B. Dereliction
   C. Damages
   D. Direct cause
   E. All of the above
   (These are the four D's of malpractice. Each of these elements is required to meet the criteria for malpractice.)

2. Which of the following are appropriate steps to take to minimize potential liability?
   A. Good communication between physician and patients as well as family member
   B. Obtaining appropriate informed consent and adequate recordkeeping
   C. Adhering to the standard of care
   D. All of the above
   (In addition to all of the above, appropriate management of a negative outcome will further mitigate the risk of a lawsuit.)

3. Countersuits are often successful. True or false?
   A. True
   B. False
   (To be successful in a countersuit, the healthcare provider must prove there was malicious intent.)

25.9 Answers

1. E
2. D
3. B

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Medical Malpractice

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_26

26.1 Proof of Malpractice

For medical malpractice to occur, a healthcare provider (hospital, physician, nurse practitioner, etc.) causes an injury to a patient through a negligent act or omission. The negligence could be due to errors in diagnosis, treatment, or follow-up care. A plaintiff who asserts medical malpractice on the part of a healthcare provider has to prove (1) the recognized standard of acceptable professional practice in the profession and specialty as it relates to the circumstances of the case (duty); (2) that the provider failed to act in accordance with the acceptable standard of care (breach); (3) as a proximate result of the breach, the patient suffered injury that would not have otherwise occurred (causation); and (4) patient incurred damages as a result of the injury (damages). Monetary damages, if awarded, typically take into account both actual economic loss and noneconomic loss, such as pain and suffering.

26.1.1 Duty

When the patient is seen preoperatively and the anesthesiologist agrees to provide anesthesia care for the patient, a doctor-patient relationship is established, which creates a duty to the patient.

In the most general terms, the duty that the anesthesiologist owes to the patient is to adhere to the "standard of care" for the treatment of the patient. This "standard of care" means that a physician will act with the same degree or skill as any reasonable and prudent doctor under the same or similar circumstances at the time of the treatment in question. The standard of care encompasses the training, education, and skills of a similar physician facing the same or similar circumstances. In most claims for medical malpractice, the standard of care must be determined by expert testimony as a layperson, a typical juror, cannot determine from their own knowledge and experience how a physician would act under the same or similar circumstances. Currently 29 states and Washington, DC, require only that a claimant demonstrate a "national standard of care" through expert testimony. In practical terms, this means that an anesthesiologist may be held accountable for his or her actions according to what any reasonable and prudent anesthesiologist, from anywhere in the United States, would do or not do under the same or similar circumstances as testified to by an expert. Other states adhere to a "locality" rule. In this circumstance, the anesthesiologist is held to the "recognized standard of acceptable professional practice in the profession …in the community in which the defendant practices." Under the "locality rule," the question is whether the physician acted in accordance with what a physician in the same or similar locality (a contiguous state) would have done, which has to be proven by an expert familiar with the community in which the anesthesiologist practices. In *Shipley v. Williams*, 350 S.W. 3d 527, 553 (Tenn. 2011), the Tennessee Supreme Court recognized that "the national standard is representative of the local standard" allowing expert testimony as to a national standard of care after it has been established that the expert is familiar with the community in which the defendant provider practices [2].

26.1.2 Breach of Duty

During trial, the jury must determine if the anesthesiologist either did something that should not have been done or failed to do something that should have been done. Both sides will present testimony from experts as to what duty was owed to the patient by the anesthesiologist and whether or not the anesthesiologist acted according to the standard of care of anesthesiologists in that community or on a national level as it relates to the circumstances of the case at issue. In other words, did the anesthesiologist act in a reasonable and prudent manner in the specific situation and fulfill his or her duty to the patient? If the jury finds that a breach of that duty occurs, the jury will then have to determine whether that breach was the cause of the patient's injury.

26.1.3 Causation

The legal definition of causation varies significantly with the intuitive medical understanding of a "cause" of harm. The proof of causation in medical malpractice hinges on the following concepts:

1. The injury would not have occurred but for the action of the anesthesiologist (but for causation).
2. The action of the anesthesiologist was a substantial factor in the injury despite other causes (proximate or legal cause).

3. The preponderance of evidence (>50%) shows that the actions of the anesthesiologist were at fault (more likely than not).
4. The "facts" speak for themselves (res ipsa loquitur).

26.1.3.1 Res Ipsa Loquitur (The Facts Speak for Themselves)

The doctrine of res ipsa loquitur is often alleged against anesthesiologists in malpractice suits. In order for the doctrine of res ipsa loquitur to apply, two requirements must be met. First, the plaintiff has to prove that in the absence of negligence, the injury would not typically occur. In other words, the "facts speak for themselves" that negligence occurred. Second, any injury must have been caused by something under the exclusive control of the anesthesiologist. The application of this doctrine is somewhat controversial as complications and bad outcomes from medical treatment can occur absent any negligence on the part of a provider. Under anesthesia, patients have been rendered insensible and are unable to protect themselves from their environment. The anesthesiologist has placed the patient in this situation and is presumed to have exclusive control over the patient. For example, in an Indiana case, the res ipsa loquitur doctrine was found to apply in a malpractice lawsuit filed against an anesthesiologist and hospital where a board supporting a patient's arm during surgery became detached leaving the arm dangling toward the floor for an unknown period of time. The anesthesiologist repositioned the patient's arm but the patient suffered an injury to the nerves in the affected limb. While others may have also had control over the patient during surgery, the court in *Thomson v. Saint Joseph Regional Medical Center*, 26 N.E.3d 89 (Ind. Ct. App. 2015) found that multiple persons could have exclusive control as they too had a duty to monitor the positioning of the plaintiff's arm during surgery [3]. However, in *Magette v. Goodman*, 771 A.2d 775 (Pa. Super. Ct. 2001), the superior court held in part that the trial court did not act erroneously in declining to instruct the jury as to the doctrine of res ipsa loquitur as the plaintiff failed to establish the requirements of this doctrine in which the patient died during surgery as death can occur while under anesthesia in the absence of any negligence on the part of the anesthesiologist [4].

26.1.4 Damages

For a medical malpractice case to be viable, the patient must show that significant damages resulted from an injury received due to the medical negligence. If the damages are small, the cost of pursuing the case might be greater than the eventual recovery. The types of damages alleged by a plaintiff may include that the injury resulted in disability, loss of income, pain and suffering, hardship, or significant past and future medical bills. Furthermore, a surviving spouse or parent may sue on behalf of a deceased patient for the wrongful death of their spouse or child, which would include damages relating to the value of the deceased patient's life and damages relating to services provided by that spouse such as childcare or housekeeping. Damages are grouped into several categories:

- Pain and suffering which directly result from the injury (general)
- Actual damages as a consequence of the injury such as medical, lost income, funeral, etc. (special)
- Punishment for wanton, fraudulent, willful, or reckless negligence (punitive)
- No intent to punish the physician but to make an example of the case to prevent any other physician from doing the same thing (exemplary)

Thirty-five states have passed laws imposing statutory caps on certain types of damages, particularly on noneconomic damages and punitive damages [5]. These laws limit the amount and type of damages that can be recovered against a physician. Recently, the United States House of Representatives drafted a bill, H.R. 4771, the Help Efficient, Accessible, Low-cost, Timely Healthcare (HEALTH) Act of 2016, which in part proposed a cap of $250,000 on noneconomic damages, like pain and suffering. This bill was opposed by the American Bar Association [6].

26.2 Process of Trial

The legal system in the United States is based on adversarial advocacy, which promotes self-resolution of civil disputes. As a result, medical malpractice cases often do not proceed to trial. The trial process consists of (1) initial pleadings, (2) discovery, (3) depositions, (4) trial (5), and appeal [7].

26.2.1 Initial Pleadings

A healthcare provider will likely become aware of a lawsuit after being served with a complaint. Almost all states have some pre-suit requirements, such as giving notice to a physician of a claim before a complaint is formally filed in the court. For example, 22 states such as Florida, Massachusetts, Tennessee, and Texas currently require that a "certificate of good faith" must be filed alongside the initial complaint. This certificate must state that the plaintiff (or the plaintiff's attorney) has consulted with one or more medical experts who have themselves provided a written statement confirming:

- Competency and qualifications to express an expert opinion under state law
- A "good faith basis" to bring the medical malpractice lawsuit based on a review of the medical records and other evidence

Seventeen other states such as Indiana require that all proposed medical malpractice claims must be submitted to a medical review panel for review prior to proceeding to court [8]. In such a situation, a healthcare provider will become aware of a potential lawsuit well before a complaint is filed in the court. If a healthcare provider receives such a notice letter, that healthcare provider's insurance carrier should be notified immediately.

After the clinician is made aware of a potential claim or after the individual is served with a complaint, the insurance carrier will likely retain counsel on behalf of the defendant in the lawsuit. The clinician will meet with the appointed attorney to review and discuss the allegations raised by the plaintiff. The chart applicable to the facts of the alleged claim will be reviewed together in order for the attorney to file an answer to the complaint on behalf of the clinician.

26.2.2 Discovery

Between the filing of the suit and trial, an extensive period of information sharing and factual understanding between the plaintiffs and defendants (discovery) occurs. This process is facilitated by requests for documents, interrogatories, and depositions. A request for medical records, hospital billing information, and/or clinic note (documents) is usually the first step undertaken by a plaintiff's attorney. Once the case is filed, attorneys submit a list of questions from one party to another to gather preliminary and demographic information. The recipients must answer the questions under oath but do so with assistance of their attorneys.

26.2.3 Depositions

Depositions are formal proceedings in which a person involved in a lawsuit is questioned by counsel under oath with a recording made for later use in court. Typically, the patient's attorney will notify the attorney defending the doctor that a deposition of the doctor is needed. All parties agree upon a convenient time and place. Many defense lawyers prefer that the deposition take place in an area of the physician's comfort either the defendant physician's attorney's office or the defendant physician's office, if possible. A deposition begins with a court reporter administering the same oath that the party being deposed would take if the testimony were to be before a judge and jury. A verbatim record of all that is said during the deposition is then available to all parties for later use in court. Depositions of a defendant physician are usually attended by the attorneys for the plaintiff and any defendants named in the lawsuit, the court reporter, and, on occasion, other defendants named in the lawsuit and not being deposed and, sometimes, the patient or patient's family members. Only the attorneys may ask questions of the witness being deposed.

When an expert witness or the defendant physician is deposed, the plaintiff's attorney directly questions the physician. Afterwards, the defendant or expert witness is asked questions by counsel for any co-defendants named in the lawsuit or if necessary, by his/her legal team. This exchange of questioning continues until all questions by both parties are answered. Facts asserted during deposition can be used to contradict the physician's later testimony in court. Depositions provide advance notice of all of the significant clinical evidence and conclusions that each witness in a malpractice action expects to offer at the trial. Each legal team uses this adversarial process to determine how best to minimize and defeat the positions taken by a witness. In contrast to television and the movies, questions can be asked that may not be relevant or admissible at the trial, such

that many objections that would be raised at the trial do not apply. Essentially, the scope of what can be asked of a physician in a deposition is very broad. In "lawyer speak," discovery is often referred to as a "fishing expedition," in which an attorney is "fishing" for any and all information that may potentially be relevant to the lawsuit. Depositions are not only a useful tool for purposes of the trial, but these depositions are oftentimes used in dispositive motions, such as motions for summary judgment, and may also be evaluated in terms of settlement.

Treating physicians not named as defendants are frequently deposed. Each physician must carefully consider any informal conversations with either the plaintiff's or defendant's legal counsel about a patient's care without receiving an order from the court or consent of the patient due to HIPAA concerns. Furthermore, some states explicitly prohibit ex parte communications with a defendant physician's attorney about the treatment of a patient, which is the subject of a medical malpractice lawsuit, without that attorney first obtaining an order from the court.

26.2.4 Trial

During the trial, the burden of proof lies with the plaintiff who must through their attorney convince the jury that it was more likely than not that the physician was negligent. The "more likely than not" standard of legal proof required in medical malpractice litigation is significantly less demanding than the "beyond reasonable doubt" standard required to convict criminal defendants. In other words, an impartial jury, after hearing and considering all the information found during discovery, has to conclude there is a greater than 50% probability that professional negligence did occur in order for a physician to be liable (preponderance of the evidence).

In addition to proving that a breach of standard of care did not occur and that the actions of the defendant did not cause the plaintiff injury, the defendant anesthesiologist must remember that a jury is assessing the credibility of the witnesses and is deciding which position taken by the parties is most persuasive. The defendant physician through his or her counsel and with the use of his or her experts must convince the jury that the defense position is the most credible explanation of what took place concerning the subject patient. The defendant's appearance, attitude, and testimony can have immense impact on the final outcome.

26.2.5 Legal Fees: Impact in Medical Malpractice

Attorneys for the plaintiff are generally hired by the patient on a contingency fee basis. In other words, the lawyer collects payment only if damages are awarded. Criticisms of this payment model believe that it encourages medical malpractice lawsuits. These contingency fees apply to monetary damages awarded by a court and from settlement. Since most medical malpractice cases never go to jury trial, the 5–50% contingency fee applies regardless if the monetary awards are from the court or by agreement as a result of settlement.

In contrast, the defense legal team is appointed by the medical malpractice insurance company on behalf of the physician. All legal fees are typically paid by the defendant's insurance company. However, the defendant physician can hire his own personal legal counsel at his/her own expense if desired.

Medical malpractice lawsuits require hours and hours of physician and attorney time sorting through a complex medical record system, exhaustive research into the medical and legal literature, and multiple interviews with expert witnesses. The process of legal discovery and subsequent negotiations between the plaintiff and defense team may last several years, particularly if the case goes to trial. The financial cost to the plaintiff's attorney often exceeds "six figures" to pay fees for expert testimony, court costs, and court reporter fees in addition to the time and money to prepare the case in anticipation of the trial. It has been estimated that a plaintiff's costs are approximately 35% percent of the amount recovered if the plaintiff recovers anything for his or her claim [9].

26.2.6 Verdicts

What ultimately happens when patients sue? The results are often surprising to many physicians. According to the Physician Insurers Association of America, 61% of these cases are dropped or dismissed, and 32% are settled. Of the 7% who go to

trial, only 2% actually result in a plaintiff verdict. Physicians win 80% to 90% of the jury trials with weak evidence of medical negligence and even 50% of the trials where strong evidence of medical negligence occurred [10].

26.2.7 Appeals

Once a verdict is reached, the losing party can either file a motion for a new trial or appeal the result to the next higher court level. In some states, a dissatisfied plaintiff may appeal the amount of damages awarded to them when judgment is entered in their favor. A physician defendant may also appeal for a reduction in the amount of damages awarded. In general, a jury trial almost always ends with the "final say." Jury verdicts are overturned on appeal only if the law was applied incorrectly.

Additionally, as result of many states' pre-suit requirements for medical malpractice claims, many cases are dismissed by the trial court and appealed in the initial stages of a litigation due to an actual or perceived procedural defect in the initial filings by the plaintiff and his or her counsel. As such, these lawsuits may be dismissed without reaching the merits of the plaintiff's claim. Alternatively, if a defendant is unsuccessful at the appellate level concerning these procedural issues, the litigation process is prolonged.

26.2.8 Settlement

Many physicians may settle cases to avoid the nuisance, harassment, and financial risk inherent in jury trials. A verdict which exceeds the policy limit places the financial responsibility on the physician for the balance of defense and indemnity (sum of money paid as compensation) costs. Most insurance policies allow the physician to have input into the settlement decision, giving the physician the authority to decide whether to settle or proceed with litigating the claim (consent-to-settle clause). However, some professional liability insurance carriers can settle a claim over the objection of the policyholder.

