Anesthetic Management for the Pediatric Airway

Advanced Approaches and Techniques

Diego Preciado
Susan Verghese
Editors

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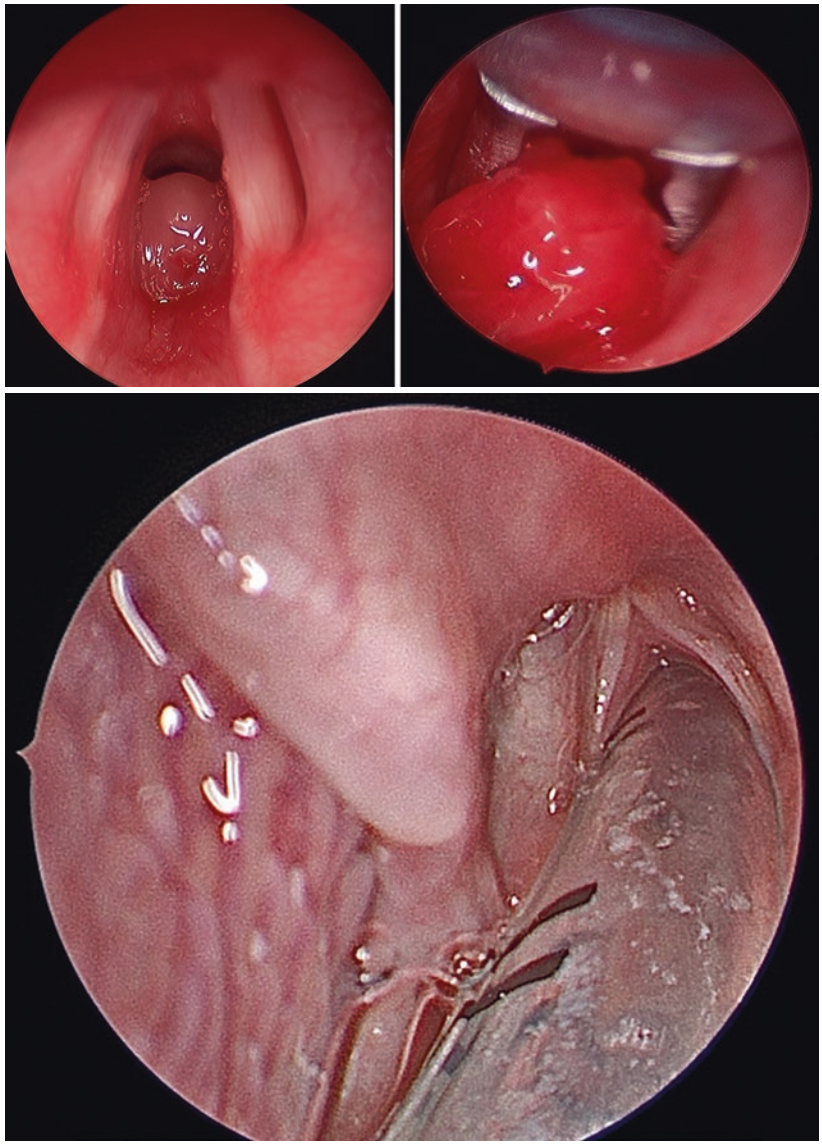

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This book is dedicated to all of our former and current teachers, colleagues and patients: Thank you all for enriching our lives!

Preface

The management of pediatric airway disorders has seen tremendous progress in surgical techniques and advancements over the past 30 years. From the introduction of novel endoscopic instrumentation, to improved open airway reconstructive techniques, the evolution of surgical approaches to improve outcomes in children with airway pathology has been substantial. Undoubtedly, many of these advances in surgical techniques have been fueled by dramatic refinements in optimal anesthetic management of children undergoing surgery in their airway. The textbook intends to be of great interest to both the pediatric anesthesiologist as well as the pediatric otolaryngology surgeon as it aims to combine the salient aspects of both specialties and describe the ideal and safe management of the pediatric patient undergoing anesthesia. Difficult airway scenarios; including subglottic stenosis, pharyngeal airway obstruction, laryngeal airway obstruction, obesity and sleep apnea, thoracic airway obstruction, among others will be covered in detail. To date there is no other leading textbook focusing primarily on the anesthetic management of children with these pathologies, yet often the anesthesiologist's level of expertise in these scenarios is as critical (if not more important than) the surgeon's. Chapters are by experts from both pediatric anesthesia and pediatric otolaryngology; focusing on scenarios where the skills and expertise of both specialists are being continually tested. This book will hopefully serve as a state of the art compendium of the anesthetic management of pediatric airway patients.

Washington, DC, USA

Susan T. Verghese
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Editor's Biography

Susan Thomas Verghese is a professor of Anesthesia and Pediatrics at Children's National Health System and George Washington University. She is a pediatric anesthesiologist who works at Children's National Medical Center in Washington, DC after completing her fellowship in pediatric Anesthesia in 1981. She earned her Bachelor of Medicine at Christian Medical College, Vellore, in Tamilnadu, India and her internship and residency in anesthesia at the Peter Bent Brigham Hospital in Boston, Massachusetts.

Dr. Verghese has authored numerous book chapters and contributed many scientific papers in anesthesia journals as well as served as a reviewer of manuscripts for many academic journals including Pediatric Anesthesia, Anesthesiology, Anesthesia and Analgesia, Critical Care Medicine and Urology. She is a member of the Editorial Advisory Board for Anesthesiology News.

She has been an invited speaker to many scientific pediatric anesthesia meetings held internationally in different parts of the world. For the last two decades, she was invited regularly to serve as a moderator and facilitator of the pediatric Anesthesia scientific sessions at the annual American Society of Anesthesiologists (ASA) and the International Anesthesia Research Society–(IARS) meetings in different cities USA and Canada. Her interest in creating and being a lead discussant in Problem Based Learning Discussion–(PBLD) sessions allowed her to help mentor junior staff to create and facilitate many such academic sessions at the ASA and the Society of Pediatric Anesthesia (SPA). Dr. Verghese has served at the ASA national leadership level as the Chair of the Scientific Abstract Review subcommittee on Pediatric Anesthesia from 2012 to 2014.

She has been active in the District of Columbia Society of Anesthesiologists (DCSA) in different capacities – serving as its president for 2 years (2006–2008) its delegate and alternate director to the ASA for a 3 year term and currently as its treasurer.

Above all, Dr. Verghese is grateful to God for the opportunity to serve as a caring pediatric anesthesiologist at CNMC in Washington, DC – a place she calls her "home" for the last 37 years.

Diego A. Preciado is a Professor with tenure at Children's National Health System and George Washington University. He serves as Vice-Chief of the Division of Pediatric Otolaryngology as well as Program Director of the

ACGME accredited pediatric otolaryngology fellowship at Children's National. His clinical practice is focused on pediatric airway reconstruction, childhood hearing loss/cochlear implants, and velopharyngeal insufficiency. He has authored over 100 vpeer-reviewed manuscripts, 10 book chapters and 2 edited books. An active basic science researcher, Dr. Preciado runs an otitis media translational laboratory funded through numerous intramural and extramural awards including R01, U01, and R21 grants from the NIH. Finally, he has served on numerous national committees including the American Society of Pediatric Otolaryngology Board of Directors and the Executive Committee for the Section of Otolaryngology of the American Academy of Pediatrics.

1 Evolution of Anesthesia for Pediatric Airway Surgery: From Ether to TIVA and Current Controversies

Susan T. Verghese

Evolution of Anesthetic Agents in Pediatric Anesthesia

General anesthesia revolutionized the practice of surgery in adults and children. The history of anesthesia from its humble origin to its present-day specialty is an incredible story of fearless pioneers and heroes who discovered new drugs and invented ingenious devices and novel routes to facilitate their delivery.

Surgery before the advent of anesthesia was a barbaric torture inflicted by bold speedy surgeons on hapless patients writhing in agonizing pain while being restrained by strong men.

The dawn of modern anesthesia begins with the discovery of two powerful inhalational agents: ether and chloroform – gases discovered within a year of each other [1–13].

In 1772, an English scientist and clergyman Joseph Priestley (1733–1804) discovered nitrous oxide, a year after he had discovered oxygen. The anesthetic and analgesic properties of nitrous oxide were not discovered until 1799 by an English scientist, Humphry Davy. He inhaled nitrous oxide gas as an experiment and to his surprise found that it made his body relax while making him giddy and cheerful forcing him to laugh. After experiencing the euphoric effect of this exhilarating gas firsthand, he named it "laughing gas." Although nitrous oxide had been used in dentistry since 1844, it lacked the anesthetic potency of diethyl ether in causing insensibility. On December 11, 1844, Horace Wells (1815–1848) a dentist and a pioneer in dental anesthesia tried to demonstrate for the first time albeit unconvincingly that the use of nitrous oxide could produce insensitivity to pain during a wisdom tooth extraction. This failed demonstration humiliated Wells, and he did not venture further to prove the effectiveness of other drugs in public even though he was experimenting with ether [4, 6]. However, this failure spurred him and others to search for a better agent. A fellow dentist William T. G. Morton (1819–1868) who was in attendance during the demonstration began investigating the effect of ether inhalation to produce insensibility for surgery. A knowledgeable chemist, Dr. Charles Thomas Jackson (1819–1868) who was a Harvard lecturer and a mentor, was able to guide him during his experiments with ether to produce a purified vapor of sulfuric ether [6].

On October 16, 1846, William T. G. Morton induced anesthesia with ether enabling John Collins Warren (1778–1856), a renowned surgeon and chief of surgery at Massachusetts General Hospital (MGH), to remove a vascular tumor from the neck of his patient, Edward Gilbert Abbott. This was the first public

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demonstration of a painless surgery performed and witnessed by many scientific minds of that day in the surgical amphitheater now known as the Ether Dome. Morton wears the mantle of fame as the discoverer of ether because it was he who first proved to the world its efficacy and safety as an anesthetic agent on that day marked as Ether Day in the history of medicine [1, 9].

This momentous milestone of ether producing a state of insensibility ushered the new era in medicine where pain could be eliminated during surgical trauma. News of this inhalational agent spread abroad and soon found its use into operating rooms in many countries. Robert Liston, another famous surgeon in London, performed the first limb amputation under ether anesthesia on December 21, 1846. Despite its popularity, ether had some undesirable properties of being flammable and unpleasant to inhale due to its strong odor. In addition to the need for a prolonged induction period, ether often caused significant nausea and vomiting in most patients who inhaled it [1].

These disadvantages prompted the search for a better inhalational anesthetic. James Young Simpson (1811–1870) an obstetrician from Edinburgh, Scotland, introduced chloroform in 1847. He believed it to be an agent superior to ether because of its pleasant smell and fast induction, requiring only a handkerchief to administer. Chloroform was used for decades, but the safety of the drug became questionable after several reports of hepatotoxicity were reported in patients anesthetized with this agent. When a demonstration showing the combined use of light chloroform anesthesia and adrenalin resulted in the patient's demise from ventricular fibrillation, interest in chloroform as an anesthetic slowly began to wane. It is unfortunate to note that the first pediatric anesthetic death reported was with Hannah Greener, a 15-year-old girl who underwent chloroform anesthetic for the removal of an ingrown toenail [1, 2, 4, 6].

The term "anesthesia" was coined by Oliver Wendell Holmes (1809–1894) from the Greek words "an" (without) and "esthesia" (sensibility) after witnessing a painless surgery under ether. Holmes was a famous physician, writer, and poet and a brilliant scientific leader, and he proposed naming this insensible painless state "anesthesia" and the procedure an "anesthetic," thus ushering the genesis of the new specialty – anesthesiology – into the practice of surgical medicine [2, 6, 7].

Now let us digress from the discovery of ether to a few other forgotten pioneers who did discover its anesthetic properties earlier but did not publish their findings in time.

Crawford Williamson Long (1815–1878), a rural physician from Jefferson, Georgia, is actually the first person to have administered the first documented and witnessed ether anesthetic in his office to a child, an 8-year-old boy for the amputation of a toe on July 3, 1842. He anesthetized other patients with ether for painless removal of digits, cysts, and neck masses in his medical practice. His caution and delay in publishing these astounding findings however prevented him from being given the recognition for discovering ether in abolishing pain during surgery [8–13].

In addition to Crawford Long, there were two other physicians mentioned earlier – Charles Thomas Jackson and Horace Wells – who were Morton's close mentors who claimed that they too had used ether before Morton or with him, and this led to "The Ether Controversy," a historical event brought about by their claims stemming from a desire for fame and recognition. It was precipitated upon publishing the article describing the incredulous events of October 16, 1846, by a surgeon Henry Jacob Bigelow (1818–1890) who was present at the ether demonstration at MGH. His article proclaimed that Jackson and Morton had discovered a way to render patients insensible to pain. When Horace Wells, Morton's former teacher in dentistry and work partner in Hartford, Connecticut, read this article, he wrote a rebuttal explaining that he had discovered this anesthetic property of ether 2 years earlier. Soon the assertion by Morton that he alone had discovered the use of ether as an anesthetic led to the feud between Jackson and Morton [8–13].

Pinckney Webster Ellsworth (1814–1896), a prominent Hartford surgeon and a staunch supporter of Wells, then wrote an article in support of Wells' assertion that appeared in the *Boston*

Medical Surgical Journal, and these articles started the ether controversy which is still debated by different supporters of these different physicians.

The Ether Monument erected in Boston's Public Garden commemorates the first public ether anesthetic demonstration at the Massachusetts General Hospital but does not give specific claim to any individual – choosing to focus only on the event in 1846, leaving Morton's name conspicuously absent [2, 4].

Morton, Wells, and Jackson bitterly contended to be recognized for the discovery of ether and endured tremendous turmoil and encountered personal tragedies. Crawford Long alone continued his work unaffected by this denial of recognition, living a peaceful life, busy with his practice and his family until he died at the age of 62. He was not a publicist, avid for fame or glory, and his own words that his career was defined as a ministry given to him by God is etched on his tombstone. It was on March 30, 1842, that Crawford Long had successfully used ether to anesthetize James Venable and then proceeded to excise a tumor from his neck painlessly. It was believed that he charged 25 cents for ether anesthesia and $2 for performing the surgical procedure. This day was the first time ether was safely used in a patient, and the delay in telling the whole world about it cost Dr. Long the honor of being known as the discoverer of ether anesthesia. It is only fitting that we celebrate "Doctors' Day" each year in March 30, to recognize this caring physician's original contribution to medicine, which remained forgotten for a long time [8–13].

First the Mask, Then the Tracheal Tube, and Then the Laryngoscope

The "Morton mask" originally used by William Morton was soon discarded, and several types of wired masks were used instead of towels and sponges. The prototype of modern face mask came from Francis Sibson (1814–1876), and it covered the nose and mouth. John Snow (1813–1858) an English physician and a leader in the adoption of anesthesia and medical hygiene was the first to use this mask and to specialize in the field of anesthesia. He is considered one of the fathers of modern epidemiology, in part because of his work in tracing the source of a cholera outbreak in Soho, London, in 1854. He is also the first physician who attempted to alleviate the pain of childbirth in women despite the existing belief that "labor pain" was to be endured and not treated. His choice of a royal subject Queen Victoria to be anesthetized for the delivery of Prince Leopold in 1853 paved the way for the future of the field of anesthesia in obstetrics [6, 7].

The Schimmelbusch mask was invented by Curt T. Schimmelbusch (1860–1895), a German physician and pathologist in 1890, and was used to deliver the anesthetic until the 1950s [14].

The wire frame of the mask was covered with layers of gauze, and the drops of highly volatile anesthetic diethyl ether or chloroform could be applied over it repeatedly when placed against the patient's face and nose. This original open anesthetic system allowed a mixture of air and evaporated anesthetic to produce anesthesia. Semi-open, semi-closed, and closed anesthetic systems developed after this simple open anesthetic system.

There were other illustrious names that were instrumental in producing the endotracheal tubes and laryngoscopes, which allowed the birth of airway anesthesia and surgery. It is interesting to note that the first endotracheal tube was created by a caring pediatrician, Joseph O'Dwyer (1841–1898), in order to overcome airway obstruction in his young pediatric patients who were suffering from diphtheria. He was able to pass these metal "O′ Dwyer tubes" blindly into their tracheas to allow them to breathe [3, 7, 15].

The first physician to perform an oral endotracheal intubation without a laryngoscope was Sir William Macewen (1848–1924). He used blind oral intubation to administer chloroform anesthesia for oral surgery to prevent blood from entering the larynx, and the concept of "securing the airway from contamination" was born. Ivan W. Magill (1888–1986) and Edgar S. Rowbotham (1890–1979) were the anesthesiologists who developed the mineralized red rub-

ber endotracheal tube to provide endotracheal anesthesia for surgery around the mouth. The technique they used for nasal intubation was to position the patients in such a way chin up that they looked as if they were "sniffing the morning air" [1, 7, 16].

In 1932, Arthur Guedel (1883–1956) and Ralph M. Waters (1883–1979) added an inflatable cuff to the existing endotracheal tubes which further enabled the anesthesiologist to provide positive-pressure ventilation.

Tracheal intubation techniques were achieved by blind or tactile (digital) means since the only possible way to visualize the larynx was by indirect laryngoscopy utilizing small mirrors at the end of specially angled instruments [2, 7, 15].

The technique of using a laryngoscope for direct visualization of the larynx to insert an endotracheal tube was first described in 1911 by Chevalier L. Jackson (1865–1958), an American pioneer in laryngology, who is known as the father of bronchoscopy and laryngoscopy. His direct laryngoscope was U shaped with no curve at the tip but had a light for better visualization. In 1941, Robert A. Miller designed the Miller blade with a slight curve at the end to retract the epiglottis.

However, it was Sir Robert Reynolds Macintosh (1897–1989), the Nuffield professor of anesthetics at the University of Oxford, who is credited with the first description of direct laryngoscopy to intubate the trachea – thus enabling the anesthesiologist a secure method of administering the anesthetic. During the administration of anesthesia for a tonsillectomy, he discovered that by indirectly elevating the epiglottis, he could have a "perfect display" of the cords. He described the method of routinely placing the tip of the laryngoscope in the epiglottic vallecula, which is attached to the base of the tongue, and gently lifting to expose the entire larynx. Macintosh argued against the traditional way of lifting the epiglottis in order to avoid bradycardia and laryngospasm that could result from vagal stimulation. It was soon evident that the use of the shorter more curved blade which bears his name (although slightly altered as McIntosh) and his modified laryngoscopic technique required less sedation and caused fewer problems with laryngospasm. Macintosh successfully popularized his blade as the "gold standard" despite the fact that many question even now the blade's superior ability to view the larynx when compared to the Miller blade. Macintosh's contribution was not so much the shape of the blade as much as the technique of laryngoscopy [15, 16, 17].

The results of a study comparing the effectiveness of Bullard laryngoscope and the short-handled Macintosh laryngoscope for orotracheal intubation in pediatric patients with simulated restriction of cervical spine movements showed the Mac blade to be superior to pediatric Bullard laryngoscope with a faster laryngoscopy time and a higher success rate [18].

First the Needle, Then the Syringe, Then Intravenous Anesthetics, and Finally the Amazing Amazonian Arrow Poison

The first recorded subcutaneous injection took place in 1844 by the Irish physician Francis Rynd (1801–1861) who had invented the hollow needle to inject a sedative subcutaneously to treat neuralgia. In 1853, Charles Pravaz and Alexander Wood manufactured a syringe with a fine hypodermic needle that could pierce the skin [19]. The development of these devices – syringes and later mechanical pumps – to deliver precise amounts of drugs intravenously continuously per minute based on patient's weight enabled physicians to administer total intravenous anesthesia (TIVA).

Pierre-Cyprien Ore' (1828–1891) was the first physician to attempt intravenous anesthesia by administering chloral hydrate in a patient in 1872, believing that this method was superior to inhaling chloroform. The combination of intravenous morphine and scopolamine produced a state of "twilight sleep" which was popular in obstetric anesthesia and was widely used throughout the WW1 era [1, 6, 7, 8, 15].

One of the intravenous drugs that made significant impact on the anesthetic management of the patient was sodium thiopental, a barbiturate

which was introduced in 1932. It was John Lundy (1894–1973) who popularized its use while he was at the Mayo Clinic, but its popularity waned because of cardiovascular depression when administered. Lundy also introduced the initial concept of "balanced anesthesia" where a combination of different drugs could be used synergistically for general anesthesia to decrease the side effects of each when used alone in large amounts [1].

Etomidate was discovered in 1973, and because of its ability to maintain hemodynamic stability, it continues to be used successfully in patients with marginal cardiac reserve. Ketamine was another interesting drug synthesized in 1962, which could be given intravenously as well as intramuscularly. Despite its hallucinogenic effects when given alone and in large amounts, it gained popularity in providing analgesia and cardiovascular stability when used in combination with other anesthetic agents as in balanced anesthesia as suggested by Dr. Lundy earlier [6, 7].

Anesthesia was practiced without the use of muscle relaxants until the discovery of curare, an alkaloid extract from the plant *Chondrodendron tomentosum*. It was used as an "arrow poison" or "flying death" to paralyze the prey by the South American indigenous people. The tips of the arrows or blow gun darts which were shot from hollow bamboo "tubes" were first dipped in this paralyzing agent called curare – a word derived from the word "wurari" from the Carib language of the Macushi Indians of Guyana.

When curare was purified, the main toxin obtained was called D-tubocurarine to denote its origins of being packed in hollow bamboo tubes.

It functions by competitively and reversibly inhibiting the nicotinic acetylcholine receptor (nAChR), which is a subtype of acetylcholine receptor found at the neuromuscular junction [20]. This causes weakness of the skeletal muscles and, when administered in a sufficient dose, eventual death by asphyxiation due to paralysis of the diaphragm. If the respiration was supported by artificial means, then the animal would wake up as if nothing had happened during the time of paralysis. It was used as an "interrupter" of the neuromuscular junction mainly to prevent traumatic complications of electroshock therapy in psychiatry.

In 1857, Claude Bernard (1813–1878) presented his experimental findings that the site of action of curare was at the neuromuscular junction, thus ushering the use of muscle relaxants into anesthesia and surgery.

"Balanced anesthesia" in its true modern sense was described by T. Cecil Gray in 1946, 100 years after the discovery of anesthesia. He introduced the "Liverpool technique," the practice of intravenous induction, muscle relaxation, light general anesthesia, controlled ventilation, and reversal of muscle relaxation with a cholinesterase inhibitor [20].

After curare, other drugs were synthesized and used but discarded because of unwanted side effects. Steroid-based intravenous muscle relaxants such as pancuronium (1966), vecuronium (1980), and rocuronium (1991) have remained in the clinical use having replaced the older drugs [6, 7].

Sigmund Freud (1956–1939) and Carl Koller (1858–1944) discovered the numbing effect of cocaine when applied topically, and regional anesthesia soon became an invaluable addition to general anesthesia. Newer drugs were soon discovered, and novel methods of applying them to produce sensory block expanded the scope of anesthesia far beyond human imagination and improved the safety and ease of administering anesthetics and analgesics to alleviate the pain during surgery [1, 2, 3].

Propofol arrived in 1977 and revolutionized the scope of intravenous anesthesia by providing smooth anesthetic induction, maintenance, and rapid emergence, thus becoming increasingly useful in adult and pediatric anesthesia. It has antiemetic properties, has a short recovery period, and is superior in suppressing laryngeal reflexes [1, 2, 3, 7]. Propofol has become the most commonly used intravenous drug in providing sedation and general anesthesia alone or in combination with a short-acting narcotic like remifentanil in TIVA during many surgeries where inhalational agent is undesirable. TIVA has gained popularity in providing anesthesia in suspension laryngoscopy and airway visualization for endoscopic surgery.

Dexmedetomidine (Precedex®) is the dextro optical isomer of medetomidine, a pharmacologically potent selective alpha-2 adrenoceptor agonist with sedative, sympatholytic, anxiolytic, and analgesic-sparing properties. It is similar to clonidine but differs in its eightfold greater affinity for alpha-2 receptors than alpha-1 receptors compared to clonidine. Dexmedetomidine produces its hypnotic action by activation of central pre- and postsynaptic alpha-2 receptors in the locus coeruleus. The quality of sedation and unconsciousness is similar to natural sleep in patients who appear cooperative and easily arousable. Dexmedetomidine can produce transient hypertension, bradycardia, and hypotension when given as a bolus because of peripheral vasoconstriction and sympatholysis. Since its approval for procedural sedation by the Food and Drug Administration in 2003, it has been used in pediatric sedation, premedication by novel routes – buccal and intranasal – and for prevention and treatment of emergence delirium in children especially if there is no intravenous line. One of the major advantages of dexmedetomidine over other sedatives is its minimal respiratory depression in adults and children [21].

The use of dexmedetomidine in children with OSA has been extremely useful in decreasing narcotic use significantly in the postoperative period. An intraoperative infusion of dexmedetomidine combined with inhalation anesthetics during T&A provided satisfactory intraoperative conditions without any adverse hemodynamic effects. The authors also reported a decrease in the incidence and duration of severe emergence agitation with fewer patients having desaturation episodes [22].

Current inhaled agents are ether-based anesthetics with either a methyl ether (enflurane, isoflurane, and desflurane) or a methyl isopropyl (sevoflurane) polyhalogenated ether skeleton –all of which are more stable and potent than its parent compound, diethyl ether. Halothane – a fluorinated alkane – was synthesized by a British chemist Charles Walker Suckling (1920–2013) in 1954 and introduced clinically in 1956. Halothane enjoyed some years of popularity in pediatric anesthesia before being shelved because of myocardial depression and the potential for hepatic damage [7]. Halothane is no longer available in the United States, but is still used in developing countries, particularly in pediatric patients. Methoxyflurane – another inhalational agent – was also removed because of nephrotoxicity resulting from high fluoride concentration during its metabolism. All halogenated methyl ethyl ethers can also cause myocardial depression as well as depress the respiratory response to carbon dioxide and to hypoxia [6, 7].

The search for an ideal inhalational anesthetic agent still continues slowly. Xenon, one of the noble gases, which has been studied because of its inertness, has limited use in clinical practice because of its prohibitive cost, which is about 2000 times the cost of nitrous oxide [23].

Xenon has anesthetic and analgesic properties and is devoid of toxicity and side effects. It displays the characteristics of an ideal anesthetic agent by providing exceptional hemodynamic stability and rapid emergence from anesthesia, as well as the ability to protect against ischemic damage to vital organs like the heart and the brain. Closed-circuit xenon delivery has been achieved clinically in study patients by utilizing an efficient gas delivery protocol, which eliminated wastage, and recovered xenon from exhaled gas by simple breathing hose alterations. These special delivery techniques may make its use clinically possible (despite the high cost) in selective patients where neuro- and cardioprotection may be at risk with conventional drugs [24]. Another noble gas, somewhat like xenon, is helium. Helium is less dense than air or oxygen, and so it can travel past airway obstruction providing a laminar airflow. The use of heliox is believed to reduce work of breathing, respiratory distress, and postextubation stridor [25]. Short-term benefit of heliox inhalation has been reported in children with moderate to severe croup [26].

Anesthesia induction has evolved from open drop ether and chloroform to semi-closed non-rebreathing and to circle systems. The newer systems with disconnect alarms and interlocks to prevent delivery of hypoxic mixtures enhance safety while reducing both the cost and

environmental pollution. Inhaled anesthetics have become much safer compared to the older agents with fewer side effects. Currently the most common inhalational agents used in pediatric anesthesia include sevoflurane, which is less pungent and thus easy to use as induction agent and desflurane, which is strictly used for maintenance of anesthesia in intubated patients. Desflurane is never used as an induction agent because of its pungency and airway irritability. It is an ideal agent for maintenance in prolonged surgeries especially in obese patients because of its lack of tissue accumulation and speed of emergence. Anesthesia delivery systems have come a long way from their modest origins, and the modern anesthesia ventilators are capable of multimodal functions and pressure waveform integration.

Extraglottic Airway Devices (EAD)

Dr. Archie Brain, a brilliant anesthesiologist in East End of London in 1981, created a new type of airway which could be inserted easily as an alternative to the endotracheal tube or the face mask [27]. This extra- or supraglottic airway was called the laryngeal mask airway (LMA) and marketed in late 1987 after undergoing some years of material and design modification. The pediatric classic LMA (cLMA) arrived into the clinical arena first followed by flexible and ProSeal LMAs with additional features and later the reusable and disposable forms. The advanced models soon followed: LMA supreme and i-gel with gastric drain port as well as the Air-Q and Ambu Aura-i, the first intubating airway devices in pediatric sizes. These newer LMAs were designed to decrease gastric insufflation, protect the airway, and allow effective ventilation as well as provide a secure definitive airway in difficult intubation scenarios [28].

The LMA became the rapidly accepted form of airway management globally, thus revolutionizing anesthetic practice in adults and children. The easy insertion of LMA without the aid of a laryngoscope enabled anesthesiologists to provide hand-free anesthesia for the first time. This was a definite game changer in the practice of adult and pediatric anesthesia. However, the question whether the frequent use of LMA may have lessened the ability of the anesthesia trainee to master the technique of the proper bag and mask ventilation during inhalational induction remains controversial.

The LMA has become an important tool in the management of the difficult airway algorithm. Both older and newer supraglottic airway devices have been studied in children and have become invaluable in managing difficult airway [29].

A recent technological update on EADs highlights the improvements in their design, safety, and functionality. These innovations include the shape of the mask, number of cuffs, and quality of the construction material used. In order to increase flexibility of the device, phthalates were used initially but eliminated later because of the adverse effect on reproductive function. The formation of the Airway Device Evaluation Project Team (ADEPT) by the Difficulty Airway Society (DAS) was initiated by the arrival of numerous airway devices with different designs into the airway market to improve the safety of the patient [30].