Why would this occur? Payouts for medical malpractice claims are at least two times greater for claims that go to verdict than those that settled before trial.

When there is strong evidence to suggest that the standard of care was met, many reasons exist to forego settlement despite potential pressure from the insurance carrier to do so. Settlements, like adverse judgments, are reported to the National Practitioner Data Bank. State licensure status may be jeopardized and the physician's reputation damaged publicly. Medical malpractice insurance rates may increase, coverage terminated, and future insurance options more difficult to obtain.

In most published studies, the likelihood and size of a settlement payment correlate with the strength of the evidence supporting negligence on the part of the physician [11]. When juries and settlements err (based upon independent review), the error is more likely to favor the defendant physician than the plaintiff patient.

26.2.9 Expert Witness

In most trials, a witness does not render an opinion but instead states the facts as the witness perceives the events that occurred. Expert witnesses are routinely used in medical malpractice cases and are specifically retained by the plaintiff and the defense to render opinions. A "jury of peers" lacks the expertise to take the facts as presented by the "fact witnesses" and reach a conclusion. As a result, expert testimony is required to prove there was a breach of duty of care by the physician as well as causation. During discovery, there may be no evidence of malpractice concerning a particular provider resulting in a dismissal of a plaintiff's claim against that provider.

The American Medical Association "encourages physicians to recognize their ethical duty as learned professionals to assist in the administration of justice by serving as experts" [12]. As a result, some physicians serve in this role to discourage inappropriate medical practice and to improve patient safety. Others are motivated financially by the fees that the expert witness receives. Expert witnesses often request a retainer fee (>$2000), charge $350 per hour (or more) for file review/preparation and $500 per hour (or more) for testimony. Desirable expert witness characteristics include board certification in the specialty of the defendant physician, subspecialty experience and certification when appropriate, effective communication skills, unbiased testimony, and familiarity with the local standard of care.

Expert witnesses must have "knowledge, skill, experience, training, or education" which will "help the trier of fact to understand the evidence or to determine a fact in issue." *See*, e.g., Fed. R. Evid. 702. Under this broad standard, a family practitioner could provide expert witness against an anesthesiologist. Some states do require a physician testifying as an expert witness in a medical malpractice case to be of the same specialty as the defendant. Others may require an expert witness testifying in that state to be licensed there. In 2001, the United States Court of Appeals for the Seventh Circuit held that the American Association of Neurological Surgeons, a professional society, could discipline one of its members on the basis of testimony in a malpractice case [12]. In 2004, the American Society of Anesthesiologists (ASA) approved a mechanism for reviewing testimony of expert witnesses in closed cases as well as providing a means for suspension or expulsion from the ASA.

Anesthesiologists testifying for both sides are usually very experienced. Defense expert witnesses are more likely to have a higher scholarly impact and to practice in an academic setting. A higher proportion of plaintiff experts testify repeatedly in medical malpractice cases than their defendant counterparts [13].

26.3 Anesthesiology: At-Risk Specialty?

Medical malpractice lawsuits are a relatively common occurrence in the United States (Fig. 26.1). Many physicians intuitively believe that anesthesiology is an at-risk specialty for medical malpractice suits. The practice of anesthesiology can be considered an intersection of patient illness, highly invasive procedures/techniques, and potentially lethal drugs. Furthermore, the anesthesia care team model invokes vicarious liability from supervision of mid-level care providers such as certified nurse anesthetists and anesthesia assistants. Anesthesiologists may be named in lawsuits despite appropriate care on their part due to medical misadventures by other physicians.

Despite these risk factors, estimates indicate that 7% of more than 40,000 anesthesiologists in the United States have a claim filed annually against them with 2% resulting in indemnity payment. In comparison, this result is the same as the average of all physicians in the analysis of data from a large professional liability insurer with a nationwide client base. Of note, the frequency of indemnity claims did not correlate with the highest average payments [1].

26.3.1 Indemnity Payments: All Physicians

The highest average payouts usually occur for patients suffering quadriplegia, brain damage, and the need for lifelong care. The mean indemnity payment was $300,000 with a median of $110,000 across specialties. The difference between mean and median reflects a skewed distribution toward large payments of more than $1 million in some specialties such as obstetrics and gynecology, pathology, anesthesiology, and pediatrics [1].

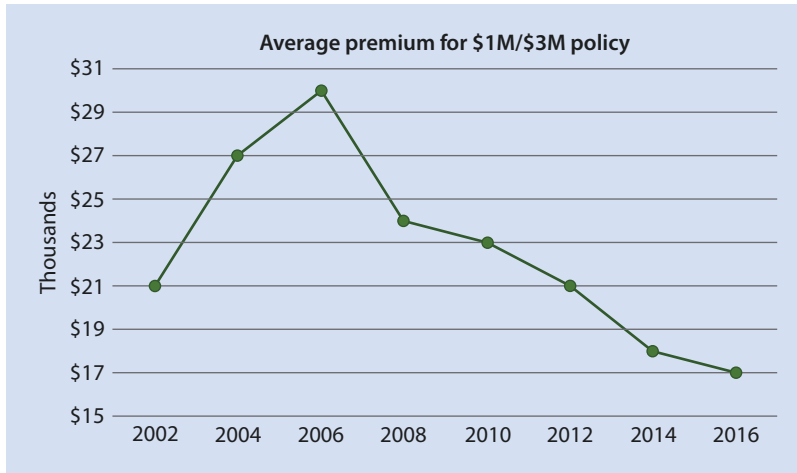

Fig. 26.1 Graph showing the 2016 malpractice payments against physicians

26.3.2 Indemnity Payments: Anesthesiologists

According to the American Society of Anesthesiologists closed claim analysis, the most common injuries from medical practice from 1990 to 2007 were death (26%) and nerve injury (22%) [14]. A more recent review of anesthesia-related mortality and morbidity trends reported by a large national malpractice insurance company revealed that death (18%) and nerve injury (14%) were again the most common injuries when dental damage was excluded. The average indemnity payment for an anesthesia claim was $309,066, compared to $291,000 for all physician specialties [15].

26.3.3 How to Minimize the Risk of Liability

Patients who sue are more likely to be unhappy with the interpersonal relationship with their physician than the actual outcome of the care they received. Following an adverse event, patients report greater satisfaction and are less apt to sue when they perceive the physician as personal, communicative, and caring. When a complication occurs, the physician should be open, honest, and readily available. In the event of a complication that may or may not be caused by physician negligence, the physician should closely collaborate with the hospital's division of risk management to proactively approach the patient and/or the family and decide upon a corrective course of action. Zhou et al. demonstrated that successfully passing the oral primary certification examination in anesthesiology is associated with a decreased risk of subsequent license actions including those due to malpractice [16].

26.3.4 Adverse Events

If an adverse event occurs, the physician may have difficulty recalling specifics about the case at a time remote from the procedure. Anesthesia providers should document adverse events not only in the anesthesia record but also the main medical record by (1) describing pertinent details without speculation ("just the facts"), (2) establishing the course of action and any recommended follow-up, (3) recording communication with other services and care providers, and (4) detailing all patient visits and conversations with the family including who was present each time. Documentation in the medical record is essential as the anesthetic record is not reviewed by most clinicians.

A provider should not admit a wrongdoing in the written medical record. Events may be interpreted differently later when new information becomes available. Accusations blaming other services of wrongdoing after an adverse event make the whole institution's care appear substandard. Lawyers representing plaintiffs benefit from physicians pointing fingers at each other.

26.3.5 The Medical and Anesthesia Records

In making written records in practice, a physician should not cross out incorrect entries in the medical record. Instead, the clinician should place one horizontal line through the incorrect entry leaving it legible. Then, the provider would add the correct information with date, time, and signature. If possible, the preferred method is to place an addendum elsewhere in the record without altering the original entry. Events should be described as they unfolded without speculation. As discussed in detail below, medical records should not be altered upon notice of a lawsuit.

The impact of electronic medical records (EMR) on medical malpractice liability has yet to be fully appreciated. Four core functional areas of anesthesia information systems are present in all EMRs, namely, documentation of clinical findings, laboratory and imaging findings, computerized order entry, and clinical decision support. In some malpractice cases, the documentation within EMRs may establish a provider's guilt, whereas in others it may help mount a defense. For example, gaps in documentation of vital signs would be readily apparent in an electronic anesthesia record where these measurements are automatically recorded. All data in an EMR is time stamped (metadata). This electronic footprint can be used to determine when documentation actually occurred. The discoverability and permissibility of metadata in malpractice litigation is determined by state law. In the era of

paper records, some anesthesiologists commonly recorded their standard documentation, such as the presence on induction, at less hectic times of the procedure. Examples exist in closed medical malpractice claims where metadata proved that a postoperative note actually occurred minutes after surgery began. A paucity of research currently exists to determine the risks and benefits of an EMR specifically as it applies to the practice of anesthesiology [17].

26.3.5.1 Notice of a Lawsuit

A clinician should notify the insurance carrier immediately upon receipt of a notice of a lawsuit. Additionally, the physician should gather all pertinent records, including a copy of the anesthetic record, billing statements, and correspondence concerning the case. Upon review of the medical record, a clinician should not alter any previous entry or discuss the case with anyone, including colleagues who may have been involved, operating room personnel, or friends. For a successful defense to occur, physicians named in the suit must cooperate fully with the attorney provided by the insurer in answering the complaint.

26.4 Medical Malpractice Insurance

Medical malpractice insurance is considered a "necessary evil" by most anesthesiologists. Most anesthesiologists will not consider practicing medicine without professional liability insurance. "Going bare" is a relatively uncommon practice but has adherents who believe that the cost of medical malpractice insurance is simply too high or that a lack of insurance will lessen the likelihood of being a "deep pockets" target. Most hospitals mandate medical malpractice coverage for independent anesthesia providers. The vast majority of anesthesiologists now purchase a "claims-made" policy with individual claim and annual aggregate limits of $1 million and $3 million, respectively. According to the American Society of Anesthesiologists, only 21% of insurance companies wrote mainly or exclusively occurrence policies.

Term	Definition
Insurance options	
Purchase	A contract with a commercial company for coverage against liability claims and when damages are awarded
Self-insure	A monetary fund is established for use in defense of liability claims and when damages are awarded
"Going bare"	A medical provider is practicing without professional liability or medical malpractice insurance
Limits	
Individual claim	Maximum payment for any individual claim
Annual aggregate	Maximum payment for the entire year
Policy type	
Claims made	Covers any claim made and filed during the policy period
Tail	Covers any claim made during the policy period but filed after the policy period has ended
Occurrences	Covers any claim made during the policy period irrespective of when the claim was filed
Terms	
Premium	Money paid for professional liability coverage
Consent to settle	The physician must give approval to the insurance company to settle a claim

The average premium for mature $1 M/$3 M policies has steadily declined (Fig. 26.2) with an average annual premium of $17,000. The variation in premiums from state to state is significant and dependent upon multiple factors to include the provider's personal claim history, urban vs. rural location, and region of the country (Fig. 26.3) [18]. In contrast to popular belief, physicians are often the "victors" in malpractice suits. Studies show that physicians successfully defended

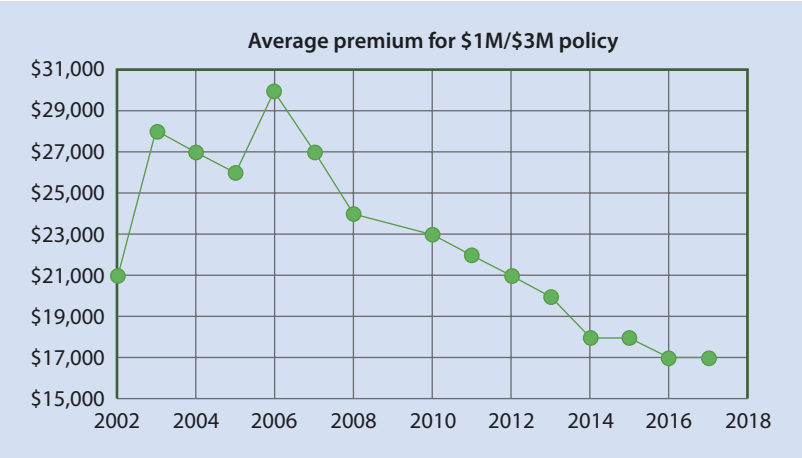

Fig. 26.2 The average premium for $1M/$3M

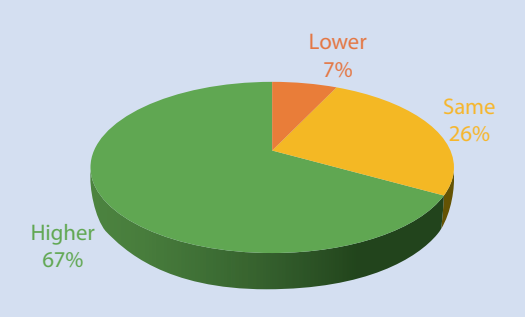

Fig. 26.3 Malpractice premiums: pain versus anesthesiology

80 to 90% of the time when weak evidence was presented to jury as to breach of the standard of care. Even when there is strong evidence of medical negligence, 50% of juries find in favor of the physician defendant [19].

26.5 Professional Liability (Tort) Reform

Many physicians and legislators have lobbied vigorously for tort reform. Historically, reasons for tort reform have centered on the increased costs of medical malpractice insurance premiums for both hospitals and individual providers. Also, most people assume the risk of excessive judgments awarded in medical malpractice lawsuits escalates the overall cost of healthcare to the consumer. Decreases in the amount of the plaintiff's average award and the number of medical malpractice lawsuits being filed usually occur in states that have passed tort reform laws.

Areas where tort reform have focused include the following:

26.5.1 Noneconomic Damages Cap

A limitation on the amount awarded for noneconomic damages such as loss of consortium or pain and suffering is often the first step in state tort reform. Earnings loss and medical bills attributed to the injury are less likely to be limited. Certain states combine the cap to include both economic and noneconomic damages. Currently caps range from $250,000 (noneconomic damages) to over $2 million dollars (economic and noneconomic damages combined). Caps on damages are controversial topics particularly to the plaintiffs and their attorneys. Many states which have successfully passed tort reform that specifically target caps on damages have seen these laws rule unconstitutional by the state supreme court.

26.5.2 Provider Apology

Any comment which can be viewed to be an admission of wrongdoing can be used as an admission of liability in some states. A simple apology or expression of sympathy by the providers can be used against them in court. Other states have statues governing tort law that prohibit this from occurring.

26.5.3 Joint and Several Liability

Many anesthesiologists believe that the limits of their liability policies should be at a minimum value ($500,000/$1,000,000 as opposed to $3,000,000/$5,000,000 or higher) for fear of becoming the "deep pocket." Under the doctrine of joint and several liability, if an injury occurs, a plaintiff may purse a claim against any one party (the "deep pocket") as if they were jointly liable with the other party for the injury. The purpose of this doctrine is to compensate a plaintiff ("make them whole") for their injuries when another defendant is insolvent. While pure joint and several liability still exists in some states in this country, several states have modified or abolished this doctrine as part of tort reform. In states that adhere to modified joint and several liability, a solvent defendant may only be responsible for the entire verdict if the percentage of fault attributed to that defendant meets a certain threshold. Other states subscribe to several liability where a defendant is only responsible for the damages that correspond to the percentage of fault allocated to the defendant by the fact finder.

26.5.4 State Patient Compensation Funds

Many states mandate that an anesthesiologist or certified registered nurse anesthetist have medical malpractice coverage but limit the provider's legal liability to a fixed amount. Any amount awarded for damages in excess of the provider's limits is paid out of a designated state fund. The state fund pays for larger settlements and awards for damages reducing what the primary insurance companies must pay (excess liability fund or excess coverage fund). For example, in Louisiana any individual award in excess of $100,000 shall be paid from the patient compensation fund, while in Indiana the fund makes payments for individual awards in excess of $250,000. In contrast, New York's patient compensation fund starts payment when the award exceeds $1.3 million. As a result, the clinician becomes a lower risk allowing the insurance carrier to offer a more competitive premium. The average premium for malpractice coverage in states where a patient medical malpractice compensation fund exists is usually among the lowest in the country. Of note, New York's premium rates are still the highest in the country. Currently nine states (IN, KS, LA, NE, NM, NY, PA, SC, and WI) have active patient compensation funds. Many other advantages often exist when physicians practice in states with patient compensation funds. Medical malpractice claims are reviewed by an approved commission for legitimacy before damages are awarded reducing frivolous claims. States with patient compensation funds often also have a statute of limitations on claims, monetary caps on damages, and limits on attorney fees. Opponents of PCFs emphasize that some states limit the total amount paid by the funds each year by waiting until the money is available or by paying out larger awards over time.

26.5.5 Contingency Fees

Some states have abolished contingency fee arrangement between plaintiffs and their attorneys in medical malpractice cases. The lawyer is paid a fixed percentage of the amount finally paid to the client. If the plaintiff loses, neither the plaintiff nor the lawyer will be awarded money.

26.5.6 Collateral Source Rule

Some plaintiffs request payment for damages that are eventually paid for by health or disability insurance and not by the plaintiff. Some plaintiffs request payment for damages that are eventually paid or have been paid for by health or disability insurance and not by the plaintiff. The collateral source rule is a rule of evidence that states that evidence that the plaintiff has received compensation from another source other than the damages sought from the defendant is inadmissible. Tort reform advocates argue for the abrogation of this rule so that the plaintiff can ultimately only recover damages for those expenses that were paid by the plaintiff or on the plaintiff's behalf as opposed to what was charged, but not ultimately paid by the insurance company. Some states have abrogated this rule in context of medical malpractice cases.

26.5.7 Punitive Damages

Punitive damages are awarded in addition to actual damages as a way of punishing the defendant. Many states limit the amount of punitive damage awards to a percentage of the compensatory award or by a flat cap.

26.5.8 Expert Witness

In several states, through tort reform, a medical expert that is to testify against a defendant must now be board-certified in the same specialty as the defendant. Some states limit the geographic location of experts testifying in their courts by requiring them to be licensed in that state "or a contiguous state" during the year prior to the incident, which is the locality rule as discussed above.

26.5.9 Certificates of Merit/"Good Faith"

In other states, tort reform includes additional measures meant to ensure that only cases with merit reach the jury. As mentioned supra, several states have passed pre-suit requirements including filing a certificate of good faith as part of tort reform. In Tennessee, as a result of passing laws as to pre-suit notice requirements, specifically filing a certificate of good faith, medical practice suits fell 36%, and medical malpractice premiums decreased 40% [20].

26.5.10 Loss of Chance

Traditional standards for negligence in medical malpractice cases require the plaintiff to prove that the physician's deviation from standard of care "more likely than not" caused the injury. When a patient has <50% chance of survival before the presumed negligence occurred, the usual standard of "more likely than not" would prevent successful litigation on behalf of the plaintiff. However, a plaintiff may have a "loss of chance" claim if it is proven that a favorable outcome to the plaintiff was more likely than not diminished due to the negligent conduct of the provider.

For example, a patient with less than a 50% chance of survival following a motor vehicle accident undergoes emergency surgery, develops anaphylaxis from antibiotic therapy, and dies intraoperatively. A review of the medical record documents that a family member clearly relayed an allergy to the antibiotic administered prior to surgery. If the plaintiff's expert witnesses can convince a jury that the decedent would have had a 10% survival chance except for the medical negligence of the physician, then the jury could find that the patent's heirs would receive compensation for the 10% chance of loss of life [21].

26.6 Cyber Liability

Over the last several years, millions of people have had their personal health information (PHI) "hacked" by cyber criminals. This loss of private information can place patients and physicians at much greater financial risk than simple credit card fraud. The personal identity theft can escalate to both prescription and insurance fraud.

26.6.1 HITECH

The Health Information Technology for Economic and Clinical Health Act of 2009 (HITECH) mandates that entities protect against unauthorized use or disclosure of PHI which includes not only the physician practice but also any business associates. Any unauthorized acquisition of PHI is presumed to be a data breach and must be reported to the federal government unless there is no significant harm to the individual. This risk for "potential harm" is based on a four-factor test:

1. Nature and extent of PHI disclosed
2. Who was the unauthorized viewer/user of the PHI
3. Whether the PHI was used or viewed
4. Whether the risk was mitigated

According to the Department of Health and Human Services (HHS), a stolen or lost laptop computer or mobile device with unencrypted PHI accounts for 60% of unauthorized disclosures and 16% (almost 30 million) of patients. In contrast, computer hacking by criminals account for 9% of the total number of disclosures of PHI affecting almost 100 million patients.

26.6.2 Costs of a PHI Breach

The Office for Civil Rights within HHS determines the level of fault and subsequent fine. The level of fault will likely be considered willful neglect if the physician practice has not implemented privacy rules that meet Health Insurance Portability and

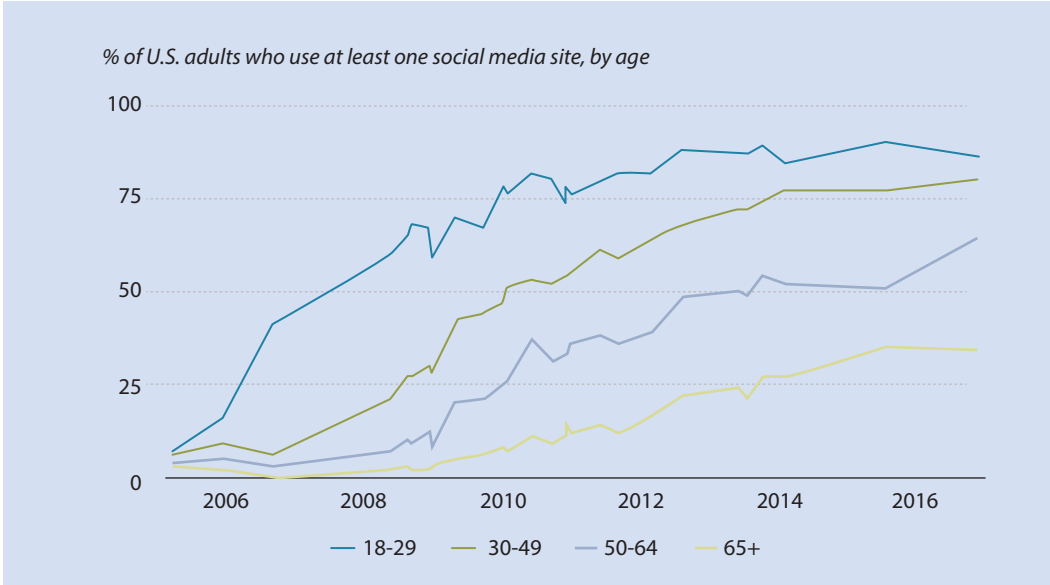

Fig. 26.4 Percentage of adults in the United States who use at least one form of social media, by age

Accountability Act (HIPAA) standards. The financial implications of a breach in patient PHI can be disastrous to an individual or group practice. The fines which can be imposed by OCR are as high as $1.5 million per year per type of violation. Other costs include patient notification, credit monitoring services, and expert consultations (public relations, legal counsel, information technology, etc.).

26.6.3 Cyber Liability Insurance

The potential costs of a breach in protection of patient PHI are enormous. Many believe that decision to purchase cyber liability coverage is not a "yes or no" decision, but rather what limits of liability should be obtained. Some medical malpractice insurance coverage policies provide cyber liability coverage. Careful evaluation is needed to determine if there is coverage for both electronic and "hard copy" PHI and breaches by business associates. The costs covered by the policy should include fines, patient notification, legal fees, cyber extortion, data recovery, and credit monitoring [22].

26.7 Social Media Liability

The use of social media like LinkedIn, Facebook, Twitter, Instagram, etc. have exploded in use from an estimate of 5% of the Internet users in 2005 to 69% in 2017 across all ages (Fig. 26.4) [23].

The online resources such as available to physicians UpToDate and PubMed have changed the practice of medicine. Social media allows for two-way communication online between healthcare providers and those seeking medical information. As a result, many view social media as an invaluable platform for health communication to the general population as well as addressing the specific questions by individual patients. Unfortunately, the use of social media has inherent liability risk. To minimize these risks, healthcare providers should follow several principles. First, remember that every post is "public" and "permanent" even if you thought it was a "private" discussion [24]. Physicians should avoid giving specific answers to particular medical questions to an online post without giving disclaimers that your thoughts are for information only and that patients should seek advice from their personal physicians about their individual health needs. Nonetheless, any medical information posted online must be factual. Clinicians should follow customary disclosure practices when discussing any device, service, or medication for which you receive compensation. Practitioners should not post any information that can identify a patient (text, video, picture, or sound). Even when exchanging test messages between physicians about specific patient issues, the use of HIPPA compliant text messaging services as opposed to conventional SMS text messages is recommended [25]. Finally, physicians should be very cautious

about the use of social media or text messaging when providing patient care. Patients can and will misconstrue physician actions.

26.8 Review Questions

1. For a patient to be successful in proving medical malpractice, the patient must prove that the physician acted negligently while providing care and that this negligence resulted in injury.
   A. True
   B. False

2. Anesthesiologists in the United States:
   A. Purchase an "occurrences" $3 million/$5 million malpractice policy
   B. Are usually self-insured for medical malpractice
   C. Purchase a "claims made" $1 million/$3 million policy
   D. Are at greater risks for successful malpractice suits compared to their peers in other specialties due to res ipsa loquitur

3. States that have established patient compensation funds often:
   A. Place caps monetary caps on damages
   B. Establish a statute of limitations on claims
   C. Set limits on attorney fees
   D. Pay out larger awards over time
   E. All of the above

26.9 Answers

1. A
2. A
3. E

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Closed Claims Project Overview

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_27

27.1 V. Methods to Reduce Most Common Claims

27.1.1 History of Closed Claims Project and Its Registries

In the early 1980s, professional liability insurance coverage had become nearly unaffordable for many medical professionals due to soaring insurance premiums. Anesthesiologists were perceived as especially bad risks, representing only 3% of insured physicians but accounting for 11% of total dollars paid due to patient injury. Hypothesizing that the prevention of patient injury would result in a domino effect of decreased claims, a reduction of payments, and subsequently reduced liability insurance premiums, the Anesthesia Closed Claims Project was created in 1984 by the president of the American Society of Anesthesiologists (ASA), Ellison C. Pierce, Jr, MD, with the goal of identifying the major areas of anesthetic-related patient injury.

In 1984, a paucity of information existed on the scope and cause of anesthetic-related injury in the United States, largely because significant anesthesia injury is a relatively rare occurrence. One of the most cost-effective approaches to data collection was found to be the study of insurance company closed claims, which typically consisted of the hospital record, anesthesia record, narrative statements of the involved healthcare personnel, expert and peer reviews, and the cost of settlement or jury awards [1]. To date this initiative consists of the Anesthesia Closed Claims Project and its attendant Registries:

- Postoperative Visual Loss (POVL) Registry
- Anesthesia Awareness Registry
- Obstructive Sleep Apnea (OSA) Death and Near Miss Registry
- Neurologic Injury after Non-Supine Shoulder Surgery (NINS) Registry
- Pediatric Perioperative Cardiac Arrest (POCA) Registry

27.2 Postoperative Visual Loss

Visual loss after a surgical procedure is a rare but devastating complication. While some of the causes may be temporary or treatable, in most cases the damage is permanent. The major causes from most to least frequent are ischemic optic neuropathy, accounting for around 90% of registry cases of POVL, followed by retinal ischemia, cortical blindness, posterior reversible encephalopathy, and acute angle glaucoma. Due to the often irreversibility of the majority of cases, the focus as anesthesiologists is identifying patients at risk and minimizing risks to the greatest extent possible.

27.2.1 Ischemic Optic Neuropathy

Either the anterior or the posterior portion of the optic nerve can be damaged perioperatively from various causes and is therefore categorized as anterior ischemic optic neuropathy (AION) or posterior ischemic optic neuropathy (PION). Both forms manifest most commonly as painless vision loss postoperatively.

The anterior optic nerve is supplied by the posterior ciliary artery. When hypoperfusion occurs through the PCA from either arteritic or non-arteritic causes, ischemia may result. Arteritic AION can occur at any time in patients with conditions such as temporal arteritis. Non-arteritic AION can occur perioperatively in patients who have risk factors to such insults such as those with a history of vascular disease, diabetes mellitus, hypertension, hypotension, prone positioning during surgery, sleep apnea, and migraines [2, 3]. Cardiac surgery, including CABG, is most often associated with AION [4].

Posterior ischemic optic neuropathy may also be categorized as arteritic or non-arteritic. The non-arteritic form of PION occurs most frequently following spine surgery [4]. As in anterior ischemic optic neuropathy, PION-induced blindness occurs as a result of hypoperfusion of the optic nerve. Hypotension, anemia, increased venous pressure, the prone position, and ocular pressure perioperatively may be contributing factors [5, 6]. The prone position may lead to increased venous pressure and resistance to blood flow or direct orbital pressure. Avoidance of direct orbital pressure and the prone position, however, does not eliminate all cases of PION; therefore, the cause is possibly multifactorial [7–9].

While the incidence of ischemic optic neuropathy is higher in cardiac surgery patients, most cases of ischemic optic neuropathy are in spine surgery patients. A study comparing 80 cases from the ASA Postoperative Visual Loss Registry

to 315 controls found that obesity, male sex, the use of the Wilson frame, longer anesthetic duration, greater estimated blood loss, and decreased percent colloid administration were independently associated with ischemic optic neuropathy after spinal fusion surgery [10].

27.2.2 Cortical Blindness

Hypoperfusion or embolism of the posterior cerebral artery may result in ischemia to the occipital cortex perioperatively. This may result in partial or complete visual field deficits that may or may not be reversible. Causes of cortical blindness in the perioperative period include cardiac arrest, hypoxemia, intracranial hypertension, hemorrhage, vascular occlusion, thrombosis, intracranial hemorrhage, vasospasm, and emboli [11]. Treatment for suspected cortical infarct is as in any suspected cerebral vascular accident and depends on whether or not the insult is due to hemorrhage or ischemia. The prognosis may be improved with prompt diagnosis and treatment but in some cases may be irreversible.

27.2.3 Retinal Ischemia

Decreased perfusion to the retina may result in partial or complete visual field deficits. The retina is supplied by the central retinal artery. Systemic hypotension, occlusion from emboli or thrombosis, increased intraocular pressure from excessive external pressure, or impaired venous drainage can all result in central retinal artery occlusion (CRAO). Most commonly the deficits are unilateral. Painless vision loss results but may be accompanied by facial edema or trauma to the eye. Rapid diagnosis may result in possible treatment in cases of increased intraocular pressure. Improper positioning resulting in ocular pressure or impaired venous drainage from excessive prolonged Trendelenburg positioning may be avoidable causes [12].