EADs have been used safely over 200 million times in the last 3 decades, and its introduction is considered as the most important development in airway management over the last 50 years [31].

Intraoperative Ventilation Techniques During Airway Surgery

The field of airway management is continuously evolving. Pediatric anesthesiologists who work daily with ENT surgeons intuitively know the usual intra-op ventilation strategy in healthy children with ASA status 1 or 2 scheduled for EUA, bilateral myringotomies and tube placement, and routine tonsillectomy and adenoidectomy as detailed in the chapter included in this book. However, if patients with ASA status 3 or 4 with unusual preoperative systemic issues are scheduled even for routine surgery, they will need special preparation and planning. These can include children who present with morbid obesity (BMI > 40), severe OSA, critical airway

narrowing, lung parenchymal loss, and global developmental delay with swallowing difficulty causing micro-aspiration, as well as children with severe systemic diseases who are unable to maintain normal ventilation because of hypotonia, loss of FRC from abdominal masses, and central apnea when anesthetized. These patients are usually intubated, and their ventilation controlled intraoperatively with or without paralysis, and if extubation is expected to be difficult in the immediate postoperative period, they are observed in the intensive care unit overnight. Significant morbidity and mortality can result from poorly planned and therefore sub-optimally managed pediatric airway. Ventilation techniques and airway management of neonatal, obese children and those with known airway problems and syndromes scheduled for routine and endoscopic surgery are detailed in several of the following chapters in this book.

The use of intravenous dexmedetomidine and ketamine as bolus and as infusion has enabled the anesthesiologist to produce sedation without causing respiratory depression. The use of ultrashort-acting narcotics like remifentanil, as an infusion during airway surgery in combination with intravenous propofol, has been very effective in producing an optimal surgical environment during endoscopic laser excision of papillomas or extraction of foreign bodies from the airway in a spontaneously breathing patient [32].

Drug-Induced Sleep Endoscopy (DISE)

It is sometimes necessary to create a pharmacologically induced sleeplike state or drug-induced sleep endoscopy (DISE) to evaluate the dynamic upper airway collapse in children with obstructive sleep apnea (OSA) using a flexible endoscope. It was pioneered at Royal National Throat, Nose and Ear Hospital, London, in 1990 and initially introduced as sleep nasendoscopy. The choice of ideal drugs during DISE is crucial for obtaining accurate results. These drugs should be able to produce analgesia while simulating a natural sleep in the patient without producing excessive respiratory depression or airway collapse and with minimal hemodynamic effect. DISE is usually reserved for those children with persistent OSA after tonsillectomy, those with OSA without enlarged tonsils, or in a child in whom you suspect the occurrence of laryngomalacia when asleep. DISE is also used to determine surgical therapy for OSA.

Intravenous infusion of propofol is the most commonly used agent for DISE in adults. A comprehensive review of literature regarding pediatric DISE concluded that the protocol using dexmedetomidine (DEX) and ketamine appeared to be safe, and they were the drugs most commonly used. The authors recommended this combination of DEX and ketamine due to the lower risk of respiratory depression and upper airway obstruction as compared with other agents. It is also recommended to discontinue the inhalational anesthetics if used for induction to insert an intravenous (IV) line as soon as intravenous sedation starts [33]. *Inhalational anesthetics have been shown to decrease upper airway muscle activity and therefore need to be eliminated to prevent compromising the findings during DISE.*

Good communication between the anesthesia providers and airway surgeon is crucial as children with OSA are at greater risk for airway obstruction and oxygen desaturation when sedated, and oversedation can result in airway compromise and/or central apnea.

Although DISE is an objective method to observe dynamic airway obstruction, the assessment and classification of the findings can become subjective and biased because of the above reasons [33].

Another review on the effects of anesthesia and opioids on the upper airway described the dose-dependent effects of propofol on the upper airway as causing uniform narrowing throughout the pharyngeal airway in infants and at the level of the epiglottis in older children. Dexmedetomidine did not show these dose-dependent effects when evaluated by cine magnetic resonance imaging when compared to sevoflurane, isoflurane, and propofol, and it caused less dynamic airway collapse than propofol [34].

In a retrospective review of the records of 59 children presenting for DISE, another group of

authors concluded that propofol when used alone or combined with sevoflurane produced more oxygen desaturations and a lower rate of successful completion than a combination of dexmedetomidine and ketamine during DISE in children with OSA [35].

A third review in children to compare the agents for DISE based on agent-specific neuropharmacology concluded that compared to propofol and midazolam, dexmedetomidine' s mechanism of action appeared to simulate natural sleep pathways [36].

Controversies in Airway Management in Children

In a comprehensive review of the current relevant literature using Google Scholar, PubMed, MEDLINE (OVID SP), and DynaMed, and the keywords Airway(s), Children, Pediatric, Difficult Airways, and Controversies, the authors identified several controversies in pediatric anesthesia: difficult airway prediction, difficult airway management, cuffed versus uncuffed endotracheal tubes for securing pediatric airways, rapid sequence induction (RSI), use of laryngeal mask versus endotracheal tube, and extubation timing.

The data collected showed that the procedural steps in airway management in pediatric anesthesia are currently based on adult airway management protocols due to lack of strong evidence-based medicine data in children [37].

Highlights

Should One Anticipate Unexpected Airway Loss in Every Patient Scheduled for Surgery and Have an LMA as a Backup Plan, Even in a Newborn?

A patient with a known difficult airway is easier to manage than an airway that suddenly becomes difficult because of unexpected airway obstruction.

For example, an infant with no history or symptom of stridor is suggestive of clinical airway obstruction when awake but becomes completely obstructed during anesthetic induction due to a pre-existing subglottic hemangioma – a scenario that can be challenging for even the most experienced pediatric anesthesiologist. High incidence of airway hemangiomas in infants diagnosed with PHACE (posterior fossa anomalies, hemangiomas, arterial lesions, coarctation of aorta, and eye anomalies) syndrome can present with or without stridor. Early detection of airway involvement is critical by performing direct laryngoscopy and bronchoscopy in all of these patients. An airway evaluation is recommended in infants with PHACE even if they are asymptomatic [38]. Anesthetizing an infant with PHACE syndrome without stridor in a remote location like the MRI suite and encountering an occluding subglottic hemangioma during the study can be a critically challenging situation for the anesthesiologist and may need termination of the imaging study and emergent evaluation by the ENT specialist [39]. Airway difficulty in asymptomatic children scheduled for non-airway surgery can and do occur, and the preoperative evaluation by history and physical examination should be undertaken in a systematic manner to prevent its possible occurrence in every patient. Availability of an appropriate-sized LMA for the patient in the room is an important part of dealing with any child who unexpectedly appears to be difficult to intubate [40].

A Cochrane review which included seven trials involving a total of 794 infants showed that LMA can achieve effective ventilation during newborn resuscitation in a time frame consistent with current neonatal resuscitation guidelines. LMA was found to be more effective than bag and mask ventilation in terms of shorter resuscitation and ventilation times and less need for endotracheal intubation [41].

Who Should Anesthetize These Children? Where?

Another controversy regarding the performance of these complex airway surgeries is the question as

to who should ideally be assigned to manage the pediatric airway. An anesthesiologist with some pediatric experience who manages an occasional pediatric patient in an adult hospital setting vs a fellowship trained pediatric anesthesiologist with airway skills in a specialized pediatric hospital.

In children with anatomical upper airway obstruction from tonsillar and adenoidal hypertrophy or upper airway collapse, mask ventilation can become difficult, and the use of high airway pressure can lead to gastric inflation and transient hypoxia due to acute reduction of functional residual capacity (FRC). Insertion of an oral airway during insufficient depth of anesthesia in a child with a partially obstructed upper airway can also lead to laryngospasm and/or bronchospasm. In the absence of an established intravenous line, early recognition and treatment of these functional airway problems are essential to prevent morbidity and mortality. As a rule it is good to have another trained person who can place an intravenous line to administer anesthetics or relaxants as needed as the anesthesia provider is managing the airway. A review of the current concepts in approaching a child with a difficult airway stated that although a normal pediatric airway that becomes "impaired" on induction may be managed by anesthetists experienced with children, the anticipated difficult pediatric airway should be managed by a dedicated pediatric anesthesia specialist in specialized centers [42]. The airway in infants and children can become challenging due to [1] the difficulty in obtaining a mask seal [2], difficulty in visualizing the vocal cords, and the rare scenario where the larynx is visualized, but the difficulty lies at or beyond that level in the form of bronchomalacia or extrinsic airway compression [43].

Use of Cuffed Endotracheal Tube Versus Uncuffed Endotracheal Tubes in Neonates, Infants, and Very Young Children: Should We Check Cuff Pressure Frequently?

Currently almost all pediatric anesthesia centers routinely use cuffed tubes in children and newborn. The popularity could be due to the fact that newer low-pressure high-volume cuffed tubes has enabled its use in neonates and small infants. New cuffed endotracheal tubes (Microcuff pediatric tracheal tube, Microcuff GmbH, Weinheim, Germany, and Microcuff® PET, Kimberly Clark, Health Care, Atlanta, GA, USA) with improved tracheal sealing characteristics and a recommendation chart for tube size selection have been introduced in the market [44]. The Microcuff tube consists of an ultrathin polyurethane cuff (10 μm), which does not form folds and channels between the cuff and the tracheal wall. The elimination of the Murphy eye has allowed the cuff to be moved more distally on the cuffed endotracheal tube shaft. The cuff is short, and when inflated, it expands below the subglottis, providing a seal with cuff pressure less than 10 cm H_2O. It has correctly placed depth markings and has low tube exchange rate. A recent meta-analysis showed that cuffed endotracheal tube reduced the need for tube changes and did not show a higher incidence of post-extubation stridor when compared with uncuffed endotracheal tubes [45]. Another study showed that the use of cuffed tubes in small children provides a reliably sealed airway at cuff pressures of 20 cm H_2O, reduces the need for tube exchanges, and does not increase the risk for post-extubation stridor compared with uncuffed endotracheal tubes. However, the cost of pediatric endotracheal tube with Microcuff is several times more than those in routine use without cuff [46]. Measuring cuff pressure is important because of potential for increase in cuff pressure which can damage underlying tracheal mucosa. Periodical monitoring of cuff pressure is recommended in children especially during long surgery [47].

Is There a Role for True Rapid Sequence Induction (RSI) in Children? Should We Use Rocuronium Instead of Succinylcholine Now that We Have Sugammadex?

The use of true RSI is controversial on two accounts: the application of cricoid pressure also

known as Sellick's maneuver (SM) to prevent gastric aspiration and the need for succinylcholine – the fastest-acting depolarizing muscle relaxant. Although the cricoid pressure is often applied in pediatric patients with full stomach, it can worsen intubating conditions and also led to a lower esophageal sphincter tone. This lowering of esophageal sphincter tone by cricoid pressure is not attenuated by metoclopramide [48]. The other problem with true RSI is the use of succinylcholine in children with full stomach scenarios after recommendations from the Food and Drug Administration (FDA) to reserve the drug only for emergency situations. Currently the use of this drug falls into the category of drugs "one should always have but seldom use." There are situations where RSI with succinylcholine may be needed as in a child with post-tonsillectomy bleed with a full stomach or a child with a bowel obstruction. Although we do not have a neuromuscular blocker with the same fast onset as succinylcholine, rocuronium can now be used at a higher dose to enable intubation in 60 s, and its action can be reversed with the newly approved reversal agent sugammadex – a chelating agent with high specificity for rocuronium reversal. This is especially important if rocuronium was used in a child for the removal of a foreign body, and the procedure is completed in less than 10 min. A dose of 2 mg/ kg of sugammadex has been used successfully to reverse a profound block due to rocuronium use in a child [49]. This can also be helpful in difficult airway scenarios to re-establish spontaneous ventilation if the airway was lost after paralysis with rocuronium.

Many pediatric anesthesiologists prefer a "modified RSI" instead of a classical RSI because they find the strict no manual hand bag ventilation rule during classic RSI difficult to follow in clinical scenarios in children. This is mainly due to the rapid fall in oxygen saturation in most young children as soon as you administer a drug to cause apnea. Neonates and young infants have reduced lung capacity, but higher oxygen consumption and oxygen desaturation are inevitable even if they are well preoxygenated prior to RSI. The "modified RSI technique" allows gentle intermittent face mask ventilation with oxygen to overcome this desaturation while providing muscle relaxation and adequate depth of anesthesia.

Extubation in Children: Deep Versus Awake

If ventilation was easily maintained with a mask airway on induction of anesthesia and endotracheal intubation was established without any difficulty and if there is no risk of aspiration in a spontaneously breathing healthy patient, then deep extubation can be undertaken to minimize coughing and cardiovascular stimulation.

Timing and Positioning for Extubation

Most experienced anesthesiologists time this extubation after suctioning the mouth and at the moment of end inspiration to decrease incidence of laryngospasm. Placing children in the lateral position and suctioning the mouth also help decrease this complication. The upper airway of a sedated, spontaneously breathing child has been shown to be wider in the lateral position in an MRI study in children. The region between the tip of the epiglottis and the vocal cords demonstrated the greatest relative percent increase in size [50]. Despite the evidence of airway diameter being wider in the lateral or recovery position in children, it is unfortunate that this particular position is not universally accepted as a safer position to transport children after deep extubation following T&As. Recovery position allows for blood and secretions to pool on the dependent side of the mouth instead of dripping back into an unprotected airway after extubation. One study looked at the incidence of laryngospasm after a carefully defined awake extubation in children after elective tonsillectomy. The technique involved turning anesthetized children into the recovery position and then turning the inhalational agents off. No further stimulation was allowed till the child awoke on his/her own. This "no-touch" technique in children placed in the lateral or recovery position prevented any coughing, desaturation, or incidence of laryngospasm [51]. Most experienced pediatric anesthesiologists currently use deep extubation technique

after T&A in children after placing them in the lateral position if they have a good airway and hemostasis. They continue with a "no-touch" or "no stimulation" technique during transport of these children in the lateral position with blow by oxygen and monitoring respirations and pulse oximetry. Upon arrival in the recovery bay, additional amounts of propofol or dexmedetomidine may be administered after monitors are placed to allow for a slow smooth wake up while maintaining the child in the same recovery or lateral position. A recent study showed that deep extubation after tonsillectomy was facilitated by a single dose of preoperative intravenous dexmedetomidine without any prolongation of postoperative recovery time [52].

However if the airway was difficult – starting with mask ventilation or became difficult after the surgery and in patients who are at high risk for aspiration – it is safer to extubate them when wide awake with protective airway reflexes and breathing spontaneously**.**

Preface

The following chapters contain information clinically useful to both the pediatric anesthesiologist and ENT surgeon or any reader interested in these two specialties. Each chapter in this text is written by an expert who has researched the topic extensively to include current accepted and safe clinical practices. The diversity in the chapters will help the reader to focus on critical situations in the airway management of obese children, newborns, and those with known difficult airway from congenital and acquired lesions. The chapter on airway pathologies requiring specialized anesthesia expertise for optimal outcomes strongly advocates the need for close collaboration between the two specialties. The author also emphasizes the need for a designated pediatric airway team, early effective planning, communication, and the use of protocols as successful tools to achieve the best result. The clinical scenarios are described and clarified with very descriptive endoscopic pictures from the author's collection of clinical case files.

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2 Preop Considerations in the Evaluation of Children with Airway Pathologies

Janish Jay Patel, Susan T. Verghese, and Diego A. Preciado

Safety in airway management begins with preoperative evaluation with a detailed physical examination. A comprehensive preoperative assessment of each child would enable the anesthesiologist to provide a safe anesthetic during surgery and ensure a smooth postoperative period with adequate pain control. However, since majority of children are scheduled to come on the day of surgery to the hospital, a routine preliminary telephone screen for preoperative evaluation is usually performed by a well-trained nursing team over the phone and the actual hands-on physical evaluation is possible only at the time of patient's admission. Information gleaned from this type of phone call includes information regarding the child's current health, family history, associated comorbid conditions, and any acute changes in their health that could potentially result in cancellation of the planned surgery. Children who need to be examined by an anesthesiologist prior to surgery are brought in earlier than the scheduled surgical time for a physical assessment of the patient. The parents are informed of the potential for cancellation after arrival and examination if the child appears sicker than what the history revealed by phone conversation.

Expert Consultation and Patient Preparation of the Complex Patient

It is beneficial for both the surgeon and the anesthesiologist to have an ideal perioperative plan before approaching the parent or patient in order to have a team approach to the perioperative care of a complex patient. Optimizing a complex patient who is being followed by multiple specialists for various medical issues is an area of critical importance. The surgical team should alert the preoperative clinical team regarding these patients sufficiently early so that the team can coordinate these consultations from the appropriate specialists.

Creation of pre-anesthesia testing (PAT) clinic in many pediatric hospitals has been useful to undertake this monumental task. A dedicated team of physicians and nurses evaluate complex patients scheduled for surgery at a future time when requested by the surgeon in a preop clinic. The PAT clinic visit provides anesthesiologist the opportunity to meet the patient, establish parent-physician rapport, outline intended anesthetic

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plan on day of surgery, and implement directives of multiple specialists to optimize the patient prior to surgery. In addition, the need for any further work-up – laboratory, radiological, and other investigational studies – is discussed. In some cases, additional consultation or follow-up care coordination with patient's primary specialists is warranted to improve their physical status in preparation for the upcoming surgery.

These clinic visits improve the communication between children, parents, and the anesthesiologist and provide an arena for discussion about potential risks of anesthesia, the modes of anesthetic induction, and options for postoperative analgesia. Cumulatively, this preoperative examination provides sufficient time for questions to be answered, improves understanding of what is expected during perioperative period, and reduces elective case cancellations for medical reasons resulting from inadequate patient optimization [1, 2].

Complex Child Followed by Multiple Specialists

An example would be a child with cystic fibrosis with pulmonary hypertension and failure to thrive who is followed by cardiology, pulmonary, and gastroenterology experts but now needs cauterization of a bleeding nasal polyp.

Children who have poorly controlled systemic diseases like diabetes mellitus, seizure disorders, thyrotoxicosis, or congestive heart failure may need to have his/her medication adjusted by the specialist to be in the best possible medical status for surgery. It is crucial for the primary specialist to be made aware of the surgical team's concerns about these patients' perioperative safety by detailing the complexity of the planned procedure, effect of special positioning – prone, lithotomy, and Trendelenburg – and anticipated duration of surgery, need for blood transfusion, and need for post-op ventilation. This critical information can help the expert consultant to formulate a plan to prepare the patient to be in the best possible clinical status. This might include the need for the complex patient to be worked up and evaluated to be optimized. They may have to undergo preoperative PFTs, polysomnogram (PSG) or sleep study, a pulmonary sick plan to improve perioperative lung function, 24 h EKG Holter monitoring to assess new onset of arrhythmias, cardiac echo, or catheterization if patient's cardiac status would improve with the help of an interventional cardiologist. In rare cases, there may be a need to place a pacemaker preoperatively or to increase cardiac function with increased dose of drugs. In complex cases, a primary cardiologist may even recommend to escalate monitoring with an intraoperative esophageal continuous echocardiogram during a complex surgery in a cardiac patient.

Considerations During Evaluation

General anesthesia in pediatric patients requiring surgery in and around the airway has always been a challenging scenario for the anesthesiologist. The shared airway can become a critical airway because of the potential for compression injury or misplacement due to unplanned movement of breathing device whether it is an endotracheal tube or a laryngeal mask airway.

A cuffed endotracheal tube is commonly used in surgeries where bleeding is anticipated in the intraoperative period. In airway surgeries, preparation begins with a close communication with the otolaryngologist regarding the plan for surgery and need for prior laryngoscopy to assess vocal cord motion or assessment of airway prior to intubation. A smooth perioperative care of the patient occurs when there is a close communication within the surgical team of preop nursing, OR nurse, OR technologist, anesthesia provider, and the surgeon.

Information Vital to the Anesthesiologist

A comprehensive understanding of the patient's health status past and present and the details of the scheduled surgery (duration, possibility of

blood loss and transfusion, positioning of patient, need for relaxation) are essential information for the anesthesiologist who can then tailor the anesthetic techniques. Selection of appropriate anesthetic agents and monitoring to optimize the perioperative safety and comfort of the patient is a main goal of a pediatric anesthesiologist.

Information regarding medication, food allergies, medical record review and evaluation of radiologic, laboratory, and other investigations that are available should be a part of this preop evaluation. Review of prior anesthetics and surgeries is essential especially in all airway procedures.

Questions about the patient's family history should include the incidence of unexplained sudden deaths under anesthesia, with special emphasis on the rare history of high fever from malignant hyperthermia or prolonged muscle weakness from pseudocholinesterase deficiency in the family.

A detailed history related to airway in a child begins with queries about (including any recent changes) nosebleeds, noisy breathing, stridor, snoring, breathing, or swallowing disorders. History of medical admissions, neonatal or any previous intubations, and airway management during previous anesthetic should be obtained.

A careful physical examination should be the whole patient starting with height and weight appropriate for the age and vital signs. The focus on airway examination is however key to determine the ease of bag mask ventilation and intubation. The ability of the patient to open the mouth wide, to protrude the tongue and mandible forward, and to move the neck from side to side as well as up and down is valuable in assessing the airway. If the patient is cooperative, assessment of the view of the open mouth for Mallampati classification can further help in the airway assessment. The size of the tonsils can also be evaluated in these children if their oropharynx can be examined. The presence of micrognathia, retrognathia, small thyromental distance, large neck circumference, large thick tongue, and large tonsils in a small mouth often predict mask airway difficulty (Table 2.1). While the overall incidence of difficult direct laryngoscopy within infants and children defined by Cormack and Lehane grade III or IV view (Table 2.2) is 1.35%, the presence of risk factors suggestive of difficult airway may be associated with higher incidence [1]. It should be routine practice during the preop visit to hear the patient phonate to rule out evidence of hoarseness or dysphonia. It is important to ask parents specifically if they noticed any recent changes of daytime somnolence, sleep-disordered breathing (SDB) in their child. The Perioperative Cardiac Arrest (POCA) Registry demonstrates that airway and respiratory events are the second most common cause for perioperative cardiac arrest in children following hemodynamic compromise related to blood loss [3].

Table 2.1 Clinical features suggestive of difficult airway

Physical feature	Clinical findings
Inter-incisor distance	Short or less than two finger breadths
Tongue	Large tongue relative or oral cavity
Oropharynx	Large tonsils, Mallampati grade 3 or 4
Mandible	Micrognathia, retrognathia
Thyromental distance	Short
Neck	Large neck circumference, limited flexion/extension

Table 2.2 Cormack and Lehane scale

Grade	Description at laryngoscopy
1	Full view of glottis
2	Partial view of glottis or arytenoids
3	Only tip of epiglottis visible
4	No glottis structure visible

In a newborn, it is important to elicit the birth history with the details of birth, whether the baby was born full term by vaginal delivery or unplanned urgent cesarean section for fetal distress. Information about initial Apgar scores, need for nasal oxygen or endotracheal intubation, and duration of NICU stay should be obtained from the parents. If the newborn was born premature, then the degree of prematurity and incidence of its sequelae – bronchopulmonary dysplasia (BPD), retinopathy of prematurity (ROP), intra-

ventricular hemorrhage (IVH) birth weight, and feeding problems – should also be obtained to plan for a safe anesthetic management.

The neonatal and infant growth history is equally important with special emphasis on the infant's ability to suck, swallow without regurgitation, weight gain, changes in muscle tone, developmental milestones, neurologic development, and physical growth.

Often the questions regarding need for premedication for separation anxiety, analgesia for postoperative period, nil per os (NPO) times, and cancellation for an upper respiratory infection (URI) in a child come up before routine airway surgeries. NPO guidelines as recommended by the ASA for patients with no known risk factors include no solid food for at least 6 h before surgery and unrestricted clear liquids until 2 h before surgery [4]. There are certain important clinical points to be highlighted when determining whether an elective airway case needs to be postponed because of URI-related problems. If the URI is associated with fever, malaise, persistent rhinorrhea, and frequent productive wet cough, then there is a definite reason to postpone the scheduled elective surgery since it is different from a clear runny nose without any systemic symptoms. Another way to confirm the degree of systemic involvement is to ask the parent if there is a history of poor oral intake, difficulty in sleeping, and playing with toys or other children associated with the onset of the URI [5].

Pre-induction Preparation

In some children with neurocognitive dysfunction, the need for premedication to allay anxiety or need for parental presence prior to anesthetic induction may be necessary to ease the separation from a parent. The introduction of child life specialists in many centers has been very successful in engaging young children with activities like blowing soap bubbles, allowing them to drive a little car to the OR, or providing videos to watch as distraction aids prior to anesthetic induction. These interventions often facilitate for unpremedicated children to get into the OR with minimum stress and ensure a smooth mask induction in OR. If there is a difficulty getting patients into the OR despite all these interventions, pre-induction medication for these resistant patients includes oral midazolam, ketamine, or alternatively intranasal dexmedetomidine [6]. The highly vascularized nasal mucosa provides a direct conduit to the brain, bypasses first-pass metabolism, producing a fast onset of action similar to IV route [7].

Children with food intolerances or allergies have recently raised unwarranted concern regarding the use of propofol in patients with egg, soy, or peanut allergy. Egg-allergic patients typically react to proteins from egg white, and not to egg lecithin, which is found within egg yolk and is used in propofol. While soy allergy is in fact extremely rare, propofol contains refined soybean oil, which removes the allergenic soy proteins during refining process. Additionally, the suspected low rate of cross-reactivity between soy and peanut is unlikely of any clinical relevance with respect to propofol allergy [8]. Interestingly, conflicting statements and the lack of confirmatory evidence lead to clinician uncertainty and avoidance of propofol without evidence. Furthermore, recent studies investigating patients with IgE-specific immunoglobulin to egg, soy, or peanuts found no evidence of propofol hypersensitivity and such food allergies [8].

Information Key to the Otolaryngologist

Although a specific preoperative evaluation outside of the routine clinic visit in which surgery is discussed is not a necessary component of the otolaryngology evaluation, certain factors specific to the risk for anesthesia should be taken into account by the pediatric otolaryngologist. In particular, whether intubation could be difficult should always be in the otolaryngologist's radar. Children with a history of difficult intubation, midface or mandibular hypoplasia, craniofacial

syndromes, mucopolysaccharidoses, and severe obesity should all trigger a plan to be prepared in the operative suite to address the possibility of difficult airway management. Although the rest of this textbook will go into great detail regarding the optimal management of these patients, as a minimum, in predictably challenging situations, the otolaryngology team should be prepared to perform rigid direct microlaryngoscopy and bronchoscopy for these children. In the most extreme and challenging cases, being prepared for emergent surgical tracheotomy may be necessary as well. Key to success is to discuss the potential plan, roadmaps, and management paradigms with the anesthesiologist prior to entering the operating room.

It is important to ascertain if the pediatric patients for surgery are using herbal or homeopathic preparations since adverse effects of some of these substances include bleeding, cardiovascular changes, and liver dysfunction. A survey conducted to assess the use of vitamins, nutritional supplements, or herbal or homeopathic preparations in children presenting for surgery showed that 3.5% of pediatric surgical patients had been given herbal or homeopathic medications in the 2 weeks prior to surgery. The most prevalent substance given to children presenting for elective surgery was echinacea, which can enhance hepatotoxicity effects of certain medications [9]. The potential complications arising from such remedies are unclear as very few have been formally researched; thus, discontinuing the use of herbal remedies 2–3 weeks before surgery is recommended by the American Society of Anesthesiologists [10]. Additionally, preoperative use of NSAIDs or aspirin for analgesia, anti-inflammation, and antipyretic effect should be avoided for 7–10 days before surgery, given the risk of surgical bleeding from impaired platelet aggregation and limited beneficial effects for patients [11]. Patients on long-term therapeutic or prophylactic anticoagulation (aspirin, coumadin, enoxaparin) require complex decision processes that comprehensively consider the risk of thrombosis with surgical risk of perioperative bleeding. For such children, collaborative consultation with pediatric cardiologist or hematologist may be required to ascertain alternative bridging therapy with heparin during perioperative period.

Summary

Children with airway pathologies undergoing elective surgery require a thorough and comprehensive preoperative evaluation to facilitate the care of the patient during perioperative period and improve patient safety. For most patients, the preoperative evaluation regarding patient's current medical status and comorbid conditions can be conducted via telephone screen by a well-trained nurse or by online survey. For complex patients, preoperative evaluation within PAT clinic may be warranted to drive decisions regarding further work-up, coordination of care, and implement preoperative optimization plans. Additionally, communication with the otolaryngologist preoperatively detailing perioperative airway management, intra- and postoperative pain control including need for ventilation support in intensive care in the postoperative period should also be included in the preoperative discussion.

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3 Airway Pathologies Requiring Specialized Pediatric Anesthesia

Diego A. Preciado

The Pediatric Airway

The pediatric airway is a unique anatomical site of the human body, in that disorders affecting this site acutely require the concerted and unified treatment efforts of multiple specialties in order to achieve favorable outcomes and avoid complications. Given that in most cases time is of the essence, pre-procedural planification, communication, and protocols are a paramount for success [1]. Indeed, simulation training for potential critical scenarios involving the pediatric airway is recommendable as an essential component of education and training [2]. First and most obvious, the infant's pediatric airway is much smaller than in the adult, with a typical diameter ranging from 3 to 4 mm at the level of the cricoid. Additionally, the larynx sits higher in the infant with the lower border of the cricoid at the lower border of the fourth cervical vertebrae, creating a situation where visualization of the glottis may be made more difficult, especially when the jaw is abnormally small, with a relatively posteriorly placed tongue base. Finally, the infant's laryngeal and tracheal musculo-cartilaginous framework tends to be less rigid than adults with a tendency for dynamic collapse during respiration.