27.2.4 Acute Angle-Closure Glaucoma

A rare form of perioperative ocular injury, acute angle-closure glaucoma, may result in permanent vision loss. Patients with a history of cataracts or genetic predisposition who receive certain medications including antihistamines, antiparkinsonian medications, anticholinergic agents, or others may present with ocular pain and blurred vision. Elevated intraocular pressures require urgent treatment from an ophthalmologist to lower intraocular pressure [13].

27.2.5 Posterior Reversible Encephalopathy

Commonly known as PRES, posterior reversible encephalopathy is an uncommon source of postoperative visual loss that may be accompanied by other neurological symptoms such as headache, seizures, or altered levels of consciousness. Patients with severe hypertension or other diseases that result in cerebral edema are at risk for PRES. Autoimmune diseases, malignancy, chemotherapy, infections, vasculitis, and preeclampsia are associated with PRES. As evident in the name of the condition, posterior reversible encephalopathy may be temporary with proper treatment [14].

27.2.6 External Ocular Injury

Trauma to the cornea is the most common cause of ocular injury in the perioperative period. Abrasions or lacerations may result in inflammation that can result in infection. Patients commonly complain of a painful irritation of the eye or a foreign body sensation. Most cases self-resolve, but ophthalmic consultation may be recommended when visual changes are present. Topical anesthetics or irrigation may be effective for pain relief.

As discussed previously in this section, postoperative visual loss (POVL) is a rare complication after surgery, and therefore specific causes are poorly understood. Most cases are irreversible; therefore, identification of patients at risk and prevention may be the most important steps to avoid this devastating complication. The ASA task force released an updated practice advisory in 2012 and made several recommendations [15]:

- Consider informing patients in whom prolonged procedures, substantial blood loss, or both are anticipated that there is a small, unpredictable risk of perioperative visual loss.
- Systemic blood pressure should be monitored continually in high-risk patients.

- The use of deliberate hypotension for spine surgery patients should be determined on a case-by-case basis.
- Central venous pressure monitoring should be considered in high-risk patients.
- Colloids should be used along with crystalloids to maintain intravascular volume in patients who have substantial blood loss.
- A transfusion threshold that would eliminate the risk of perioperative visual loss related to anemia cannot be established at this time.
- There is insufficient evidence to provide guidance for the use of alpha-adrenergic agonists in high-risk patients during spine surgery.
- Direct pressure on the eye should be avoided to prevent CRAO. The high-risk patient should be positioned so that the head is level with or higher than the heart when possible.
- Consideration should be given to the use of staged spine procedures in high-risk patients.

27.3 Neurologic Injury After Non-supine Shoulder Surgery

A rare but serious complication of shoulder surgery is catastrophic neurological injury such as stroke, spinal cord injury, ischemic brain injury, or death. While the exact causes of these infrequent complications are not fully understood, a number of mechanisms have been suggested. Paired with identification of patients with risk factors, prevention of this devastating complication is necessary to the extent possible.

27.3.1 Causes

Suggested possible causes for neurologic injury after non-supine shoulder surgery include the beach chair position [16–28] as well as reduced cerebral perfusion pressure resulting in ischemia [17, 18, 26, 29].

27.3.2 Risk Factors

Risk factors for neurologic injury after surgery have been categorized into patient risk factors, surgical risk factors, and perioperative adverse events. Patient risk factors are similar to those at risk for perioperative stroke, cerebrovascular disease, cardiovascular disease, atrial fibrillation, carotid artery disease, infective endocarditis, diabetes mellitus, and patent foramen ovale and include male gender, smoking, and advanced age. Surgical risk factors include major vascular, neurologic, and cardiac operations. Perioperative adverse events include cardiac arrest, dysrhythmias, embolic events, and severe hypotension.

Neurological injuries and ischemia after other types of surgery including shoulder surgery are less understood, and risk factors are less well defined [18, 29].

27.3.3 Prevention

As with any perioperative adverse event, prevention requires identification of patients with significant risk factors and minimizing the risks to the patient through all means available. While specific risk factors for neurologic injury in the non-supine shoulder surgery patient are difficult to identify, factors that contribute to neurological injury in general should be optimized in the perioperative period. The focus of these neuroprotection elements includes maintenance of cerebral perfusion pressure, blood glucose control, reducing embolic load, hypothermia, hemoglobin concentration, arterial CO2 tension, brain tissue oxygen tension, and osmotherapy [30]. While controlling many of these elements in the perioperative period for non-supine shoulder surgery is not feasible, some factors have been the focus of investigations.

27.3.3.1 Blood Pressure Management

Identification of appropriate blood pressure parameters to allow for sufficient cerebral perfusion pressure in the sitting position is still unknown. Traditional estimations of cerebral autoregulation between MAP of 50–150 mmHg may not be appropriate for all patients due to individual variation, particularly in the beach chair position [31, 32]. Cerebral perfusion pressure can decrease approximately 15% when the head is raised above the position of the heart. Blood pressure monitoring on the arm or the wrist therefore should take the reduction in cerebral perfusion pressure into account when managing in the perioperative period. While some authors advocate for a MAP within 20% of baseline, definitive recommendations are not available.

27.3.3.2 Neuromonitoring for Ischemia

Monitoring for ischemia in the sitting position may be done with an awake patient under regional anesthesia. For general anesthesia cases however, electroencephalography, transcranial Doppler, somatosensory evoked potentials (SSEPs), and cerebral oximeters may be used to monitor for cerebral ischemia. Cerebral oximeters have reported a high incidence of cerebral desaturation in patients in the beach chair position [19, 24, 33–35]. Cerebral desaturation events however have not been correlated with neurological injury. Transcranial Doppler may be limited by technical difficulty [35] or could not be performed due to the lack of a bone window in 10–15% of the population [36]. SSEPs are useful for regional but not global ischemia and may be of limited use in beach chair shoulder surgery [37]. Continuous electroencephalography is the most sensitive way to monitor for cerebral ischemia in the perioperative period [38–41]. Such monitoring however is limited due to the need of a trained neurophysiologist to interpret the electroencephalography and allow for interventions to correct ischemia.

27.3.3.3 CO2 Monitoring

Hypocapnea with mechanical ventilation can cause cerebral vasoconstriction. Continuous monitoring is necessary with general anesthesia in the sitting position. Establishment of the degree of Alveolar-arterial gradient may prevent relative hypocapnea in patients with altered pulmonary mechanics, such as those with chronic obstructive pulmonary disease (COPD).

27.4 Anesthesia Awareness

Awareness under general anesthesia is an infrequent but potentially terrifying experience for patients. As opposed to wakefulness which represents intraoperative patient arousal without the ability to remember the event, awareness can have significant consequences postoperatively. The incidence of awareness under anesthesia, or recall, varies depending on patient, surgical, and anesthetic factors present. Methods to reduce the incidence continue to be evaluated for success, but despite all available modalities, some patients continue to experience this complication.

27.4.1 Incidence

The overall incidence of anesthesia awareness under general anesthesia has been evaluated in multiple studies over many years and is most commonly cited to be between 0.1 and 0.2% [42–44].

27.4.2 Patient Risk Factors

A history of alcohol or drug abuse has been associated with an increased incidence of intraoperative awareness in some studies [45, 46]. Chronic drug or alcohol abuse may increase tolerance for anesthetic agents, thus resulting in an overall increased risk in such patients. Females have shown in some studies to be at higher risk than men for intraoperative awareness. It has been suggested that females emerge more quickly from anesthesia than their male counterparts [47, 48]. Higher incidences of awareness have been found in the young [44, 49–51] as well as the elderly [52].

27.4.3 Surgical Risk Factors

Cardiac surgery where cardiopulmonary bypass is used has been associated with an increased incidence of awareness. The range of awareness in such studies varies considerably but is above 1% in several studies [53–55]. Surgery for cesarean section likewise has been linked to an increase in awareness under general anesthesia compared to the overall incidence although not to the same degree as cardiac surgery [46, 56, 57]. Trauma surgery has been found in comparison to have much higher incidences of awareness. Studies have found as many as 40% of poly-trauma patients may experience awareness [58, 59]. In the above three surgical procedures, concerns or findings of the inability to tolerate the same levels of anesthetics have been discussed as possible reasons that these surgeries have a greater incidence of awareness.

27.4.4 Anesthetic Risk Factors

Despite the choice of using a total IV anesthetic, inhaled anesthetic, or a balanced anesthetic, awareness is still possible during surgery. Inhaled anesthetics can have equipment malfunction, loss of vaporizer, or lack accurate monitors to measure

their concentration. Total IV anesthetics rely on an uninterrupted flow into the venous system. Kinking of tubing or infiltration of veins may result in awareness under anesthesia. The administration of a balanced anesthetic compared to a total IV anesthetic may decrease the incidence of awareness [60].

Additionally the avoidance of the use of neuromuscular blocking drugs may add a degree of protection from awareness during anesthesia. The minimum alveolar concentration to prevent wakefulness is approximately 1/3 that required to prevent movement to surgical stress on average. The ability of the anesthesia provider to monitor for movement in response to surgical stress, rather than being masked by the use of paralytics, is another tool to prevent awareness. The use of neuromuscular blocking medications should be reserved for patients that cannot tolerate higher doses of IV or inhaled anesthetics or for surgical cases that require muscle relaxation. Several studies have supported this increase in awareness in patients that have received neuromuscular blocking drugs. One meta-analysis found that those receiving neuromuscular blocking drugs had almost twice the incidence of awareness compared to those patients who did not receive neuromuscular blocking drugs [61].

27.4.5 Sequelae of Anesthesia Awareness

Patients who experience awareness under anesthesia should be counseled about their experience as they are at increased risk for psychological disorders. These include post-traumatic stress disorder (PTSD) or other emotional disorders [47, 62]. In a review of reported cases in the literature, Ghoneim and others found that approximately 15–20% of patients who experienced awareness developed nightmares, sleep disorders, or daily anxiety [46]. Psychiatric or psychological counseling and treatment may be necessary for these patients who experience such complications.

27.4.6 ASA Practice Advisory

In 2006 the American Society of Anesthesiology issued a practice advisory for Intraoperative Awareness. The ASA appointed a task force of ten members to review literature, consult with experts in the area of awareness, and develop recommendations to help reduce the incidence of awareness under anesthesia.

Regarding preoperative evaluation, they recommend a history and physical assessment that focuses on risk factors for awareness under anesthesia including age, sex, and history of awareness and tolerance to drugs. They also recommend considering the type of surgery the patient will have as some surgical cases have an increased risk of awareness as described previously in this chapter. Only patients at increased risk for intraoperative awareness should be counseled on the possibility of awareness.

In the pre-induction phase, the task force recommends strict adherence to anesthesia machine and equipment checklist protocol. Many cases of intraoperative awareness can be prevented by proper identification of malfunctioning equipment including circuit leaks, vaporizer malfunction, or gas monitoring. The task force recommends that the use of amnestic drugs for awareness prophylaxis should be decided on a case-by-case basis.

Intraoperative monitoring should include the depth of anesthesia and should be multimodal. Clinical signs such as patient movement, as well as monitoring systems such as EKG, capnography, blood pressure, and end-tidal anesthetic concentration, should be used routinely to prevent awareness. The use of brain function monitors has expanded dramatically in the past 20 years. The task force agrees that such monitors should be considered in patients at increased risk of awareness perioperatively. They acknowledge that there is insufficient evidence to justify their use in high-risk patients as a standard. Their use, according to the task force, should be determined on a case-by-case basis.

Intraoperative and postoperative interventions in patients who are determined to have experienced awareness were investigated by the task force. They were unable to reach a consensus regarding the value of administering additional benzodiazepines or the administration of postoperative questionnaires in patients deemed to have experienced awareness. They did agree that a structured interview should be taken in these patients and that they should be offered psychological counseling [63]

A 2016 Cochrane Review of 160 randomized controlled trials focused on the use of various monitors as well as medication administration in

the prevention of intraoperative awareness. They found that anesthetic depth monitors had similar effectiveness in preventing awareness to the conventionally used clinical and electrical monitoring. They also found that benzodiazepines reduced awareness when compared to ketamine and thiopental. They also found that ketamine and etomidate reduced the incidence of wakefulness when compared to thiopental. Likewise not surprisingly, higher doses of inhaled anesthetic agents reduced wakefulness in comparison to lower-dose inhaled agents [64].

27.5 Obstructive Sleep Apnea Death and Near Miss Registry

Obstructive sleep apnea (OSA) is characterized by periodic, partial, or complete obstruction of the upper airway due to a reduction of pharyngeal muscle tone during sleep. Acutely this can result in episodic oxygen desaturation and intermittent hypercarbia, while, chronically, cardiovascular dysfunction due to systemic and/or pulmonary hypertension, cardiac dysrhythmias, and right heart failure (cor pulmonale) [58, 65] can ensue. The gold standard for definitive diagnosis is polysomnography (PSG) and utilizes an apnea hypopnea index (AHI), defined as the average number of abnormal breathing events per hour of sleep (apneic event refers to cessation of airflow for 10 s, while hypopnea occurs with reduced airflow and concomitant desaturation ≥4%) [66]. Severity of disease is based on an AHI, as follows:

- Mild OSA: AHI ≥ 5 but <15 per hour
- Moderate OSA: AHI ≥ 15 but <30 per hour
- Severe OSA: AHI ≥ 30 per hour

OSA is the most prevalent sleep-breathing disturbance, affecting 24% of men and 9% of women in the general population [67, 68]. Even more noteworthy are the estimates that nearly 80% of men and 93% of women with moderate to severe sleep apnea are undiagnosed [69]. The anesthetic implications of this are profound as untreated OSA patients are known to have a higher incidence of difficult intubation, numerous postoperative complications, increased intensive care unit admissions, and greater duration of hospital stay [70]. Hence, it is woefully inadequate to ask patients if they suffer from sleep apnea, as the reply will far too often be a misguided "no." Unfortunately, routine screening with PSG is both costly and resource-intensive, creating a substantial barrier to widespread use. To assist the anesthesiologist in diagnosing this prevalent sleep disorder during the preoperative evaluation, a variety of alternative screening tools exist. Published in 2008, the STOP Questionnaire was the first screening tool for OSA that was validated in surgical patients and consists of four simple yes/no questions:

- **S** – Do you snore loudly (louder than talking or loud enough to be heard through closed doors)?
- **T** – Do you often feel tired, fatigued, or sleepy during the daytime?
- **O** – Has anyone observed you stop breathing during your sleep?
- **P** – Do you have or are you being treated for high blood pressure?

Utilizing this screening tool, a patient is deemed to be at high-risk for undiagnosed OSA if two or more positive responses are obtained. To further increase the sensitivity of this screening tool, four additional variables were subsequently incorporated, resulting in the STOP-BANG questionnaire:

- **B** – BMI > 35 kg/m^2
- **A** – Age > 50 years
- **N** – Neck circumference >43cm (17 inches) in male and 41 cm (16 inches) in female
- **G** – Male gender

With respect to the STOP-BANG questionnaire, the likelihood of disease is based upon the following:

- **Low risk**: Yes to 0–2 questions
- **Intermediate risk**: Yes to 3–4 questions
- **High risk**: Yes to 5–8 questions or:
  - Yes to two or more of four STOP questions + male gender
  - Yes to two or more of four STOP questions + BMI > 35 kg/m^2
  - Yes to two or more of four STOP questions + neck circumference> 43cm (17 inches) in male and 41 cm (16 inches) in female

Various other questionnaires have been validated in the surgical population including those such as the Berlin Questionnaire and ASA Checklist, which will not be discussed further within this chapter (Table 27.1).