The most common presenting symptom for children with lesions affecting the airway is stridor. As such, it is imperative for the airway team to be familiar with the different types of stridor and how the nature of the stridor may offer clues as to the nature of the underlying pathology. Stridor is characterized by a high-pitched noise during respiration derived from turbulent airflow due to narrowing or obstruction of the upper airway. Inspiratory stridor suggests obstruction at the glottic level or higher, while expiratory stridor reflects intrathoracic or severe obstruction. Inspiratory and expiratory, biphasic stridor suggests fixed obstruction, most often subglottic. Stridor which has been present from birth suggests an underlying anatomic cause. This generally denotes a fixed congenital narrowing such as choanal atresia, laryngeal web, bilateral vocal cord paralysis, subglottic stenosis, or tracheal narrowing [3, 4].

The Pediatric Airway Team

Management of pathologies of lesions involving the pediatric airway entails the active and concerted efforts of the pediatric anesthesiologist and pediatric otolaryngologist along with the personnel staffing the operating suite, including but

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not limited to the circulating nurse and the surgical technician. It helps to discuss the case and start the procedure with a previously agreed plan of attack. As opposed to most other surgical cases, in those performed for pediatric airway lesions, the operation's "start time" is not considered at incision but instead coincides exactly with the anesthesia "start time." *As such, it is critical for the pediatric otolaryngology team to be present and actively engaged in the case as soon as anesthesia is administered.* Indeed, difficulty in managing the pediatric airway is the single most important cause of anesthesia-related morbidity and mortality, especially in children with airway pathologies [5]. In pediatric patients, intubation is typically performed asleep, after gentle mask induction, while preserving spontaneous ventilation. Muscle relaxation is generally universally avoided for all of these cases. Depending on the degree of expected difficulty, there is a backup plan for intubation including the use of an intubating laryngeal mask airway, video-assisted laryngoscopes, flexible laryngoscopy, rigid bronchoscopy, and surgical airway securement (emergent tracheotomy). Care should be taken to avoid multiple intubation attempts, as this may lead to airway edema and difficulty with mask ventilation. Oral and nasopharyngeal airways are useful in the ventilation of children with obstruction at the level of the oral cavity and oropharynx, respectively. If intubation fails and mask ventilation is difficult despite two-provider ventilation, then a laryngeal mask airway (LMA) should be inserted. Failure of the LMA necessitates emergency airway ventilation, such as a rigid bronchoscope by the otolaryngologist. If this is unsuccessful, the team should be prepared to establish a surgical airway if needed. *In many of these events involving difficult mask ventilation, the use of neuromuscular blockade often catalyzes the transformation of the scenario from a difficult one to an emergent one.* In cases of difficult mask ventilation, if neuromuscular blockade is established, it is absolutely required for the airway team to take over and be able to intubate the airway immediately. For this reason, neuromuscular blockade is generally avoided for patients with suspected airway lesions.

Pediatric Airway Lesions

For purposes of this discussion, we will group these lesions into tumoral, stenotic (congenital and acquired), functional (congenital and acquired), and infectious. Undoubtedly, a profound understanding of these pathologies is of paramount importance when dealing with these patients surgically.

Airway Masses

Masses within the pediatric airway are most frequently benign – presenting in a variety of ways including hoarseness or abnormal cry, stridor, or respiratory distress. Lesions include vallecular cysts, saccular cysts/laryngoceles, subglottic cysts, subglottic hemangiomas, and recurrent respiratory papillomatosis (RRP) (Fig. 3.1). Depending on the location of the lesion, intubation can become quite challenging, if not physically impossible. As such, the children should be maintained under spontaneous ventilation upon induction and maintenance of anesthesia, while the otolaryngologist works to secure the airway by *navigating around the lesion endoscopically or through ablation of the lesion*.

Functional Pathology of the Airway

The glottis is comprised of the anterior membranous vocal cords, which serve primarily a phonating function, and the posterior arytenoid vocal processes which serve an airway passage function. Pathologies that affect the function of the glottis may compromise the airway, produce aspiration, and/or affect phonation. In general, anterior pathologies such as glottic webs, nodules, or papillomas affect phonation producing hoarseness, while posterior pathologies such as posterior glottic stenosis affect the airway producing stridor and obstruction.

Laryngomalacia and tracheomalacia describe the flaccidity of the airway leading to collapse, especially during the increased exertion of coughing, feeding, or crying. Laryngomalacia is typically congenital and characterized by inspiratory stridor and collapse of the supraglottic tissue during inspi-

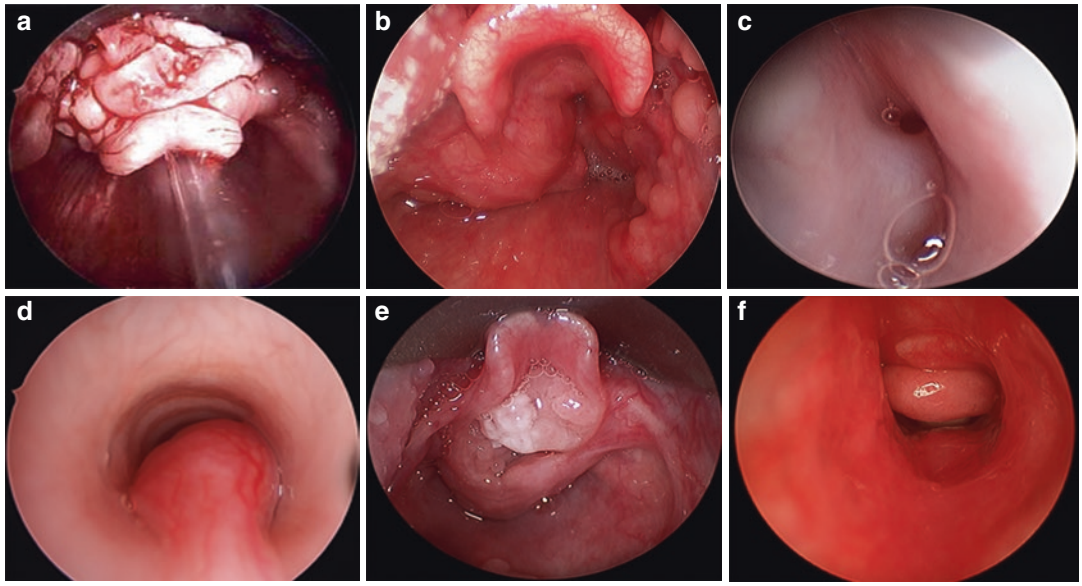

Fig. 3.1 Endoscopic photographs of common masses in the pediatric airway. (**a**) Vallecular cyst. (**b**) Laryngocele. (**c**) Subglottic cyst. (**d**) Hemangioma. (**e**) Papilloma. (**f**) Granuloma

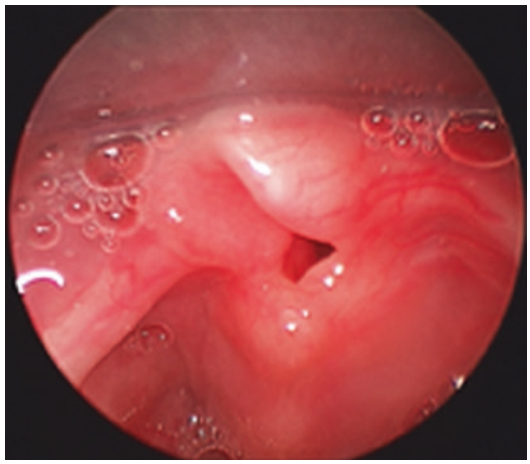

Fig. 3.2 Endoscopic photograph of laryngomalacia

ration seen on flexible laryngoscopy. It is the most common congenital cause of stridor. It occurs due to collapse of the supraglottic larynx, creating a narrow airway and turbulent airflow (Fig. 3.2). Laryngomalacia is self-resolving in a vast majority of infants by 9–18 months of age [6]. Surgical correction is reserved only for severe cases accompanied by apneic spells, failure to thrive, and/or feeding difficulties. In several series, a high prevalence of gastroesophageal reflux disease (GERD) has been reported in patients with laryngomalacia (50–100%) [7]. Late-onset laryngomalacia is becoming increasingly recognized in association with sleep apnea, exercise-induced stridor, and dysphagia and therefore may be seen in older patients, especially those with neuromuscular disorders. Tracheomalacia can be due to either intrinsic or extrinsic reasons [8] (Fig. 3.3). Intrinsic tracheomalacia occurs due to inherent weakness in the tracheal walls, resulting in diffuse collapse of the airway. Intrinsic malacia is often dynamic in nature, like laryngomalacia, causing positional stridor, worsened with agitation or exertion. Intrinsic tracheomalacia often improves with growth and frequently coexists with tracheoesophageal fistulas. Conversely extrinsic tracheomalacia, when symptomatic, will require surgical intervention, with correction or removal of the compressive cause. The most common cause of vascular compression of the trachea is from an anomalous innominate artery where a more distal origin of the innominate artery from the aorta causes compression of the right anterior trachea. An aberrant pulmonary artery may also compress the trachea. In these cases, an aberrant left pulmonary artery arises on the right side and courses in between the trachea and esophagus, causing poste-

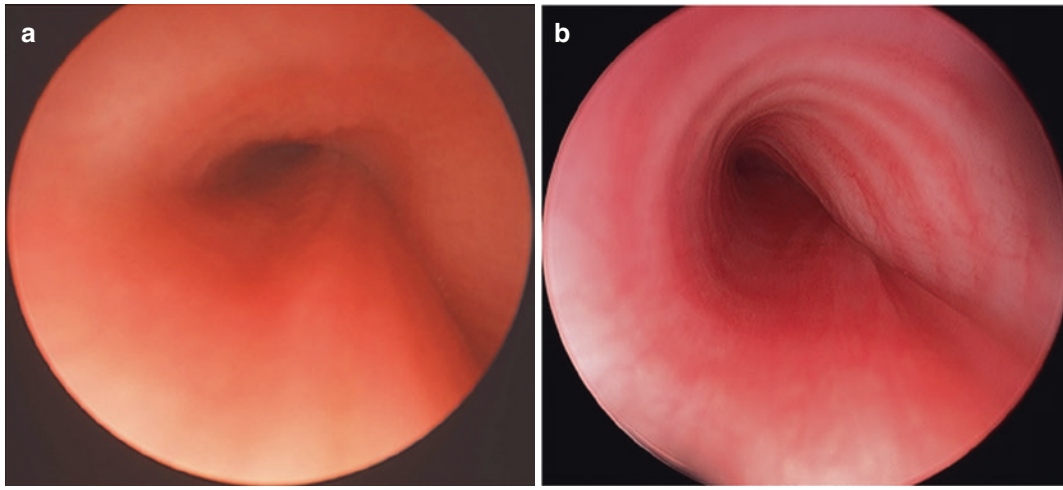

Fig. 3.3 Endoscopic photograph of tracheomalacia. (**a**) Intrinsic. (**b**) Extrinsic

rior tracheal compression, and a classic anterior esophageal compressive notch on esophagram. An aberrant left pulmonary artery will thus also cause dysphagia, which has been traditionally termed "dysphagia lusoria." Finally, vascular rings are also a cause of tracheoesophageal compression, the most of which is a double aortic arch.

Bilateral vocal cord paralysis in infants will cause severe obstruction as in these cases the cords are almost universally immobile in a closed, adducted position. Bilateral vocal cord paralysis (BVCP) represents the second most common laryngeal cause of infant stridor. The stridor is present at birth and usually inspiratory or biphasic, with a high-pitched musical quality. Most frequently these newborns present with acute airway distress requiring early intubation. Luckily, these children are generally not difficult to intubate.

Thankfully, the induction and maintenance of anesthesia, including airway endoscopy for functional lesions of the pediatric, can most often be readily performed without much difficulty.

Airway Stenosis

Stenoses of the airway can occur anywhere along the respiratory tract from the oropharynx to the pulmonary bronchi, with the most common site being the posterior glottic or subglottic level of the airway. The etiology of stenosis is most commonly a consequence of trauma, surgery, and intubation or due to congenital thickening of the cricoid cartilage walls (Fig. 3.4). The majority of intubation-related injuries are due to excessive cuff pressures or the use of an endotracheal tube (ETT) too big for the infant's airway.

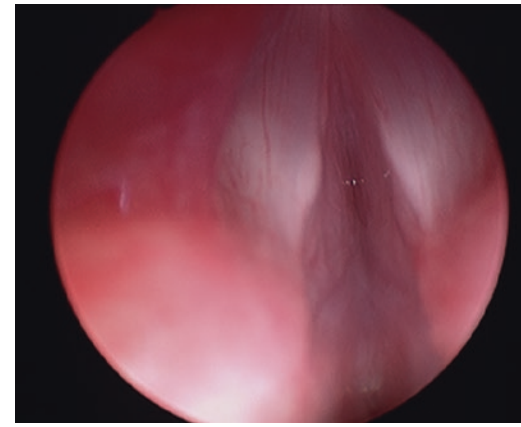

Fig. 3.4 Congenital subglottic stenosis

Although lateral and AP radiographs may suggest subglottic narrowing, direct laryngoscopy and bronchoscopy are needed to fully diagnose subglottic narrowing. The stenosis is then graded: grade I, less than 50% obstruction; grade II, 51–70% obstruction; grade III, 71–99% obstruc-

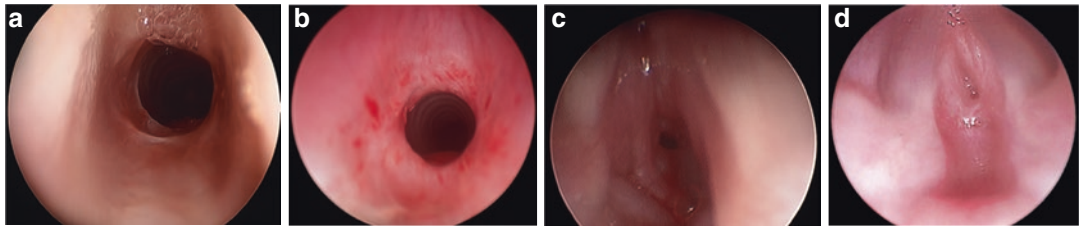

Fig. 3.5 Acquired subglottic stenosis. (**a**) Grade I. (**b**) Grade II. (**c**). Grade III. (**d**) Grade IV

tion; and grade lV, no detectable lumen [9, 10] (Fig. 3.5). Congenital stenosis is generally rare and associated with failure of normal embryologic recanalization of the cricoid ring. Children with Down syndrome very frequently have a mild degree of congenital subglottic stenosis. Symptomatic acquired soft subglottic stenotic lesions can be treated with endoscopic techniques with balloon dilation and/or laser treatment [11]. Congenital or more severe acquired subglottic stenosis is treated with open airway surgical reconstruction either through laryngotracheoplasty airway expansion or with partial cricotracheal resection [12]. Tracheotomy may also be needed in some cases to bypass the stenosis.