The inherent collapsibility of the upper airway and associated systemic effects of the disease place surgical OSA patients at increased risk of serious complications, including:

Table 27.1 Berlin Questionnarie and ASA Checklist

Berlin Questionnaire	ASA Checklist	STOP Questionnaire	STOP-Bang Questionnaire
Netzer [30]	Gross [32]	Chung [29]	Chung [29]
Clinician-administered	Clinician-administered	Self-administered	Clinician-administered
Validated in primary care setting and perioperative setting	Validated in perioperative setting	Validated in perioperative setting	Validated in perioperative setting
10-item	14-item	4-item	B-item
3 categories: Snoring, daytime sleepiness, driving	3 categories: predisposing characteristics, symptoms of OSA, complaints	No categories	No categories
High risk if 2 or more categories score positive	High risk if 2 or more categories score positive	High risk if 2 or more items score positive	High risk if 3 or more items score positive
For AHI >30	For AHI >30	For AHI >30	For AHI >30
Sensitivity 87%	Sensitivity 87%	Sensitivity 80%	Sensitivity 100%
Specificity 46%	Specificity 36%	Specificity 49%	Specificity 37%
PPV 32%	PPV 28%	PPV 30%	PPV 31%
NPV 93%	NPV 91%	NPV 90%	NPV 100%
For AHI >15	For AHI >15	For AHI >15	For AHI >15
Sensitivity 79%	Sensitivity 79%	Sensitivity 74%	Sensitivity 93%
Specificity 51%	Specificity 37%	Specificity 53%	Specificity 43%
PPV 51%	PPV 45%	PPV 51%	PPV 52%
NPV 78%	NPV 73%	NPV 76%	NPV 90%
Complicated scoring procedure	Clinician required to complete checklist	Concise, easy-to-use	Improve sensitivity compared with the STOP questionnaire

- Twofold higher risk of pulmonary complications in OSA patients after noncardiac surgery vs. non-OSA patients with OSA patients more likely to receive ventilatory support [71]
- Fifty-three percent incidence of postoperative delirium in OSA patients vs. 20% in non-OSA patients [72]
- Increased odds of postoperative cardiac events including myocardial infarction, cardiac arrest, and arrhythmias (OR 2.1), respiratory failure (OR 2.4), desaturation (OR 2.3), ICU transfers (OR 2.8), and reintubations (OR 2.1) [73]

It should be mentioned that while sleep apnea can be classified as either (a) obstructive sleep apnea (OSA), (b) central sleep apnea, or (c) mixed sleep apnea, this registry and its recommendations focus solely on obstructive sleep apnea, the most common form. Central sleep apnea, defined as the cessation of airflow without respiratory effort [74], affects very few patients and is of little concern to the anesthesiologist, except under three circumstances [75]:

- Central sleep apnea with snoring – patients should be treated as if they have OSA.
- Central sleep apnea due to heart failure.
- Central sleep apnea with hypoventilation syndrome – patients may require unanticipated assisted ventilation during surgery and postoperatively.

Aside from its vast anesthetic implications, chronic untreated OSA leads to multisystem disease and is an independent risk factor for

increased all-cause mortality in the general population [76, 77]. It is for these reasons that the Society of Anesthesia and Sleep Medicine and the Anesthesia Closed Claims Project established the Obstructive Sleep Apnea (OSA) Death and Near Miss Registry – to investigate unanticipated perioperative deaths and near misses in patients with OSA and identify common themes or factors associated with OSA-related adverse perioperative events. Inclusion criteria for cases submitted to this Registry include:

- Age of 18 years or older
- Event occurred between 1993 and 2016

Given the overwhelming evidence linking the diagnosis of OSA with adverse perioperative outcomes, precautions, specifically emphasizing airway maintenance and frequently associated cardiopulmonary abnormalities, should be taken to reduce complications in this group of patients. In 2014, the ASA Task Force on Perioperative Management of Patients with Obstructive Sleep Apnea released updated practice guidelines and made several recommendations [78]; a comprehensive, but not complete, list follows.

27.5.1 Preoperative Evaluation

- In patients with the possibility of OSA, a protocol should be established to allow evaluation preoperatively with ample time for preparation of a perioperative management plan.
- Preoperative evaluation should include a comprehensive review of previous medical records, if possible.
- Review of sleep studies is encouraged.
- If preoperative evaluation suggests that a patient has OSA, a joint decision between the anesthesiologist and surgeon should be made regarding the necessity of a formal sleep study and possible indicated OSA treatment prior to surgery.
- The patient and his/her family, as well as the surgeon, should be informed of the potential implications of OSA on the patient's perioperative course.

Of paramount importance is how to integrate the known or suspected OSA patient into today's healthcare climate that often focuses on the delivery of outpatient surgery for a variety of medical procedures. ASA guidelines on the perioperative management of OSA patients advise that superficial surgery, minor orthopedic surgery under local/regional anesthesia, and lithotripsy may be performed as day surgery cases [79]. In 2012, the Society for Ambulatory Anesthesia (SAMBA) developed a consensus statement addressing OSA patients and ambulatory surgery that is summarized below (see Fig. 27.1) [80].

Lastly, the need for high-dose oral opioids in the postoperative setting is often a contraindication for ambulatory surgery in the OSA patient to the risk of respiratory compromise that may go unrecognized following discharge.

27.5.2 Preoperative Preparation

- Consider preoperative initiation of continuous positive airway pressure (CPAP), particularly if OSA is severe. Consider noninvasive positive pressure ventilation if response to CPAP is not adequate.
- Patients with known or suspected OSA may have difficult airways and should be managed according to the "Practice Guidelines for Management of the Difficult Airway: An Updated Report."

27.5.3 Intraoperative Management

- Due to the propensity for airway collapse, patients with OSA are highly susceptible to the respiratory depressant and airway effects of sedatives, opioids, and inhaled anesthetics; therefore, the potential for postoperative respiratory compromise should be considered with the selection of intraoperative medications.
- For superficial procedures consider the use of local anesthesia and/or peripheral nerve blocks with or without moderate sedation.
- If moderate sedation is used, ventilation should be continuously monitored by capnography due increased risk of undetected airway obstruction.
- Consider CPAP or using an oral appliance during sedation to patients previously treated with these modalities.

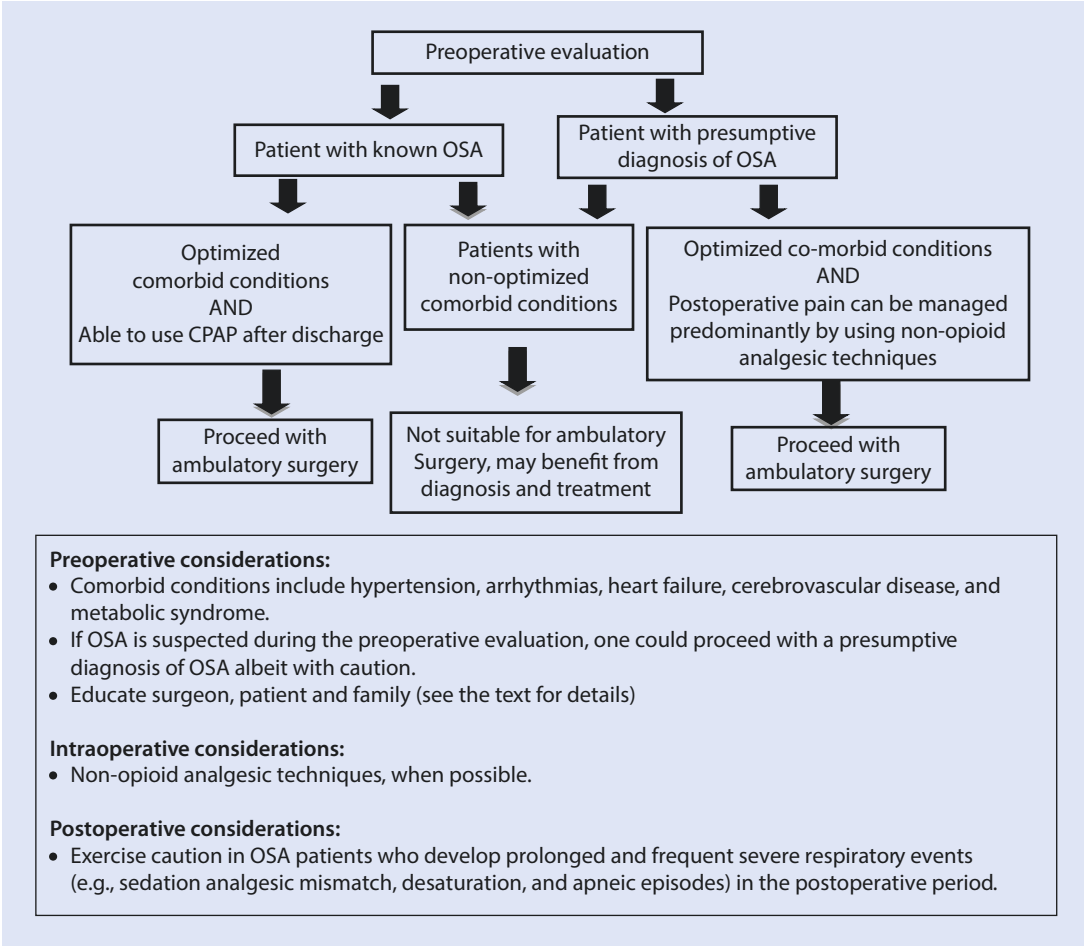


Fig. 27.1 Society for Ambulatory Anesthesia (SAMBA) consensus statement addressing OSA patients and ambulatory surgery that is summarized below

- General anesthesia with a secured airway is preferable to deep sedation without a secure airway.
- Unless a contraindication exists, patients with OSA should be extubated awake.
- If neuromuscular blocking drugs are utilized, full reversal should be verified prior to extubation.
- When possible, extubation and recovery should occur in the lateral, semi-upright, or other non-supine positions.

27.5.4 Postoperative Management

- Regional anesthetic techniques should be considered to reduce or eliminate the need of systemic opioids.
- If neuraxial analgesia is planned, weigh the benefits (decreased need for systemic opioids) and risks (respiratory depression from rostral spread) of using an opioid or opioid-local anesthetic mixture rather than a local anesthetic alone.
- Avoid background infusions (basal rate) of opioids if patient-controlled analgesia (PCA) is used.
- Consider multimodal analgesic options to reduce need for opioids.
- Supplemental oxygen should be supplied to patients with OSA until they are able to maintain their baseline oxygen saturation on room air.
  - Caution must be exercised as this may increase the duration of apneic episodes and possibly hinder the detections of atelectasis, transient apnea, and hypoventilation by pulse oximetry.
- Unless contraindicated by the surgical procedure, CPAP or noninvasive positive pressure

ventilation (with or without supplemental oxygen) should be continuously administered to patients who were using these modalities preoperatively.
  - Consider having patients bring CPAP or noninvasive positive pressure ventilation equipment with them to the hospital to improve compliance.
- If possible, maintain non-supine positions throughout the recovery process.
- Hospitalized patients at increased risk of respiratory compromise from OSA should have continuous pulse oximetry monitoring after discharge from the recovery room.
- If frequent or severe airway obstruction or hypoxemia occurs during postoperative monitoring, initiation of CPAP or noninvasive positive pressure ventilation should be considered.

27.5.5 Criteria for Discharge to Unmonitored Settings

- Discharge from the PACU to an unmonitored setting (i.e., home or unmonitored hospital bed) should not occur until the patient is no longer at risk of postoperative respiratory depression. This can potentially result in a prolonged PACU course due to the propensity for airway obstruction and/or central respiratory depression.
- Patients should be observed in an unstimulated environment, preferably while asleep, when assessing adequacy of oxygen saturation levels on room air.

Of note, case submission to this registry was closed on December 31, 2016. Cases are currently undergoing data cleaning and analysis for future publication.

27.6 Pediatric Perioperative Cardiac Arrest (POCA) Registry

Beecher and Todd first recognized the increased risk of perioperative cardiac arrest in children, as compared to adults, in their 1954 pivotal study published in the *Annals of Surgery* [81]. Fifty years later, in 1994, the Pediatric Perioperative Cardiac Arrest (POCA) Registry was formed by the Committee on Professional Liability of the American Society of Anesthesiologists (ASA) and the American Academy of Pediatrics Section on Anesthesiology to investigate the incidence and causes of cardiac arrest, defined as the need for CPR or death, in pediatric patients during the administration of or recovery from anesthesia. It was closed in 2005 after collecting 373 cases of cardiac arrest (all submitted anonymously) and representing 73.5 million pediatric anesthetics across approximately 68 medical centers (58–79 institutions were enrolled in the Registry each year), including both academic institutions and community hospitals throughout the United States and Canada. Of the anesthesia care providers involved with this registry, 95% were certified by the American Board of Anesthesiology (or the equivalent), and 82% had fellowship training in pediatric anesthesiology.

27.6.1 General Pediatric Population

In the July 2000 edition of *Anesthesiology*, Ann Bailey, MD (a pediatric anesthesiologist at UNC Hospitals, Chapel Hill, NC), published the following findings with respect to the potential cause(s) of perioperative cardiac arrest in the pediatric population as a whole after evaluating data collected from 1994 to 1997.

- **Most common causes:**
- Medication, usually halothane overdose, and cardiovascular.
- Infants <1 year of age accounted for 55% of arrests.
- ASA III–V patient and emergencies were associated with increased risk.

- **Results:**
- Incidence of <0.015% (150 anesthetic-related deaths in over 1 million anesthetics).
- 55 events were medication related:
  - 26 arrests were due to halothane alone and 11 were halothane + other medications.
  - Two arrests were ASA III patients who are arresting during an inhalational induction with sevoflurane.
  - Four cases were secondary to intravascular injection of bupivacaine + epinephrine during caudal placement.

- Most cardiac causes involved underlying cardiovascular disease (discussed in detail below), ASA III–V patients, or hemorrhage.
- Respiratory events accounted for 20% of all cardiac arrests (nine events due to laryngospasm) in mostly ASA I–II patients.

Summary:

- Healthy kids <1 year of age can suffer from cardiac arrest under anesthesia, usually due to medication overdose and/or airway obstruction. Less healthy kids who have cardiac arrest related to anesthesia have a higher mortality.

27.6.2 Congenital and Acquired Heart Disease

The final report from the POCA Registry, published in the May 2010 edition of Anesthesia-Analgesia, examined all available data in the registry (1994–2005) with the aim of comparing anesthesia-related cardiac arrests in children with heart disease to those without heart disease [82]. Children were classified as having heart disease if they had congenital or acquired disease, with the most common conditions including single ventricle, left-to-right shunts (septal defects), obstructive lesions (coarctation of the aorta, aortic stenosis, pulmonary stenosis), cardiomyopathy, tetralogy of Fallot, and truncus arteriosus.

27.6.2.1 Risk Factors for Cardiac Arrest

Congenital or acquired heart disease accounted for 127 (34%) of patients in this Registry. Nearly half (47%) of cardiac arrests occurred at the age of 6 months or younger, while 70% of cardiac arrests occurred in children 2 years or younger. The culprit cardiac lesions were more or less equally split across several major defects; see Table 27.2.

Table 27.2 Cardiac Lesions in Children with Heart Disease

Lesion	*n* (% of 127)
Single ventricle	24 (19%)
Hypoplastic left heart syndrome	9
Double outlet right ventricle	5
Unbalanced AV canal	4
Tricuspid artresia	3
Pulmonary artresia	2
Double inlet left ventricle	1
Left-to-right shunt	23 (18%)
Ventricular septal defect	9
Patent ductus arteriosus	5
Atrioventricular canal	4
Combined lesions (ASD, VSD, PDA)	5
Obstructive lesions	20 (16%)
Aortic stenosis	13[a]
Coarctation of the aorta	6
Aortic obstruction	1
Cardiomyopathy	16 (13%)
Dilated	4
Hypertrophic	2
Restrictive	1
Disease specific	
Duchenne muscular dystrophy	4
Renal disease	2
AIDS	1
Unspecified	2
Tetralogy of Fallot	15 (12%)
Truncus arteriosus	6 (5%)
Miscellaneous	23 (18%)
Pulmonary hypertension	4
Status post-heart transplant	3
Heart block	3
Wolff-Parkinson-White	2
Other[b]	11

AV atrioventricular, *ASD* atrial septal defect, *VSD* ventricular septal defect, *PDA* patent ductus arteriosus, *AIDS* acquired Immunodeficiency syndrome
[a]Two with Williams syndrome and 4 with pulmonary stenosis
[b]Other includes anomalous pulmonary veins, coronary artery disease, Ebstein's anomaly, interrupted aortic arch, left ventricular hypertrophy, myocarditis, prolonged QT syndrome, sick sinus syndrome, systemic hypertension, transposition of the great vessels, and unspecified (1 each)

27.6.2.2 Location of Cardiac Arrest

Cardiac arrests in children with heart disease were most commonly reported in the general operating room ($n = 69$, 54%). The most frequent surgical procedures were gastrointestinal procedures (i.e., fundoplication, gastrostomy tube placement, esophagogastroduodenoscopy, and colonoscopy; $n = 17$). This was followed by ear, nose, and throat procedures (myringotomy with tube placement, bronchoscopy, choanal atresia repair, and tracheostomy; $n = 16$) and placement of permanent central venous catheters (Broviac catheter or Port-A-Cath; $n = 13$). Urologic, orthopedic, ophthalmologic, plastics, dental, and thoracic procedures each accounted for five cases or less.

27.6.2.3 Anesthetic Phase During Cardiac Arrest

Contrary to the commonly accepted notion that the greatest degree of cardiovascular instability occurs during the induction of and/or emergence from general anesthesia, cardiac arrest in children with heart disease occurred most commonly during the maintenance phase (48%) of anesthesia. This seemingly implicates the surgical procedure itself or its resultant noxious stimuli as provocative factors in POCA, although this is not proven or supported in the literature. The presurgical and postsurgical periods correlated with 36% and 16% or cardiac arrests, respectively.

27.6.2.4 Etiology of Arrest

Cardiovascular causes of cardiac arrest were most common.

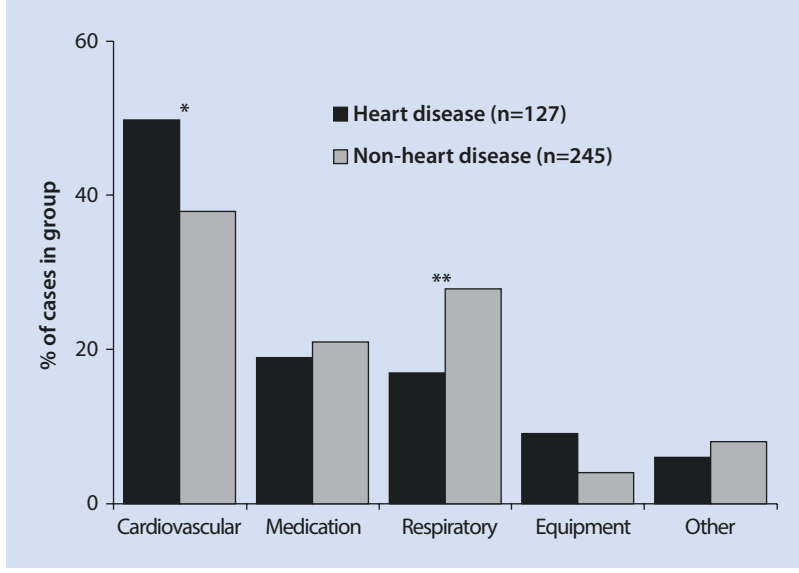
Please refer to ◘ Fig. 27.2 and ◘ Table 27.3 for further details.

27.6.2.5 Outcome Following Arrest

Overall mortality for pediatric patients with heart disease exceeded patients without heart disease (33% vs. 23%); however, when ASA physical status III–V patients were compared, there was no difference between groups (34% for both). For patients with heart disease, there was no association with age, phase of care, cause of cardiac arrest, or year of cardiac arrest. Mortality rates following cardiac arrest in the cardiac OR, general OR, and catheterization laboratory were 45%, 26%, and 33%, respectively.

27.6.2.6 Summary

- In the setting of POCA, children with underlying heart disease were sicker, more likely to arrest due to cardiovascular causes, and less likely to survive when compared to children without heart disease.
- Greater than 50% of all cardiac arrests in children with heart disease occurred in the general OR.
- Patients with single ventricle, aortic stenosis, and cardiomyopathy were of particular interest due to the frequency of cardiac arrest and the high mortality rates that followed.



◘ **Fig. 27.2** Causes of anesthesia-related cardiac arrest associated with heart disease ($n = 127$) versus non-heart disease ($n = 245$). *$P = 0.03$, **$P = 0.01$

Table 27.3 Cardiac arrest causes in patients with pre-existing heart disease

Cause of arrest	*n* (% of 127)
Cardiovascular	63 (50%)
Myocardial ischemia	5 (4%)
Hyperkalemia	3 (2%)
"Tet" spell	3 (2%)
Hypovolemia: preexisting	3 (2%)
Sudden arrhythmia	3 (2%)
Hypovolemia-blood loss	2 (2%)
Other miscellaneous CV cause[a]	11 (9%)
Presumed CV: unclear etiology	33 (26%)
Medication	25 (20%)
Inhaled anesthetic CV depression–	
Halothane	8 (6%)
Sevoflurane	6 (5%)
Isoflurane	1 (1%)
Intravenous drug CV depression	
Prapofol	1 (1%)
Narcotics	1 (1%)
Wrong dose	3 (2%)
Medication combinations	2 (2%)
Other[b]	3 (2%)
Respiratory	21 (17%)
Laryngospasm	6 (5%)
Inadequate oxygenation	6 (5%)
Difficult intubation	2 (2%)
Airway obstruction	2 (2%)
Other miscellaneous respiratory cause[c]	5 (4%)
Equipment	11 (9%)
Central line complications	9 (7%)
Breathing circuit obstruction	1 (1%)
Endotracheal tube obstruction	1 (1%)
Multiple events	3 (2%)
Unknown cause	4 (3%)

Table 27.3 (continued)

CV cardiovascular
[a]One case each: air embolism, hypovolemia from surgical redaction, left ventricular outflow obstruction, pacemaker failure, right-to-left shunt, severe valvular dysfunction, vagal response, acidosis, pulmonary hypertensive crisis, myocardial dysfunction, and severe coronary artery disease
[b]One case each: epinephrine-induced ventricular fibrillation, prostacyclin effect, and intravascular injection of local anesthetic
[c]One case each: esophageal intubation, premature extubation, penmothorax, endobronchial intubation, presumed respiratory, and cause unclear

Overall, the take-home message from the POCA Registry is that high ASA physical status and emergency surgery are independent predictors of mortality from perioperative cardiac arrest and that patients with congenital heart disease were at significant and increased risk of perioperative cardiac arrest during noncardiac procedures. Additionally, data also suggests that the use of halothane is particularly hazardous for infants.

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Peer Review in Perioperative Medicine

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_28

Success is not final, failure is not fatal: it is the courage to continue that counts.
—Winston Churchill

Interactions in the perioperative setting are complex and include factors such as time and performance pressures, high-risk patients, acute situations, intergenerational differences [1], and the high impact and necessity of interprofessional teamwork [2]. While audits, checklists, guidelines, and practice advisories have significantly improved safety in the perioperative setting, human qualitative factors such as adaptive coordination, emotional intelligence, resilience [3, 4], and peer review are of tremendous importance for perioperative leadership too. In this chapter, we discuss the value of peer review to prevent, manage, and learn from catastrophic perioperative events.

We define catastrophic perioperative complications as consequential, unexpected, unplanned events that should not happen or have happened and that are or were potentially preventable. When they do happen, they can affect patients, peers, equipment, clinical infrastructure, leadership, and departmental strategy, i.e., being the best performing department with the fewest complications. Catastrophic perioperative complications have myriad causes.

28.1 Peer Review by Definition

Peer review is not primarily a teaching tool but rather an assessment by a peer, e.g., according to the Oxford Dictionary, "a person of the same age, status, or ability as another specified person." Additionally, peer review is rather intended to improve both personal and organizational performance. Peer review is a well-established practice in corporate cultures and in some medical systems, but recognition of its value is only just emerging in others and in relation to preventing, managing, and learning from catastrophic perioperative events.

Contrary to peer review, feedback, i.e., a conversation with "a view to narrowing the gap between observed and desired performance," is an established and well-recognized teaching and supervision tool in clinical training to reinforce good and improve poor performance [5]. The Oxford Dictionary defines feedback as "information about reactions to […] a person's performance of a task, etc. which is used as a basis for improvement." Further, depending on the cultural setting and the mindsets of the protagonists involved, feedback might be weakened by confusion between content of the feedback and the relationship between parties.

Even though both feedback and peer review can be formalized as process-oriented tools to improve performances and patient care, feedback is of a more hierarchical nature, usually initiated and led in a vertical top-down fashion. Peer review, on the contrary, is a less hierarchically influenced, horizontal assessment from a co-worker of similar knowledge and expertise. Figure 28.1 illustrates the different levels of interaction within a hierarchy at which the processes of peer review and feedback take place.

The search for a greater amount of assessment opportunities in the workplace, as well as the different hierarchical directions in which these interactions take place, may be a reflection of a more global phenomenon, initiated by the new generation of workers, known as the Millennials. Indeed, Millennials are characterized by their expectation of close relationships and frequent feedback from supervisors [6], as well as a preference for a flatter hierarchy and a team-oriented environment [7].

Pressure from advances in management sciences, the rise of a multicultural and multigenerational workforce together with the ever-increasing patient safety, and quality requirements are encouraging both the implementation and

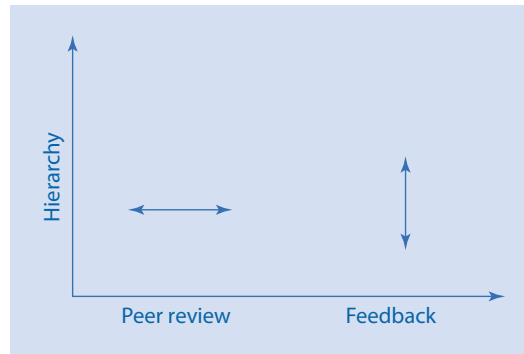

Fig. 28.1 Peer review and feedback take place between different levels in the hierarchy of an organization. Both of these process-oriented tools can be formalized to improve performance and patient care, however peer review, in contrast to feedback, is a less hierarchically influenced, horizontal assessment from a co-worker of similar knowledge and expertise

refinement of peer review in medicine. This is of even greater importance in the setting of perioperative and acute medicine, where interactions are complex and the potential for catastrophic complications significant.

Peer review provides the framework for a systematic evaluation of both an individual's performance and medical systems of care and offers both individuals and medical systems the opportunity to improve their performances with the ultimate goal to reduce morbidity and mortality.

» Peer review and feedback take place between different levels in the hierarchy of an organization. Both of these process-oriented tools can be formalized to improve performance and patient care, however, in contrast to feedback, peer review is a less hierarchically influenced, horizontal assessment from a coworker of similar knowledge and expertise.

28.2 Personal Attitude to Establish a Peer Review-Friendly Culture: From Improving Oneself to Learning

"Success is not final, failure is not fatal: it is the courage to continue that counts" (*Winston Churchill*). The sentiment expressed in this statement suggests the cultural frame and personality traits required to implement and maintain an institutional environment in which peer review is a constant presence that proactively drives improvement in one's performance. Such self-motivating characteristics are well described in leadership and human resource sciences. In 1996, the American psychologist Daniel Goleman published a landmark paper on "what makes a leader," introducing the self-management and relationship skills of self-awareness, self-regulation, motivation, and empathy, as well as social skills such as emotional intelligence. He concluded that a thirst for constructive criticism, a self-deprecating sense of humor, comfort with ambiguity and change, passion for work itself, optimism in the face of failure, an ability to develop others, sensitivity to cross-cultural differences, and effectiveness are crucial [8]. Similarly, an appetite for life-long learning and self-development, an attitude towards finding meaning in and learning from negative events, and the ability to emerge from adversity stronger have been described as crucibles of leadership [9]. In brief, Peter Drucker advised being one's own career manager by constantly evaluating three questions: "what are my strengths?", "how do I work?", and "what are my values?" [10]. We suggest to add a fourth question, i.e., "how can I learn from and improve my weaknesses and/or mistakes?"

Jim Collins suggested that deep personal humility and intense professional will represent the "level 5 leadership" [11], a mindset enabling all of the above questions. Regardless of whether one is targeting personal or corporate leadership goals, individuals should feel like the one leader of their own continuous improvement, and application of such self-motivating characteristics will help them throughout their career.

In addition to that, it may be necessary for individuals to make some adaptive changes to be able to react to feedback more easily and in a constructive way. Performance reviews of all kinds remain too often perceived as blame or personal criticism, and fears and assumptions about it can generate maladaptive behaviors such as cynicism, procrastination, denial, brooding, jealousy, or self-sabotage. Learning to acknowledge negative emotions, reframing constructively fear and criticism, creating support systems, and rewarding oneself can help individuals to make positive adaptive changes toward feedback [12].

» The application of self-motivating characteristics described in leadership sciences, such as "… thirst for constructive criticism, a self-deprecating sense of humor, comfort with ambiguity and change, passion for work itself, optimism in the face of failure, an ability to develop others, sensitivity to cross-cultural differences, and effectiveness in leading...", as well as adaptive changes for individuals to react more easily to feedback, are necessary components of individual attitude to favor a peer review-friendly culture.

28.3 Organizational Culture to Establish a Peer Review-Friendly Environment: From Blaming to Encouraging

Even though necessary, a change in personal attitude alone will not be sufficient to establish a peer review-friendly culture. Peer review does

not happen by itself. When defining, building, and adjusting the mission, vision, and culture of an organization or department (i.e., defining what has to be done, how priorities should be embraced, and what a "perfect world" would look like), it is essential to remember the importance of people being guided by a sense of purpose and being responsible for their relationships [13]. It should be part of an organization's/department's mission to want to evolve from a peer review-adverse, or even blaming culture to promote an open and supportive peer review environment. Indeed, not only the fear of performance review, but also the lack of it can generate a dysfunctional work environment.

Different barriers and incentives have been described for related topics in perioperative medicine. Sanchez and Barach, for example, describe individual, organizational, and societal dimensions for successful learning from adverse events [14], which can be adopted in establishing a successful culture of peer review.

Although useful, peer review can be a potentially sensitive process and needs to be managed correctly to avoid unwanted repercussions. Peer review should be honest, fair and unbiased, relevant and adapted to people and situations, not tied to merit increase, should not increase the feeling of job pressure.

Already 50 years ago, Frederick Herzberg argued that extrinsic incentives work only as long as it takes to get the next raise, if at all, whereas intrinsic rewards, such as the opportunity to achieve and to grow into greater responsibility, are the only effective ways to motivate people [15]. The new generation of workers are eager to connect and involve themselves with causes in the workplace and put greater value on being organizational influencers.[1] Today's worker requires an environment in which teamwork thrives.