Tracheal stenosis may also occur due to acquired reasons, but indeed most causes of intubation injury in children occur in the larynx. Congenital tracheal stenosis is typified by abnormally complete tracheal rings. These rings will inherently narrow the tracheal lumen. Symptoms will vary according to the degree of narrowing and number of complete rings (length of the stenotic segment). Thus, long-segment stenosis with a markedly limited tracheal diameter ordinarily present in early infancy with evidence of respiratory obstruction is often life-threatening. Rigid endoscopy is the best means to characterize tracheal stenosis, but must be performed with utmost care, as any swelling induced by the procedure may result in potentially fatal further narrowing. In these cases, intubation and even placement of a surgical tracheotomy may not be physically possible due to the limited airway diameter. As such, when evaluating an infant with suspected complete tracheal rings under anesthesia, the airway team should be able to rapidly deploy extracorporeal membrane oxygenation as the sole means of providing in case the distal tracheal airway is lost due to edema gas during the case. Indeed, complete tracheal rings are associated with congenital great vessel cardiopulmonary anomalies in a majority of cases; therefore, echocardiography is recommended in all cases of diagnosed congenital tracheal stenosis to fully evaluate the cardiopulmonary vascular trunk. Although mild cases of tracheal stenosis may be managed conservatively, allowing for natural airway growth with time, more severe cases are managed surgically, with slide tracheoplasty being the preferred corrective surgical technique [13, 14].

Infectious Lesions of the Airway

Epiglottitis

Epiglottitis or supraglottitis (Fig. 3.6) is a rapidly progressive, life-threatening airway emergency typified by high-pitched stridor, drooling, severe retractions, throat pain, and dysphagia. The child often assumes the classic "tripod" position (i.e., seated, with the hands braced against the bed and the head held in the sniffing position to maximize airflow through a narrowed laryngeal inlet). Sudden laryngospasm may occur with aggressive oropharyngeal examination and/or aspiration of secretions into an already compromised airway, producing respiratory arrest. Lateral neck radiographs in those with epiglottitis reveal swelling and rounding of the epiglottis with thickening and bulging of the aryepiglottic folds. These children should be intubated as soon as the diagnosis is made. Thankfully, a precipitous decline in the inci-

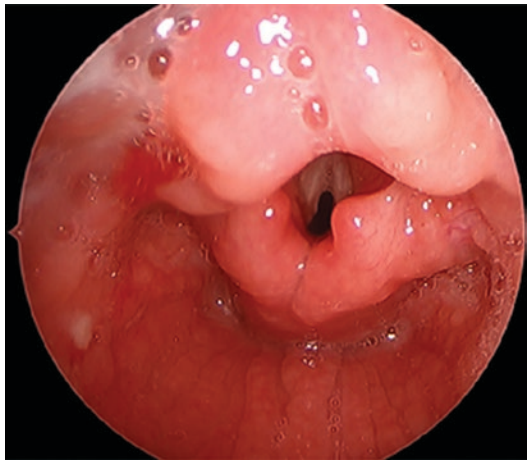

Fig. 3.6 Acute epiglottitis

dence of supraglottitis in children has occurred since the introduction of the *Haemophilus influenzae* type b (HIB) vaccine [15].

Acute Laryngotracheitis

Viral laryngotracheitis, or croup, is the most common form of infectious upper airway tract obstruction in children. It accounts for 90% of infectious airway obstructions and that 3–5% of children have at least one episode of croup [16]. Children will present between 6 months and 3 years of life with an acute onset of barking cough and, in more severe presentations, inspiratory stridor. The most common viral pathogen causing croup is the parainfluenza virus types 1 and 2. Anterior neck radiographs are classically characterized by a "steeple" sign, representing the swollen area of the subglottic airway. In most cases treatment involves systemic steroids, nebulized racemic epinephrine, and humidified oxygen. Surgical evaluation should be avoided in these typical cases of croup.

Conclusion

For any and all of these suspected pathologies, it is imperative that the anesthesiologist and otolaryngologist become familiar with any potential imponderable worst-case scenarios which may come up during their surgical evaluation and management. The goal of this text will be to provide detail for each of these potential scenarios and to summarize a review of the contemporary anesthesia methods for the successful treatment of children with these pathologies.

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4 Preferred Anesthesia for Routine Otolaryngologic Procedures

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Anesthesia for Tympanostomy Tube Placement

Tympanostomy tube insertion is among the most common operative procedures in childhood. In the United States in 2006, 667,000 children less than 15 years of age underwent surgery for the insertion of tympanostomy tubes [1, 2].

Chronic otitis media (OM) is characterized by fevers and ear pain, and it is common in young children. OM is usually associated with upper respiratory tract infections of viral or bacterial origins [3]. If untreated or poorly managed, it can lead to hearing loss and formation of cholesteatoma [4]. A cholesteatoma is an accumulation of desquamating epithelium within the middle ear that may grow to envelop the ossicles and result in conductive hearing loss and destruction of the ossicular chain.

The middle ear is a close space that requires periodic replenishment of mucosally absorbed air via the eustachian tube. The ventilating function of the eustachian tube is less well-developed in young children than in adults. Underventilation of the middle ear results in negative pressure that may lead to aspiration of nasopharyngeal secretions and transudation of intracellular fluid, important steps in the development of acute otitis media and otitis media with effusion [5]. OM can be treated with oral antibiotics, but repetitive infections may require surgery, which involves myringotomy, creation of a hole in the eardrum, to relieve pressure and to drain middle ear secretions [3]. Myringotomy provides middle ear ventilation; however, these simple perforations close rapidly [6]. When the incision heals, the drainage path is occluded. Therefore myringotomy is frequently accompanied by placement of a ventilation tube. Successful ventilation of the middle ear by myringotomy and insertion of a straight, narrow polyethylene tube that remained in place for a few weeks were described in a series of patients in 1954 [7]. The initial tube design has since been modified to achieve greater duration of function and lower rates of permanent perforation after extrusion. A small plastic tube (a variation of the grommet or the T-tube) inserted in the tympanic membrane serves as a stent for the ostium, and the small 1 mm opening in the tympanostomy tube prevents the development of negative pressure in the middle ear. The tube does not "cure" otitis media, but bypasses the child's immature and poorly functioning eustachian tube to equalize middle ear and atmospheric pressures. Tympanostomy tubes also allow administration of antibiotics to the middle ear topically. These

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tubes are also referred to as pressure-equalizing (PE) tubes or ventilation tubes [8]. This procedure is very short, but requires the child to remain very still; therefore, anesthesia is usually necessitated. These tubes facilitate continuous drainage from the middle ear until the tubes are naturally extruded in 6 months to a year or surgically removed at an appropriate time [4]. Only 30–40% of children initially treated with short-term tubes require additional tubes or surgery for otitis media [9]. Otitis media declines rapidly as the immune system and eustachian tube reach maturity [10].

Children with craniofacial anomalies, such as cleft palate, have a high frequency of middle ear disease compared with the noncleft population, because of associated abnormalities of the cartilage and muscles surrounding the eustachian tubes [11]. Surgical drainage and ventilation tube insertion is often necessary and is performed at the time of the surgical repair of the cleft.

Myringotomy with tube insertion is a very brief procedure; therefore, premedication is often omitted because the duration of action of the medication exceeds that of the procedure. However, an anxious child may still benefit from a sedative premedication, such as oral midazolam.

Anesthesia for this procedure is usually attained with inhalational agents, such as sevoflurane, oxygen, and nitrous oxide administered by face mask and maintaining spontaneous ventilation. Many surgeons use microscopes to aid in this procedure, and minor head movements are greatly amplified through the microscopes. Therefore, maintaining a patent airway with an oropharyngeal airway may help reduce head movement. Occasionally, a laryngeal mask airway (LMA) may be used in children in whom the procedure is expected to be prolonged (children with narrow ear canals such as in trisomy 21). Most children can be managed safely without intravenous (IV) access [12].

Children with chronic otitis frequently have persistent rhinorrhea and suffer recurrent upper respiratory tract infections (URIs). Eradication of middle ear congestion and improved fluid drainage often resolves the concomitant symptoms. Morbidity is not increased in children who present for minor surgery with acute uncomplicated mild URIs, provided tracheal intubation can be avoided [13, 14].

In some instances, a retained tympanostomy tube must be removed. This can be easily accomplished in the surgeon's office without anesthesia. Some stiff-flanged grommet tubes, however, require general anesthesia for removal. The anesthetic would be the same as that for the tube placement [4].

Preschool-aged children who receive sevoflurane without an analgesic for myringotomy and tube insertion may exhibit emergence delirium and postoperative agitation. Pain may be partially responsible for these responses. Pain management for myringotomy and tube insertion includes acetaminophen, either via the oral route preoperatively or the rectal route intraoperatively. The recommended dose of oral acetaminophen to achieve therapeutic blood levels is 10–20 mg/kg and 30–40 mg/kg when administered rectally [15–18]. Oral acetaminophen is very rapidly absorbed and achieves therapeutic blood levels in minutes, whereas rectal acetaminophen is slowly absorbed, with a time to onset of action of 60–90 min and a time to peak effect of 1–3 h [19–22]. Since this procedure is so brief and IV access is not usually established, intranasal fentanyl, 1–2 mcg/kg, has been shown to provide analgesia and to reduce the frequency of emergence agitation [23, 24]. Other medications, such as IV ketorolac (1 mg/kg) and intranasal dexmedetomidine (1–2 mcg/kg), have been shown to reduce the pain after myringotomy and tube insertion [25–27].

Most young children require general anesthesia for tympanostomy tube placement, but older children may tolerate topical anesthesia. This may be performed by applying lidocaine-prilocaine cream (EMLA cream) to the ear canal for 1 h and then suctioning it out before the procedure [4].

Anesthesia Approaches for Same-Day Surgery

Same-day surgery in pediatric patients is becoming increasingly common. According to a CDC report, in 2006, there were three million pediat-

ric ambulatory cases performed, and over half of them were otolaryngologic surgeries [1]. Same-day surgery is defined as a surgery that does not require an overnight stay and has a number of advantages for the child, family, and hospital. These advantages include increased patient comfort, higher child and parental satisfaction, and reduced hospital stays [28].

Disadvantages typically are from postoperative factors that cannot be managed after patient discharge, such as pain, nausea, and vomiting. For optimal same-day surgery, children should be carefully evaluated for suitability. Coordination of care between the surgeon, pediatrician, and anesthesiologist is key for successful ambulatory care. More specifically, anesthesiology care in ambulatory care is pivotal in the perioperative aspect and for successful discharge.

Anesthetic Considerations for Same-Day Surgery

Children presenting for same-day surgery require preoperative assessment and expert anesthesiology evaluation perioperatively. Selecting patients who are ASA 1 or 2 and older than 3 years of age has been associated with less risk in the ambulatory setting [29]. Common conditions that are encountered in children presenting for ear, nose, and throat (ENT) procedures include asthma, obstructive sleep apnea (OSA), and URIs. These conditions in children presenting for same-day surgery need further attention before a decision can be made to proceed with surgery and anesthesia. Children presenting with the following comorbidities are likely to need overnight monitoring postoperatively and may not be appropriate for same-day surgery [30]:

- Full-term infant less than 45–50-week gestational age
- Preterm infant less than 55–60-week gestational age
- Diagnosed obstructive sleep apnea
- Congenital cardiac disease
- Asthma/reactive airway disease
- Craniofacial abnormalities

Upper Respiratory Infections

Children presenting with URIs for same-day surgery are at increased risk for perioperative respiratory events, and risk assessment is essential in determining when to postpone anesthesia. Potential consequences of proceeding with anesthesia in the setting of URIs include respiratory failure, intensive care unit (ICU) admission, and death. Several factors can be used to assist with the decision to proceed with anesthesia and can be divided into patient factors, anesthetic factors, and surgical factors.

Patient factors to consider include symptoms and severity and duration of illness. Symptoms such as rhinorrhea, high fever, and lethargy can indicate higher risks of adverse events. A waiting period of 4 weeks after a URI begins will decrease the risk of respiratory adverse events as increased airway reactivity may still be present after 4 weeks. Surgical factors can also influence respiratory adverse risks. Airway surgery has a higher risk of adverse respiratory events. However, simple cases such as adenoidectomy can have lower risk. Myringotomy cases have the lowest risk due to lack of airway manipulation and short length of cases. Finally, airway *management* has a high risk of causing adverse respiratory events. The risk is highest with intubation and lowest with a face mask [31, 32].

Obesity

Approximately 16% of children in the United States are obese, and this includes those that may present for ambulatory surgery. Obese children are more likely to have complicating comorbidities that can be challenging to manage for same-day surgery. Asthma, OSA, and gastroesophageal reflux disease are among the comorbidities found in this cohort of patients. Anesthetic concerns correlated to obesity include increased risk for respiratory adverse events after tonsillectomies, such as intraoperative desaturation, airway obstruction, and difficult laryngoscopy and mask ventilation. For these reasons, obese children should be carefully evaluated if they present for same-day surgery [33].

Obstructive Sleep Apnea

OSA is frequently encountered in pediatric patients presenting for adenotonsillectomy. These patients may require sleep studies to evaluate the extent of the apnea. Due to the increased sensitivity to opioids and increased risk of respiratory events in patients with OSA, patients with diagnosed severe OSA are recommended to undergo surgery and anesthesia in a hospital setting. This allows for postoperative overnight monitoring [34, 35].

Perioperative Care

Perioperative anxiety in children is a significant hurdle to overcome. It is particularly challenging for same-day surgery. Risk factors for anxiety include young age, prior behavioral problems, history of multiple procedures, and anxious parents. Most pharmacological medications, such as midazolam, used for anxiolysis will prolong recovery and delay discharge [36, 37].

Innovative methods involving videos for children, music, or a prior tour of the facility can help reduce child anxiety. In addition, parental presence at induction of anesthesia is an option that can be effective. A patient preparation program is an effective method that has been shown to reduce anxiety and emergence delirium as well as decrease the use of postoperative pain medications [38–40].

Neuromuscular blockers are often avoided or minimized during same-day surgeries as these procedures do not take long but require intubation, such as tonsillectomies.

Discharge from Same-Day Surgery

Timely and safe discharge is of prime importance in same-day surgery. Obstacles to overcome include emergence delirium, postoperative nausea/vomiting, and pain. Emergence delirium is most common in children between the ages of 2 and 5 years. It is defined by agitation and inconsolable crying where the child does seem aware of their surroundings. Emergence delirium has also been associated with perioperative anxiety, and volatile anesthetics have been shown to increase the risk of postoperative delirium. Small doses of dexmedetomidine (0.5 mcg/kg) and propofol (0.5 to 1 mg/kg) administered at the end of the case have been shown to decrease the risk of emergence delirium [41, 42]. These medications should be utilized judiciously as they can prolong recovery. It is imperative to ensure pain is controlled first when treating emergence delirium.