With processes becoming more complex and workers being more eager to connect, the time spent by workers collaborating with colleagues keeps increasing significantly. This fact provides organizations such as perioperative medicine with optimal settings and a great opportunity to implement a more collaborative, team-oriented, and peer review-favorable environment in the workplace. While the output of working groups comprises results from individuals acting under individual accountability, the output of a team is the product of mutual accountability. Achieving such status requires that team members listen, respond constructively, provide support, and share an essential commitment to the common purpose [16], dimensions to be defined in an organization's/department's mission and vision.

It is an unfortunate fact in medicine that individuals and care systems tend to learn in a more robust way from suboptimal performances and from the occurrence of near-missed and adverse events, which can be particularly critical in the setting of perioperative medicine. However, one of the most valuable keys to improvement is based in the occurrence of these primarily "negative" events. To turn complications in perioperative medicine into an opportunity for change and improvement, personal attitude and application of leadership's characteristics, individual's effort to adapt to reviews, as well as organizations' priority in creating an open, supportive, and mindful environment for peer review are mandatory elements to ensure optimal learning from complications in perioperative medicine and help improve the strategies to avoid them and reduce morbidity and mortality. Organizations which understand the multifaceted benefits of promoting a collaborative and peer review-friendly culture will benefit from it at many different levels.

» It should be part of an organization's/department's mission to want to evolve from a peer review-adverse, or even blaming culture to promote an open and supportive peer review environment. Indeed, not only the fear of performance review, but also the lack of it can generate a dysfunctional work environment.

28.4 Dimensions and Situations for Peer Review

Having established an atmosphere of trust with a culture of peer review, departments involved can progress to a benchmarking process specifically aimed at reducing catastrophic perioperative complications, e.g., by increasing professional competencies. The explicit inclusion of peer review dimensions in a departmental mission and vision statement is of essence. The associated

1 Jean Case, Millennials and the power of influence, June 24 2015, Forbes. Printout from ▶ https://www.forbes.com/sites/jeancase/2015/06/24/millennials-influence/#a5178c5095c8, accessed Sept 30 2017.

Fig. 28.2 Professional performance, compliance with the organization's/department's strategy, and personality traits as dimensions to be included in peer review processes to help preventing, managing, and learning from catastrophic perioperative complications. All dimensions can be benchmarked with the departmental mission, vision, and values, defined in the strategy

values should be exemplified by leadership. The dimensions of professional performance (i.e., the delivery of established best medical practice), compliance with departmental strategy (i.e., department's specific directives), and personality traits (i.e., a person's pattern of behaviors revealed in different situations), which are included in peer review, interact and overlap (Fig. 28.2). The parameters of strengths, weaknesses, opportunities, and threats with respect to each dimension can be addressed proactively, retrospectively, and acutely and can be benchmarked with the departmental mission, vision, directives, and values, defined in the departmental strategy. The process can help to highlight strengths or weaknesses not only in individual but also in collaborative, structural, and infrastructure performances.

Professional performance is probably the easiest dimension to evaluate through peer review, because medical standards and benchmarks are globally available and exist independently from the departmental mission and vision. Addressing strengths, weaknesses, opportunities, and threats proactively can help individuals to meet appropriate clinical standards and hence prevent catastrophic perioperative complications. Addressing them retrospectively when debriefing such events can help highlight unexpected deficiencies and can be used to correct and further align performances with the departmental directives. In the situation of an ongoing catastrophic perioperative event, peer review can help reinforce the need for a strong collaborative approach.

Peer review of compliance with an organization's/department's strategy is more complex and depends on an appropriately defined mission and vision, as well as values and directives. Again, however, strengths, weaknesses, opportunities, and threats can be addressed proactively, retrospectively, or acutely. In the situation of an ongoing catastrophic perioperative event, peer review might rather focus on providing appropriate support, backed up by the departmental culture.

Personality traits are probably the most complex dimension to address in peer review. It is delicate and difficult to make objective observations, and there is uncertainty whether psychological dimensions are a learnable function, an inherent trait, or a combination of the two [4]. Established methods such as Myers-Briggs personality indicator tests [17] or components of 360° feedback programs within and across departments involved in perioperative care can provide insight. In the moment of a catastrophic perioperative event, peer review of personality traits is probably best avoided or conducted by a peer who understands the support needs of the affected individual. Different styles for such moments have been described [18], including coercive ("do this, now, how I tell you"), authoritative ("come with me"), pacesetting ("if I have to tell you, you are the wrong person for the job"), or coaching ("try this") styles. The choice to conduct the review and the choice of style are subject to the discretion of the reviewing peer.

» Professional performance, compliance with departmental strategy, and personality traits can be addressed preventively, retrospectively, and acutely, and can be benchmarked with the departmental mission, vision, and values, defined in the strategy.

28.5 Mindsets Required for Change Management Derived from Peer Review

Every dimension of emotional intelligence introduced by Daniel Goleman [8] and described previously can be incorporated and tested in job

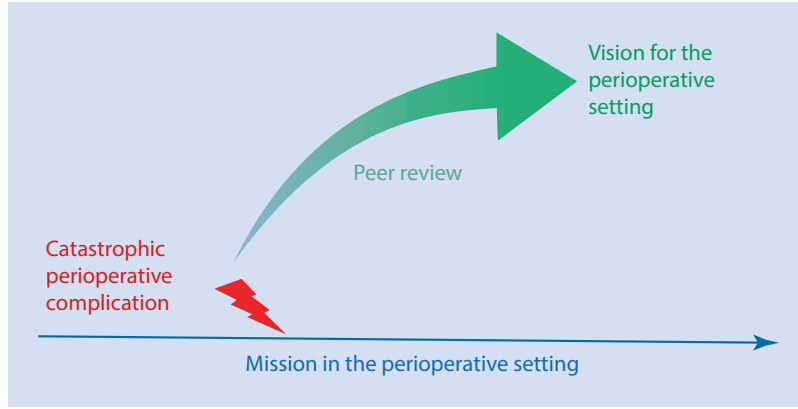

Fig. 28.3 With a peer review system in place, both individuals and departments involved in perioperative medicine can systematically improve to prevent, deal with, and learn from catastrophic events. Additionally, such a system can help to leverage catastrophic perioperative events for change management and align a department's mission to its vision

interviews for positions in perioperative medicine.[2] This might be the first step in ensuring the promotion and perpetuation of a peer review-friendly culture and may help to select individuals showing specific personality traits and qualities in line with this concept and the company's culture, thus setting the stage for a career-long process that is in the best interest of the individual and of the department. Eric Mosley, founder of the conference "WorkHuman: Unlock the Future of The Human Workplace," recommends that to successfully build, maintain, and support an effective peer review system, leadership must "ensure that the metrics on which people are recognized are aligned with your company's mission."

The exact process of peer review can vary. However, regardless of the strategy chosen, Eric Mosley[3] advises to favor the following points to give the peer review process the best chance to bring constructive elements and succeed in the long term:

- "Pick a program that is intuitive, easy to use, fun, interactive, engaging, and fully mobile [because] peer reviews shouldn't feel like work."[3]
- "Position the program as a change designed to help recognize and celebrate employees, and not a new way to monitor or judge them."[3]
- "Make sure that any employee, at any level, feels empowered to participate." "Encourage frequent, timely recognition" and "empower managers to track results."[3]

When benchmarking professional performance, compliance with strategy, and personality traits with the organization's/department's mission, vision, and values, leadership has to remember that, by nature, people are usually reluctant to alter habits; they need help and management of their emotions. Both leadership and peers in perioperative medicine have to be aware that change is not an event but rather a process that requires time, has to follow specific steps, and has to be planned strategically in advance [19]. Therefore, John P. Kotter advises communicating a vision proactively, empower others to act on it, and institutionalize new approaches [derived from peer review] [19]. Figure 28.3 illustrates how a peer review system for catastrophic perioperative events can help both individuals and departments involved in perioperative medicine to systematically improve to prevent, deal with, and learn from catastrophic perioperative events. Additionally, such a system can help to leverage catastrophic perioperative events for change management to align a department's mission to its vision.

» Both leadership and peers in perioperative medicine have to be aware that change is not an event but rather a process that requires time, has to follow specific steps, and has to be planned strategically.

2 Markus M Luedi et al.: Screening future employees for emotional intelligence as a crucial step towards improved perioperative efficiency and patient safety. Printout from ► http://www.esahq.org/~/media/ESA/Files/Downloads/Resources-Abstracts-Euroanaesthesia%202017/ESA2017_HI.ashx, accessed Sept 30 2017.

3 Eric Mosley: Creating an effective peer review system. Printout from ► https://hbr.org/2015/08/creating-an-effective-peer-review-system, accessed Sept 30 2017.

28.6 Conclusion

Peer review provides a valuable leadership tool for individuals and organizations to improve in the face of ever-increasing complex workplace settings and is a key element toward preventing and dealing with catastrophic perioperative complications. Peer review and feedback take place between different levels in the hierarchy of an organization. While the concept of feedback has been institutionalized across various settings over the past decades, successful peer review depends heavily on individual and departmental culture, which might have to be built strategically over the long term. Professional performance, compliance with organization/department strategy, and personality traits are dimensions to be included in peer review processes among acute care physicians to help preventing, managing, and learning from catastrophic perioperative complications. Aiming at reducing morbidity and mortality, it is the responsibility of respective departments' leadership to build a culture, implement a system, and encourage individuals to participate in peer review to avoid and attenuate catastrophic perioperative complications.

28.7 Review Questions

1. What are the crucial differences between traditional feedback and peer review in the perioperative setting?

2. What dimensions were suggested to successfully build, maintain, and support an effective peer review system?

3. What dimensions can be subjected to peer review among acute care physicians to prevent, manage, and learn from catastrophic perioperative complications, and what benchmarking can be applied?

28.8 Answers

1. Contrary to feedback, which is a teaching tool to reinforce specific measures, peer review is not primarily a teaching tool but rather an assessment by someone of the same status and ability, intended to provide information pertinent to self-improvement by the reviewed individual.

2. According to Eric Mosley, to successfully build, maintain, and support an effective peer review system, leadership in perioperative medicine must "ensure that the metrics on which people are recognized are aligned with your company's mission." "Pick a program that is intuitive, easy to use, fun, interactive, engaging, and fully mobile [because] peer reviews shouldn't feel like work." "Position the program as a change designed to help recognize and celebrate employees, and not a new way to monitor or judge them." "Make sure that any employee, at any level, feels empowered to participate." "Encourage frequent, timely recognition" and "empower managers to track results."

3. Professional performance, compliance with strategy, and personality traits are dimensions to be included in peer review processes. Institutional mission, vision, and values can help benchmarking and also be subjected to change management deriving from peer review.

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Perioperative Complications Chapter: Shared Decision-Making and Informed Consent

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C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5_29

29.1 Introduction

The relationship between the physician and patient is especially unique among professional relationships. Many professional and fiduciary responsibilities involve trust, empathy, and nuanced communication, but physician relationships are distinguished, most importantly, by their care for human beings and the attendant complexities. The trust and faith extended in physician-patient relationships requires patients to have at least a basic understanding of risks and benefits inherent in the course of treatment. Although it may appear to be a simple and straightforward process as a patient agrees to undergo an anesthetic and surgery, it is only because dramatic improvements in patient safety have been so closely intertwined with the process of informed consent over the last century [1].

Over the past few decades, medical paternalism has yielded to a process of shared decision-making. Today, informed consent is a patient-centered process based on the principle that autonomous patients can make informed, rational decisions when given the opportunity to do so. Shared decision-making is an extension of informed consent and facilitates the complex process of medical decision-making. The stepwise exchange of information between patient and physician occurs in accordance with individual patient preferences, goals, and beliefs regarding their care.

29.2 A History of Informed Consent

When the American Medical Association published its first code of ethics in 1847, there was no mention of informed consent. The idea of an informed and autonomous patient would not be developed for several decades. At this time, physicians elicited *assent*, or simple permission, from patients prior to invasive procedures. By the early twentieth century, the concept of informed consent slowly began to emerge. It was guided in no small part by the US legal system and a series of influential appellate decisions.

29.2.1 Invasive Procedures Without Consent Is Assault

The first major decision came in 1914 in *Scholendorff v. Society of New York Hospital* [2]. Mary Scholendorff agreed to an ether exam under anesthesia during a routine work-up for a fibroid tumor. She declined a surgical operation, but while she was under anesthesia, the surgeon removed the tumor. Her recovery was complicated by gangrene and the subsequent amputation of several fingers. In the appellate decision, the judge argued that

> » Every human being of adult years and sound mind has a right to determine what shall be done with his own body; and a surgeon who performs an operation without his patient's consent commits an assault, for which he is liable in damages.

Further, the court emphasized that the case was not a simple matter of medical negligence, but rather an assault. Prior to *Scholendorff* physicians made many medical decisions for patients. Liability for assault or battery prompted a dramatic change in physician practice patterns and began the modern era of patient-centered decision-making.

29.2.2 Patients Should Be Informed of Risks

By the mid-twentieth century consent quickly evolved into *informed* consent. In *Salgo v. Stanford* (1957) [3], the plaintiff agreed to undergo translumbar aortography but became permanently paralyzed in his legs as a direct complication of the procedure. The defendant did not disclose to the patient any risk of permanent neurologic damage. The court clarified that "a physician violates his duty to his patient and subjects himself to liability if he withholds any facts which are necessary for the basis of an intelligent decision by a patient to a proposed treatment." They further noted that risks could not be minimized for the purposes of inducing consent. Hereafter, a physician could not obtain consent for surgery (or procedures) without making the patient aware of any inherent risks. The concept of an *informed* patient had emerged.

29.2.3 How Much to Disclose? A Physician Standard and a Patient Standard

Physicians now had a medicolegal responsibility to appropriately inform patients of the risks

and benefits to a proposed treatment. Legal and medical challenges continued regarding how and what to disclose. Two cases established the current general standards by which adequate disclosure was measured. In *Nathanson v. Kline* (1960) [4], a patient sued on the grounds that the risk of injury was not adequately disclosed after she experienced severe burns secondary to radiation therapy for cancer. The Supreme Court of Kansas disagreed and established that

> The duty of the physician to disclose… is limited to those disclosures which a reasonable medical practitioner would make under the same or similar circumstances. How the physician may best discharge his obligation to the patient in this difficult situation involves primarily a question of medical judgment. So long as the disclosure is sufficient to assure an informed consent, the physician's choice of plausible courses should not be called into question if it appears, all circumstances considered, that the physician was motivated only by the patient's best therapeutic interests and he proceeded as competent medical men would have done in a similar situation.

> The primary basis of liability in a malpractice action is the deviation from the standard of conduct of a reasonable and prudent medical doctor of the same school of practice as the defendant under similar circumstances. Under such standard the patient is properly protected by the medical profession's own recognition of its obligations to maintain its standards.

Today, the medical profession's obligations to maintain transparency is known as the "reasonable physician" standard of disclosure and is closely tied to professional self-regulation. Establishing the adequacy of disclosure to a patient can be determined during a jury trial with expert physician testimony to explore what a different physician would have done in the same or similar circumstances.