Pain management in same-day surgery is critical for safe discharge and prevention of readmissions. Decreased use of opioids in the ambulatory setting is associated with less nausea and vomiting and faster discharge. The use of IV acetaminophen (10–15 mg/kg) and nonsteroidal anti-inflammatory medications (NSAIDS), if appropriate, can decrease the need for opioids [43].

Dexamethasone has also been shown to decrease postoperative pain after otolaryngologic surgery in addition to decreasing the incidence of postoperative nausea and vomiting (PONV). PONV is a common side effect of anesthesia, and successful discharge requires adequate prevention. This is particularly important in the setting of same-day surgery. The use of propofol, dexamethasone, and serotonin antagonists, such as ondansetron and granisetron, has been shown to be effective. In addition, adequate IV fluid replacement can decrease the risk of nausea and vomiting postoperatively [44].

Optimal Anesthetic Management of Tonsillectomy/Adenoidectomy

Tonsillectomy and adenoidectomy are two of the most common surgical procedures performed in children. Approximately 530,000 tonsillectomies are performed each year in the United States in children younger than 15 years of age [45]. Chronic or recurrent tonsillitis and obstructive adenotonsillar hyperplasia are the major indications for surgical removal [4]. Tonsillar hyperplasia may lead to chronic airway obstruction, resulting in sleep apnea, carbon dioxide reten-

tion, nocturnal hypoxemia, cor pulmonale, failure to thrive, swallowing disorders, and speech abnormalities [4]. Many of these adverse effects are reversible with surgical excision of the tonsils. Adenoidectomy is usually performed at the same time as tonsillectomy, but it is occasionally performed alone. Indications for adenoidectomy alone include chronic purulent adenoiditis, recurrent otitis media with effusion secondary to adenoidal hyperplasia, and chronic sinusitis [4]. Chronic nasal obstruction can result in orofacial abnormalities with a narrowing of the upper airway and dental abnormalities, which may be avoided by the removal of hypertrophied adenoid tissue [4].

Severe airway obstruction from adenotonsillar hypertrophy leads to disordered sleep patterns, and obstructive sleep apnea (OSA) is the most severe form of sleep-disordered breathing [4]. The prevalence of obstructive sleep apnea syndrome in children is estimated to be 1–3% [46]. Obstructive apnea in children is commonly defined as an obstructive effort that includes more than two obstructive breaths, regardless of the duration of the apnea [47]. Hypopnea is defined as a reduction in airflow of more than 50% [47]. The apnea-hypopnea index (AHI) is the summation of the number of obstructive apnea and hypopnea events and is similar to the respiratory disturbance index (RDI). The severity of OSA predicts the nature of perioperative respiratory complications. An RDI of greater than 20 events per hour is associated with breath-holding during induction, and an RDI of greater than 30 events is associated with laryngospasm and desaturation during emergence [48]. Impaired breathing, or hypoventilation, can lead to elevated blood carbon dioxide levels, which constrict the pulmonary artery and result in pulmonary hypertension. If available, patients with severe OSA and pulmonary hypertension can be treated with a continuous or bi-level positive airway pressure-breathing device for a few days before surgery, especially during nighttime sleep. These devices will improve breathing, reduce carbon dioxide levels in the blood, and lessen the severity of pulmonary hypertension. Surgical management of adenotonsillar hypertrophy and treatment of OSA-induced pulmonary hypertension prevent the progression of the pathophysiology of pulmonary hypertension [3]. Young children with significant nocturnal oxygen desaturation and carbon dioxide retention may require admission to the pediatric ICU after adenotonsillectomy for observation.

The risk of respiratory morbidity after adenotonsillectomy in otherwise healthy children is less than 1%, but this risk increases to 20% in children with OSA [49, 50]. These children are more likely to require supplemental oxygen, oral airway use, and/or assisted ventilation on emergence [48].

In addition to evaluating children for OSA, anesthesiologists must determine the need for premedication. Children with symptoms of OSA should be closely observed if they receive oral midazolam premedication, although the desaturation is transient and infrequent [51]. Anesthetic techniques for adenotonsillectomy include inhalational or IV induction, endotracheal tube (ETT) or laryngeal mask airway (LMA) for airway management, and spontaneous or controlled ventilation.

Induction medications are critical in adenotonsillectomies as these procedures start immediately with no surgical preparation time, are short in duration, and have an intense surgical stimulus [52]. Anesthetic induction is usually performed by inhalation of sevoflurane or intravenously with propofol or ketamine. Due to the short nature of these procedures, muscle relaxants are not commonly used, but if necessitated, short- to intermediate-acting agents may be used to facilitate tracheal intubation, such as succinylcholine 1–2 mg/kg or rocuronium 0.6 mg/kg [3]. Caution should be maintained when administering succinylcholine as it is associated with hyperkalemia and cardiac arrest in patients with muscular dystrophy. This condition may be undiagnosed in young male patients who have not yet started walking [3].

Tonsillectomy and adenoidectomy procedures are associated with significant postoperative pain, which can lead to inadequate oral intake and sleep, behavioral changes, postoperative nausea and vomiting, and prolonged hospital

stays [53]. Opioids are often used to treat this pain, but patients with severe OSA are quite sensitive to opioids. The morphine dose required to achieve a uniform analgesic endpoint in children with OSA, who exhibited a low preoperative oxygen-saturation nadir during sleep (less than 85%), was less than in those whose preoperative saturation nadir was greater [35]. Young age is also associated with an increased sensitivity to opioids. Children with OSA have increased respiratory complications after adenotonsillectomies, which are often seen within 2 h of opioid administration [35, 54]. When administering opioids, the dose of opioid should be titrated to effect so as to not cause apnea. This can be accomplished by maintaining spontaneous ventilation during maintenance of anesthesia, administering small amounts of opioid at a time, and waiting 3–5 min to determine their effect before administering more. Although a low-potency oral opioid may have a reduced perioperative risk, the use of codeine is not recommended in children with OSA. Codeine is metabolized by the cytochrome p450 CYP2D6 to its active analgesic metabolites [4]. The CYP2D6 gene displays polymorphism, including gene duplication (ultrarapid metabolizers) and inactive genes. Adults and children who have ultrarapid metabolism of codeine have greater fractions of morphine in their systems and are more at risk for respiratory arrest [55]. Alternatively, 10% of children lack CYP2D6, rendering codeine an ineffective analgesic [4]. Due to the broad variability in codeine metabolism, the use of codeine should be avoided in children with OSA. Another option for pain management includes IV ketamine. Ketamine does not depress respiratory efforts and, at low doses, should not cause hallucinations [3]. Dexmedetomidine, a selective alpha-2 adrenoreceptor agonist, is another option for anesthetic management as it has analgesic and sedative properties and minimal impact on respiratory parameters [56]. Pestieau et al. performed a study comparing IV doses of fentanyl (1–2 mcg/kg) to dexmedetomidine (2–4 mcg/kg) in children undergoing tonsillectomies. They concluded that high-dose dexmedetomidine decreases opioid requirements, prolongs the opioid-free interval after tonsillectomy, and decreases overall opioid requirements postoperatively [56]. Patel et al. performed a study in children with obstructive sleep apnea undergoing adenotonsillectomies and showed that an intraoperative bolus of IV dexmedetomidine (2 mcg/kg) followed by an infusion of dexmedetomidine (0.7 mcg/kg/h) reduces postoperative opioid requirements and decreases the incidence of emergence delirium [52]. The above two studies noted no significant hemodynamic changes associated with dexmedetomidine. Other agents without respiratory depressant effects, such as nonsteroidal anti-inflammatory drugs, acetaminophen, and local anesthetics, are often inadequate to treat postoperative tonsillectomy pain when used as sole agents [15, 57–61]. The routine use of NSAIDs for adenotonsillectomy remains controversial due to the potential for postadenotonsillectomy hemorrhage [4]. The Cochrane Collaboration assessed the effect of NSAIDs on bleeding after pediatric tonsillectomy in 13 trials and found no increase in bleeding that required reoperation for hemostasis [62]. Unlike aspirin, the effects of ketorolac on platelet function are reversible. Therefore, NSAIDs may be administered in adenotonsillectomies after consulting with the surgeon and after achieving hemostasis [4]. Intraoperative administration of IV dexamethasone 0.15–0.5 mg/kg decreases postoperative pain, reduces edema at the surgical site, and reduces the incidence of postoperative nausea and vomiting [63].

Infiltration anesthesia of local anesthetics bupivacaine, lidocaine, and/or ropivacaine can effectively decrease pain after tonsillectomy and adenoidectomy [64, 65]. This technique involves injecting local anesthetic to the upper, middle, and lower poles of the tonsils and adenoids as well as the posterior arch. The application of local anesthetics attenuates postoperative pain and reduces the administration of analgesics after adenotonsillectomies by blocking the transmission of pain impulses to the central nervous system and providing analgesic effects in the tonsillar fossa [66, 67]. The pain relief is transient, and risks include intracranial hemorrhage, deep cervical abscess, and bulbar paralysis [68, 69]. Infiltration of local anesthetic can be problematic in children with

OSA as their pharynx is smaller in size and more collapsible [70, 71]. Topical anesthesia applied to the mucosa of the pharynx of children with OSA reduces the caliber of the pharynx compared with control subjects [72].

Tonsillectomy and/or adenoidectomy in the pediatric age group represents a high percentage of PONV, accounting for 70% of cases [73–75]. Opioids increase the incidence of PONV, whereas propofol infusions, ondansetron, and dexamethasone reduce this incidence after adenotonsillectomy [76]. Different treatments or prophylaxis modalities have been suggested; however, currently, there is no universally accepted approach for reducing PONV incidence [77]. An alternative treatment for PONV is acupuncture, an ancient technique that has been used for medical purposes in China for over 2000 years [73, 78]. Following the approval of this technique by the World Health Organization as a complementary measure in treating some medical conditions, including PONV, many centers have utilized acupuncture in addition to standard medical approaches [79]. The National Institutes of Health stated in 1998 that the stimulation of the P6 point is effective in preventing nausea and vomiting that is caused by chemotherapeutic agents [79]. Ozmert et al. conducted a randomized study in 70 pediatric patients undergoing tonsillectomy and/or adenoidectomy in which they provided acupuncture to the patients in the study group. Acupuncture was performed by placing an acupuncture needle in the P6 acupuncture point, which is 2 cm below the transverse crease of the wrist, between the palmaris longus and flexor carpi radialis tendons, for 20 min during the surgery. The PONV rate was significantly less in the group who received acupuncture. Streitberger et al. also reported that acupuncture application with stimulation of the P6 point was effective under general anesthesia and the irritation of needle insertion, which could be problematic in pediatric patients, was eliminated with general anesthesia [80].

Children undergoing adenotonsillectomies have higher incidences of airway reactivity and laryngospasm [4]. Respiratory complications such as bronchospasm, laryngospasm, and hypoxemia are common during adenotonsillectomies due to the patients' small airways, hyperreactivity to infectious and inflammatory processes, and the presence of secretions [81]. Laryngospasm is among the most feared respiratory complications as it causes severe hypoxemia and requires immediate treatment, and adenotonsillectomy is associated with the highest rate of laryngospasm among other surgical procedures performed in children [82]. The factors that increase the risk of laryngospasm include young age of child, inhalational induction, endotracheal intubation, inadequate anesthetic depth, respiratory infections, and presence of secretions in the pharynx [81]. Treatment for laryngospasm consists of positive-pressure ventilation with a face mask, which can cause regurgitation, as well as succinylcholine, which can trigger cardiac arrhythmias and hyperkalemia. Complications of endotracheal intubation include laryngeal trauma and edema, injury to the teeth and lips, and cardiovascular stimulation [83]. To reduce the risks associated with this procedure, Williams et al. used reinforced LMAs for adenotonsillectomy cases and noted a reduced incidence of laryngospasm, cough, and hypoxemia [84]. The newer LMAs are more flexible and are able to fit under the mouth gags without becoming easily dislodged or compressed [4]. The LMAs form a low-pressure seal above the laryngeal inlet and are easy to insert and have minimal risk of oral and laryngeal edema [83]. Williams et al. noted that the LMA did not interfere with surgical access and protected the lower airway from blood and secretions. This study showed no cases of aspiration of blood into the larynx in the LMA group undergoing adenotonsillectomies compared to aspiration of blood in 54% of children in the intubation group [84]. They did note that suction was required more often in the LMA group to clear excessive amounts of blood and secretions pooling in the mouth, and this was attributed to the LMA preventing fluids from being swallowed or aspirated. Junior et al. performed a similar study to Williams et al. approximately 20 years later, which showed performing adenotonsillectomies in pediatric patients with LMAs resulted in lower intraoperative oxygen saturation by pulse oximetry compared to using endotracheal tubes (ETTs).

This was attributed to impaired surgical access by the LMAs leading to increased operative time, increased need for aspirating oral blood, and decreased amount of tonsil tissue removed. Junior's team noted that cervical hyperextension performed by surgeons would lead to anterior displacement of the LMA, requiring repositioning to contain the gas leak. They did note that respiratory events (wheezing, stridor, laryngospasm, and bronchospasm) were similar between the two groups [81]. Peng et al. also compared the use of LMAs and ETTs in pediatric adenotonsillectomy patients and noted no difference in rates of laryngospasm, but children in the LMA group were noted to have significantly less stridor after the procedure [85].

Use of the LMA for adenotonsillectomy is widespread in Canada and Europe [86]. The LMA tube may kink with the opening of the mouth gag, and this obstruction is minimized by using reinforced LMAs [84]. Studies from Peng, Webster, and Junior suggest that the LMA is a safe alternative to ETT in pediatric adenotonsillectomy without interfering with surgical access and by adequately protecting the airway. Children with OSA may have small oropharynges and adenotonsillar hypertrophy, both of which may increase the difficulty in properly inserting LMAs [4].

Regardless of the type of airway device utilized, adenotonsillectomies are associated with an increased risk of airway fire. This risk is higher when electrocautery is used rather than radiofrequency ablation [87, 88]. To reduce the risk of airway fire, the inspired oxygen concentration should be below 30% throughout the procedure, and cuffed ETTs should be considered. The cuff of the ETT serves as a barrier to minimize oxygen from leaking out from the trachea and accumulating around the operative site [88]. Should an airway fire occur, the ETT or LMA should be immediately removed from the airway, the flow of all airway gases should be turned off, flammable materials should be removed from the airway, and the airway should be flooded with saline or water. After the fire has been extinguished, the ETT should be inspected to ensure that it is intact and that no fragments are left in the airway. Ventilation should then be managed via face mask, and then the airway should be intubated with a new tracheal tube [89].