Alternatively, *Canterbury v. Spence* (1972) [5] established a patient-centered standard of disclosure. In this case, the patient agreed to a laminectomy after suffering from years of back pain. While recovering he fell from his bed, reinjured the surgical site, and underwent a second emergency operation to further decompress the spinal cord. He was left partially paralyzed and incontinent. In trial, the surgeon admitted to minimizing the risk of paralysis though noted that his discussion of risks was consistent with professional custom. The District of Columbia Circuit Court of Appeals held in favor of the defendant Canterbury and clarified several essential elements of informed consent:

- Physicians have a *duty* to disclose:
- It is a *duty* to warn of the dangers lurking in the proposed treatment, and that is surely a facet of due care. It is too a duty to impart information which the patient has *every right to expect*. The patient's reliance upon the physician is a *trust* of the kind which traditionally has exacted obligations beyond those associated with arms-length transactions. Just as plainly, due care normally demands that the physician warn the patient of any risks to his well-being which contemplated therapy may involve.
- A reversal of the physician custom standard and creation of the "reasonable patient" standard:
- Respect for the patient's right of self-determination on particular therapy demands a standard set by law for physicians rather than one which physicians may or may not impose upon themselves.
- A standard for the scope of how much to disclose to patients:
- A risk is thus material when a reasonable person… would be likely to attach significance to the risk or cluster or risks in deciding whether or not to forego the proposed therapy… the topics importantly demanding a communication of information are the inherent and potential hazards of the proposed treatment, the alternatives to that treatment, if any, and the results likely if the patient remains untreated.

A large number of jurisdictions across the United States have adopted the precedent established in *Canterbury v. Spence*. This landmark decision concisely affirmed the physician's duty to disclose risks, benefits, and alternatives, created a more patient-centered "reasonable patient" standard for disclosure, and lastly, defined a measure of disclosure commonly known as the "materiality clause." The new disclosure standard also eliminated the need for expert physician testimony as

juries could now decide what a reasonable patient in the same or similar circumstances might have decided. The case remains perhaps the most thoughtful and elaborate discourse on the doctrine of informed consent to date.

29.3 Further Clarifications of Disclosure

Subsequent decisions clarified the adequacy of disclosure. *Cobbs v. Grant* (1972) [6] echoed *Canterbury* in that "the patient's right of self-decision is the measure of the physician's duty to reveal." However, they noted that all possible risks and complications need not be disclosed. Indeed, "the patient's interest in information does not extend to a lengthy polysyllabic discourse on all possible complications… a mini-course in medical science is not required." This decision limited the scope of disclosure to material or realistic risks. *Kissinger and Lofgren* (1987) [7] determined that physicians are also not obligated to disclose risks that are commonly known or of which patients may already be aware.

In *Matthies v. Mastromonoco* (1999) [8], the plaintiff argued that consent to *nontreatment* and its associated risks should also be disclosed. The plaintiff, Matthies, agreed to bed rest as an alternative to surgical fixation of a broken hip. The surgeon had recommended against surgery given the defendant's age and comorbidities. She never regained her independence and was permanently bed-bound. The court held that

> For consent to be informed, the patient must know not only of alternatives that the physician recommends, but of medically reasonable alternatives that the physician does not recommend. Otherwise, the physician, by not discussing these alternatives, effectively makes the choice for the patient.

Restated, alternatives to treatment must also be disclosed including the risks of nontreatment or noninvasive treatment. For example, a patient should be made aware that electing for medical treatment of acute cholecystitis in lieu of surgery carries its own set of risks including continued pain and inflammation, ascending cholangitis, sepsis, and the need for a more complex surgical approach such as open cholecystectomy.

29.4 Informed Consent in Practice

Today, adequately disclosure of risks, benefits, and alternatives to proposed medical treatments remains challenging. Many patients have a poor understanding of their own medical conditions or have significant deficits in the decision-making process around the time of surgery [9]. Physicians should always adhere to their best judgment in accordance with hospital policy, state law, professional custom, and guidelines. These general standards though may be inadequate to appropriately engage individual patients and physicians in complex healthcare discussions.

The American Society of Anesthesiologists recommends that "the two most powerful protections available to anesthesiologists in the medicolegal context are (1) provision of a thorough and compassionate discussion of the risks and benefits of the anesthetic procedures with the patient, allowing time for all questions to be answered; and (2) meticulous documentation of said discussions in the medical record" [10]. Hospital general legal counsels and ethics committees are often excellent resources for physicians. Table 29.1 highlights a number of common clinical scenarios and suggested legal precedent for reference.

A review of the American Society of Anesthesiologists Closed Claims Database [20] shows that of 4559 cases only 1% involved informed consent decisions. Generally, anesthesiologists and hospitals have commonly paid for damages when

- Specific requests were ignored resulting in personal injury (e.g., requests for no resident involvement or requests to not be intubated).
- Informed consent occurred but a specific risk was not discussed.
- There was no evidence of informed consent (e.g., failure to document).
- Failure to adequately explain potential risks and complications.

Even after an appropriate informed consent process, injury to patients may still occur. Appropriate informed consent does not absolve physicians of liability for medical negligence. For instance, disclosing a risk of stroke does not make a provider immune from failing to treat hypotension in a timely manner. Medical liability should be viewed as two separate liabilities—negligence and informed consent—and both are the responsibility of any practicing physician.

Table 29.1 Examples of legal precedent for common questions. It should be noted while these cases have established some legal precedent, they are interpretations of existing laws and may not be recognized or applied in all US jurisdictions. See also Ref. [11] for additional examples

How much detail is necessary when disclosing risks?	The courts have generally held that statistical outcomes are not necessary But an exception is noted in *Johnson v. Kokemoor* (1996) [12]: "When different physicians have substantially different success rates with the same procedure and a reasonable person … would consider such information material, the court may admit this statistical evidence"
Is it necessary to disclose physician experience level?	The courts are mixed *Avila v. Flangas* (1996) [13]: surgeon experience is not relevant to informed consent; it is not an actual risk of the procedure *Degennaro v. Tandom* (2005) [14]: experience is material to decision-making
Does the involvement of mid-level providers or residents need to be disclosed?	Generally speaking, no: *Zimmerman v. New York City Health and Hospital Corp* (1983) [15] and *Dingle v. Belin* (2000) [16]; no obligation to disclose resident role *Henry v. Bronx Lebanon Medical Center* (1976) [17]: seeking care at a training hospital implies consent to resident participation
Should research or financial interests be disclosed?	Yes *Moore v. Regents of the Univ. of California* (1990) [18]: disclose "personal interests unrelated to the patient's health, whether research or economic, that may affect the physician's professional judgement" Generally, physician incentive schemes (surgical volume or HMOs) need not be disclosed
Can a patient with decision-making capacity refuse any or all treatment regardless of medical advice?	Yes. Any patient with capacity may refuse treatment regardless of risks of refusing to do so *Shine v. Vega* (1999) [19]: "A competent patient's refusal to consent to medial treatment cannot be overridden because the patient faces a life threatening situation"

29.5 Elements of Informed Consent

Informed consent and shared decision-making are processes that empower autonomous patients to make rational and informed decisions regarding their medical and surgical care. To provide informed consent for treatment, three elements must exist:

1. *Disclosure* of sufficient information by which to make a decision.
2. The patient must have sufficient *decision-making capacity* to make that particular decision.
3. The decision must be *voluntary*.

29.5.1 Disclosure

The first requirement is not as obvious as it may first appear. Any invasive procedure—especially one that requires general anesthesia—could lead to a wide range of outcomes. Simply appending a list of possible complications to consent forms and discussions might offer some basic medico-legal protection, but from an ethical perspective, it does little to empower the patient to make a thoughtful decision about whether to proceed. Physicians must strive to place relative risks into context, so that the patient is able to grasp the implications of consenting to a given procedure (including informed refusal or care). Medical ethicist Onora O'Neill argues that "genuine consent is apparent where patients can control the amount of information they receive, and what they allow to be done" [21].

29.5.2 Capacity

A physician disclosing relevant information does not guarantee that the patient comprehends that information or that the latter's subsequent consent is "informed." The patient must possess sufficient

decision-making capacity, which is distinct from "competence". Whereas competence is a legal concept—and thus only a court has the power to declare a patient incompetent—capacity is a clinical determination. It is also decision-dependent, meaning that decisions that are especially serious or complex require a greater degree of capacity.

Decision-making capacity includes four basic elements [22, 23]: communicating a choice, understanding relevant information, appreciating the consequences of a decision, and manipulating information rationally.

1. A patient with capacity must be able to express a decision either verbally or nonverbally.
2. A patient must have the ability to understand the relevant information provided, in terms of risks, benefits, and alternatives of various courses of action. Clinicians should attempt to avoid complex terminology and should provide the information in stages, allowing time for questions and clarification [24].
3. The patient must be able to appreciate on a personal level the consequences of whatever decision he makes.
4. Lastly, the patient must be able to reason from the information to the conclusion. This requires the patient to apply their own values to a specific clinical situation. The decision need not be a "rational" decision as viewed in the eyes of an external observer who may have different values and expectations.

29.5.3 Voluntariness

The third and final requirement of informed consent is that the patient's decision be voluntary. This refers to protecting the patient from the *improper* external influence of friends, family, or healthcare providers. Some physicians may be reluctant to offer their own opinions and perspective, for fear of pressuring the patient into what they perceive to be the best course of action [25]. In one multicenter study, for instance, physicians refrained from making a recommendation in 47% of cases, including 50% of the time when specifically asked to do so [26].

It is important to recognize that professional recommendation is a crucial part of the informed consent process [27], and that patients seek the physician's perspective, not just the "bare facts" [28]. Rather than compromising the patient's autonomy, a thoughtful recommendation—while accounting for the patient's expressed goals and values—is actually a component of "enhanced autonomy" [29]. As such, it is integral to the process of shared decision-making that is now recognized as the ideal [30].

Informed consent has been described as "the modern clinical ritual of trust" [31]. It should be viewed as an opportunity to engage patients in an honest discussion regarding the risks, benefits, and alternatives to care rather than a bureaucratic nuisance. The precise balance of patient autonomy and physician disclosure or recommendations is unique to every patient. And though "one cannot know with certainty which medical consent is valid until a lawsuit is filed and resolved" [18], all efforts should be made to engage the patient in a reasonable conversation. This should ideally satisfy the patient's need for information and establish expectations in the perioperative period.

29.6 Shared Decision-Making

While the volume of informed consent litigation remains small, the process of informed consent occurs prior to every anesthetic and is an integral part of the perioperative period. Patients today are largely interested in participating in medical decision-making [32]. Shared decision-making is a collaborative decision-making process between the patient and provider for preference-sensitive healthcare-related decisions. Benefits of shared decision-making include improved communication between patients and providers, increased patient satisfaction, decreased perioperative anxiety, cost savings, and decreased litigation [33]. While barriers to implementation of shared decision-making processes exist, recent evidence demonstrates that the overall impact to the healthcare environment is positive.

The impact of shared decision-making in preoperative processes may be significant, especially for patients with chronic conditions. Montori showed that diabetes management improved when patients were directly involved with the decision-making process [34]. Wilson showed similar outcomes for patients with asthma [35]. Anesthesiologists should be encouraged to implement shared decision-making as chronic diseases have significant implications in the perioperative

period and anesthesiologists are well positioned to manage the patient throughout the entire perioperative process. Furthermore, shared decision-making can assist in the preoperative evaluation of higher-risk patients [36, 37].

A fundamental concept underlying shared decision-making is the recognition that each patient is unique and has a right to select his or her preferred treatment options. The role of the physician is to provide his or her expert opinion on the options available as well as demonstrate the evidence for (and against) each. Charles [34] suggested that shared decision-making processes share the following characteristics:

1. Two (2) participants: the physician and patient.
2. Information is shared.
3. Consensus is built in a stepwise fashion.
4. An agreement is reached on the treatment plan.

Together, the patient and physician can develop a consensus and treatment plan consistent with the patient's goals of care. In practice, there are circumstances where the limits of shared decision-making will be tested or when they are impractical (e.g., incapacitated patients, emergencies, or circumstances where there is only one appropriate treatment option).

Shared decision-making can also help reduce bottlenecks which occur in operating rooms on an operational level [38]. In the long run, anesthesiologists may be able to reduce the costs of care by reducing rates of unnecessary surgery or delaying such procedures. In 2012, Group Health in Washington State demonstrated that a shared decision-making educational platform reduced both surgery rates and costs for total joint replacements [39]. The authors also advanced the discussion regarding an expanded role for the anesthesiologist in the perioperative period. Anesthesiologists may facilitate conversations with surgeons, hospital administrators, and insurance companies to function more broadly as perioperative physicians.

A growing body of evidence suggests that development and implementation of shared decision-making processes are most successful with standardized tools and physician training. The National Quality Forum has developed guidelines for the creation of evidence-based shared decision-making tools as well as metrics for measuring the impact and success of implementation [40]. As outlined in their report, successful deployment of a shared decision-making process should include the following steps:

1. Development and certification of shared decision-making aids
2. Promotion of and training for competency in use of the tools and processes
3. Measurement and monitoring of the process
4. Development of a shared decision-making culture

A 2017 Cochrane review [41] showed that among 105 clinical trials patient decision aids improved patient knowledge of options and outcomes, patient knowledge of risks, and patients were also better able to articulate their values and beliefs. The review also showed that patient decision aids also reduced decisional conflict or uncertainty about the course of action to take [42].

As with all institutional changes, promoting the value of shared decision-making as a means of improving both provider and patient satisfaction will facilitate a cultural shift in the provider/patient relationship [43]. This trend has been ongoing for decades and with more recognition of formalized shared decision-making tools and processes, providers and healthcare systems can expect patients to continue taking more active roles in the development of treatment plans.

29.7 Summary

Informed consent has evolved over the course of the twentieth century and now become the basis of shared decision-making. Patient's are largely interested in engaging physicians in their care and understanding the risks, benefits, and alternatives to treatment. Any serious conversation must incorporate the patients' unique values, beliefs, and experiences that shape their expectations of anesthesia, surgery, and medical treatment.

Case law may serve as a useful guide regarding the informed consent process. Anesthesiologists should also always be mindful of regional practice patterns and relevant state laws or statute. Most medical malpractice involves situations where patient expectations do not match the actual outcomes. Shared decision-making and informed consent will prove to be essential tools in ensuring realistic expectations and outcomes that should lead to greater patient satisfaction.

Summary of Major Legal Decisions in Informed Consent

Case	Key points of the decision
Scholendorff v. Society of New York Hospital (1914)	Medical or surgical interventions without consent is assault
Salgo v. Stanford (1957)	Risks must be disclosed to inform the patient
Nathanson v. Kline (1960)	Risks disclosed should be consistent with local or regional physician custom
Canterbury v. Spence (1972)	Physicians have a duty to disclose risks Created the "reasonable or prudent patient" standard of disclosure Established a standard of how much information to disclose ("materiality clause")
Matthies v. Mastromonoco (1999)	Alternatives to treatment must be disclosed including reasonable treatment a physician does not recommend

The Four Basic Elements of Informed Consent

Communicating a choice	The patient must be able to express a decision either verbally or nonverbally
Understanding relevant information	The patient must reasonably comprehend the risks, benefits, and alternatives to treatment
Appreciating consequences	The patient must acknowledge and appreciate the consequences of any decision
Rational manipulation of information	The patient demonstrates the ability to utilize information received in the context of his or her own values

Key Aspects of Shared Decision-Making

Definition	Shared decision-making is a collaborative decision-making process between the patient and provider for preference-sensitive healthcare-related decisions
Key aspects of shared decision-making	Two (2) participants: the physician and patient Information and experience are shared Consensus is built in a stepwise fashion An agreement is reached on the treatment plan
Benefits of shared decision-making	Improved communication between patients and providers Increased patient satisfaction Decreased perioperative anxiety Cost savings Decreased litigation Better patient comprehension of risks Improved articulation of patient values and beliefs

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Supplementary Information

C. J. Fox, III et al. (eds.), *Catastrophic Perioperative Complications and Management*,
https://doi.org/10.1007/978-3-319-96125-5

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