In addition to maintaining vigilance regarding airway fires, special consideration must be given to select populations undergoing adenotonsillectomies, such as patients with Down syndrome. Down syndrome is the most common autosomal chromosomal disorder causing mental retardation, and most children with Down syndrome have trisomy 21 [90]. Associated anomalies include congenital cardiac disease, developmental delay, cervical spine disorders, obesity, and obstructive sleep apnea. In fact, OSA may cause hypoxemia and elevated pulmonary vascular resistance, thereby contributing to the noncardiac pulmonary hypertension that occurs in these children [91, 92]. Predisposing factors for OSA in Down syndrome include midfacial hypoplasia, micrognathia, narrow nasopharynx, macroglossia, small oral cavity, and obesity [90, 93]. Respiratory complications requiring intervention are five times more likely in children with Down syndrome after these procedures [94]. The most frequent interventions are supplemental oxygen therapy, positioning of the child, insertion of a nasal airway, and treatment with nebulized racemic epinephrine [94].

At the end of adenotonsillectomies, the trachea can be extubated, while the patient is still fully sedated or when the patient is awake. The optimal time to withdraw the tube remains debatable. When the patient is fully awake, the airway is more protected, but this is associated with increased bleeding [81]. Extubating a sedated patient, however, can lead to obstruction and lack of protection against aspiration. A common practice is to position the child in the lateral position at the time of extubation to permit blood and secretions to pool in the dependent cheek and drain out of the mouth rather than accumulate at the laryngeal inlet [4]. Positioning is important during recovery from anesthesia. Extension of the cervical spine, the sniffing position, the lateral recovery position, and mouth opening with anterior advancement of the mandible all increase the dimension of the pharynx and reduce the risk of upper airway obstruction [95–99].

The severity of OSA is a predictor of the outcome after adenotonsillectomy [100]. Children

with OSA continue to demonstrate obstructive apnea and desaturation during sleep on the first night after adenotonsillectomy, with the frequency of the obstructive events and the severity of desaturation usually greater in those children with severe OSA [101, 102]. Despite the removal of the hypertrophied tonsils and adenoids, children with OSA continue to experience symptoms on the first postoperative night. Therefore, these children should be admitted to a hospital for continuous monitoring postoperatively. Long-term follow-up studies in children with OSA show that 6 months after tonsillectomy, symptoms completely resolve in those with mild OSA (AHI less than 10) but are persistent in 35% of those with severe OSA (AHI greater than 20) [100].

Post-tonsillectomy Bleed

Post-tonsillectomy bleeding may occur immediately after surgery, while the child is in the recovery room (primary), and the child should be taken to the operating room as soon as possible for re-exploration. Bleeding may also occur 7–10 days after surgery when the wound scab covering the tonsillar bed peels off (secondary). Approximately 75% of postoperative tonsillar bleeding occurs within 6 h of surgery [103]. Primary bleeding is more serious than secondary bleeding because it is usually more brisk and profuse. When the bleeding occurs, the child initially swallows the blood. Therefore, by the time the child starts coughing up or regurgitating blood, the stomach typically contains significant amounts of blood. The hemoglobin levels have decreased by this point. By the time the child arrives at the hospital, he/she may be dehydrated from decreased PO intake and may also be hypovolemic from bleeding. These patients must have IV access established prior to the operating room to initiate fluid resuscitation and possible blood transfusions. However, IV access may be challenging to obtain in these hypovolemic patients, in which case, intraosseous access should be considered [3]. If blood loss is severe, lactic acidosis and a state of shock may develop [4]. To compensate for the acute blood loss, the child may have an increase in catecholamine release, resulting in peripheral vasoconstriction, thereby delaying the onset of hypotension. When anesthesia is induced, vasodilation will occur, and profound hypotension may develop. Therefore, hemodynamic stability must be achieved prior to induction with crystalloids, colloids, and/or blood products.

Once the patient has been resuscitated with fluids and/or blood transfusions, he/she should be brought to the operating room, and rapid sequence induction of anesthesia should be initiated. Regardless of when the child last ate, the stomach is full of blood; therefore, the child is at significant risk for aspiration. Induction can be performed with IV propofol 1–2 mg/kg or ketamine 1–2 mg/kg or etomidate 0.2 mg/kg as well as succinylcholine 2 mg/kg or rocuronium 1 mg/kg. Propofol should be used with caution in these volume-depleted patients as propofol decreases peripheral vascular resistance and may lead to hypotension [3].

Two separate large-bore Yankauer-type suction tips should be available for removing blood from the oropharynx during tracheal intubation. Bleeding may be aggravated by direct laryngoscopy and obscure visibility of the vocal cords during tracheal intubation. If bubbles are identified coming through the blood, this can serve as a guide to the location of the vocal cords. A cuffed ETT should be used to minimize the chance of aspirating blood. The surgical procedure to control bleeding only lasts a few minutes and is not very painful. Pain medicine should therefore be administered judiciously, and the patient should be extubated once fully awake [3].

Cochlear Implantation with Sensory Monitoring

Cochlear implantation is used in the treatment of sensorineural deafness and severe hearing disorders in infants and children. Early treatment enables patients to hear, which allows speech and language development [104, 105]. The cochlear implant device functions by receiving the sound via an external microphone and processing it by a portable

speech processor. The sound is then transmitted to a stimulator, which is implanted in the mastoid bone. A radiofrequency transmitter is placed behind the ear, and the sound signals are transmitted to the auditory nerve. The electrically elicited stapedius reflex is crucial in fitting the speech processor of the device. The type of intraoperative anesthetic can affect the stapedius reflex [106].

Anesthetic Considerations for Cochlear Implantation

Children with sensorineural deafness requiring cochlear implantation may have other comorbidities to consider when planning the anesthetic. Many children requiring a cochlear implant have idiopathic hearing loss. However, a significant number of children present for cochlear implantation as a result of perinatal complications such as prematurity, cerebral palsy, meningitis, and congenital syndromes [107]. This should be taken into consideration when preparing a patient for surgery and anesthesia. The following syndromes are associated with deafness [108]:

- Treacher Collins syndrome – associated with facial abnormalities that can cause a difficult airway
- Klippel-Feil syndrome/anomaly – associated with vertebrae fusion that can cause a difficult airway
- Pendred syndrome – genetic disorder leading to congenital bilateral sensorineural hearing loss and goiter with euthyroid or mild hypothyroidism
- Alport syndrome – characterized by glomerulonephritis, end-stage kidney disease, and hearing loss
- Usher syndrome – associated with congenital cataracts
- Jervell and Lange-Nielsen syndrome – associated with long QT
- Stickler syndrome – mid-face hypoplasia, progressive myopia, and arthropathy

Premedication may be required in children over 12 months of age with anxiety, or parental presence may be utilized during inhalational induction. Midazolam 0.5 mg/kg by mouth, up to 20 mg, has been found to be effective for anxiolysis [36]. Anxiety is particularly important to treat older children who may not understand what is happening and are unable to communicate. If a child has a hearing aid or can use sign language, communication should be continued with the child to help them understand the perioperative environment.

Induction of anesthesia is usually started with inhalational induction for IV line placement. Intubation can be achieved with propofol 2–3 mg/kg, and analgesia can be accomplished with fentanyl 1–2 mcg/kg intravenously. Patients should be intubated without the use of a paralytic as facial nerve monitoring is needed in this procedure. If neuromuscular blockade is needed to secure the airway, a short-acting option should be considered. The procedure takes about 2–3 h with the patient positioned supine, and the bed is usually rotated 180 degrees away from the anesthesiologist.

During cochlear implantation surgery, the device is inserted, and then sensory monitoring is achieved by the electrically elicited stapedius reflex threshold (ESRT) and the elicited compound action potential (ECAP). Volatile anesthetics may affect the stapedius reflex threshold, which can impact maximum comfort level, leading to pain when the cochlear implant is stimulated. Volatile anesthetic requirement can be reduced by either using total intravenous anesthesia with propofol or using a balanced anesthetic technique using a volatile anesthetic in conjunction with a remifentanil infusion [109]. Setting the cochlear device under anesthesia is necessary in infants and young children. Minimizing the effect of the anesthetic on the device is important for proper hearing [110, 111].

Smooth emergence is important at the end of surgery. Coughing, bucking, or agitation at the end of the case can cause dislodgment of the device. Deep extubation or use of dexmedetomidine at the end of the case may be beneficial. Nausea and vomiting are common after inner ear surgeries, including cochlear implantation. It is necessary to preemptively treat nausea and vom-

iting with dexamethasone and ondansetron [112]. Pain management is also important and can be accomplished using opioids, acetaminophen, and NSAIDs. Acetaminophen and NSAIDs can be used to decrease the use of opioids and their side effects, such as nausea, vomiting, and pruritus [113, 114].

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5 Anesthesia Methods for Airway Endoscopy

Benjamin Kloesel and Kumar Belani

Introduction

In pediatric practice, airway endoscopy is a commonly performed procedure. It includes elective as well as emergent interventions (Table 5.1) and can be considered one of the more challenging procedures as it often involves an unprotected airway, maintenance of spontaneous ventilation, and provision of adequate anesthesia to blunt protective reflexes. Furthermore, communication is key as the airway is shared with the otolaryngologist and access is limited. By the same token, otolaryngologists understand the importance and urgency of ensuring airway patency during their procedures. The anesthesia care team assumes the crucial role of monitoring the patient's vital signs and plane of anesthesia to allow for excellent conditions for the endoscopist, including anesthesia, analgesia, suppression of upper airway reflexes, and immobility while providing backup to ensure any required ventilation is provided in a dynamic fashion during or after the procedure. Diagnostic airway endoscopy may require spontaneous ventilation for evaluation of the upper and lower airway during active breathing. The procedure may also reveal findings that necessitate interventions which can include foreign body extraction, balloon dilation, tissue resection with knife, forceps, microdebriders, cryotherapy, electrocautery, or laser therapy [1].

Table 5.1 Indications for airway endoscopy

Elective	Urgent/emergent
Assessment of upper and lower airways with flexible bronchoscopy	Foreign body removal
Assessment of upper and lower airways with rigid bronchoscopy	Evaluation and treatment of tracheal or bronchial obstruction (mucus plugs, tissue, tumor)
Assessment of larynx with suspension microlaryngoscopy	Evaluation and treatment of hemorrhage
Subglottic stenosis	Evaluation of airway trauma
Laryngomalacia	Evaluation of airway inhalation
Tracheomalacia	Evaluation of airway aspiration
Bronchomalacia	Difficult intubation
Vocal cord palsy	
Subglottic granuloma	
Congenital laryngeal cyst	
Diagnostic or therapeutic bronchoalveolar lavage	
Chronic cough	

Spontaneous Ventilation Versus Controlled Ventilation

One aspect that is heavily influenced by regional practice variations and preferences on the side of the otolaryngologist and anesthesia provider is

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the question of whether the procedure will be performed with the patient maintaining spontaneous ventilation or being ventilated in a controlled manner. Of note, it is important to recognize that the line between those two options can often be dynamic, e.g., a case may start with the patient ventilating spontaneously, but with changes in the anesthetic plane, the patient may lose central ventilatory drive temporarily and require assisted or even controlled breathing to maintain oxygenation. For a few cases, a clear distinction may be present, for example, if the patient is intubated and paralyzed.

While excellent communication is key during the procedure, this also applies for preoperative preparation. The anesthesia provider should consult with the otolaryngologist to determine the exact plan and to develop an approach to create ideal conditions that allow the initial diagnostic question to be answered.

Secured Airway with Endotracheal Tube, Controlled Ventilation

The airway is secured with an endotracheal tube after injection of a muscle relaxant. The patient is paralyzed and receives controlled positive-pressure ventilation. A major benefit of this approach is complete immobility, maintenance of a secure airway, and the ability to control ventilation parameters. Major disadvantages include inability to use a rigid bronchoscope, inability to assess the airway during spontaneous respirations, and obstruction of the otolaryngologist's view by the endotracheal tube.

Secured Airway with Endotracheal Tube, Spontaneous Ventilation

The airway is secured with an endotracheal tube without the use of a muscle relaxant. Similar conditions to approach #1 can be achieved with provision of a deep anesthetic plane.

Unsecured Airway, Spontaneous Ventilation

After anesthesia induction, spontaneous ventilation is maintained. An anesthetic plane that preserves the patient's respiratory drive while blunting airway reflexes and providing unconsciousness needs to be found and maintained.

Intermittent Apnea Followed by Controlled Ventilation Periods via Facemask or Endotracheal Tube

In this technique, the patient can be paralyzed or brought to a deep level of anesthesia that inhibits the respiratory drive. Controlled ventilation is established either via facemask or by placement of an endotracheal tube or laryngeal mask airway (LMA). After the patient is oxygenated and ventilated, the facemask/LMA is removed, the patient is extubated, and the otolaryngologist gets a window of time to work, while the patient is apneic. As soon as a certain level of desaturation is reached (which should be agreed upon by the otolaryngologist and anesthesiologist in advance), facemask ventilation is resumed, or the endotracheal tube is reinserted. The advantage of this technique is that the otolaryngologist can work without any obstruction while the patient is immobile. Disadvantages include repeated airway manipulation, the need to be confident in the ability to reestablish the airway (if an endotracheal tube/LMA is used), and the intermittent use of positive-pressure ventilation in an unsecured airway (if a facemask is used). Furthermore, if desaturation to a low oxygen level has occurred, facemask ventilation is occasionally not able to quickly restore oxygenation (presence of significant atelectasis; in rare instances, patients may become more difficult to ventilate with a facemask over time), which may create an unsettling situation in which oxygen levels can drop precipitously. During this technique, attention needs to be placed toward stomach distension during face-

mask ventilation periods; an orogastric tube may need to be used intermittently to deflate the stomach.

Unsecured Airway with High-Frequency Jet Ventilation

Jet ventilation is a technique that uses low tidal volumes delivered at very high rates; it is able to maintain oxygenation of a patient at the cost of impaired ventilation (e.g., patients frequently become hypercapnic over time). Advantages of jet ventilation include the absence of inflammable material (such as an endotracheal tube), the ability to utilize the jet ventilation cannula above or below the vocal cords (supraglottic versus subglottic jet ventilation), patient immobility from paralysis, and unobstructed access to the surgical field. High-frequency jet ventilation (HFJV) is most frequently used during airway procedures if the otolaryngologist is planning interventions using a laser and the space in the operative field is severely limited, making the placement of an endotracheal tube impractical. It will likely be preferable if the procedure can be performed with an anesthetized, spontaneously breathing patient, but if comorbid conditions preclude this approach, HFJV becomes an alternative. In addition, patients with severe upper airway obstructive lesions can be managed with percutaneous transtracheal HFJV, which requires placement of a ventilation cannula through the cricoid membrane, followed by bronchoscopic confirmation of correct placement.

The Ongoing Debate: Spontaneous Versus Controlled Ventilation During Airway Foreign Body Retrieval

While advantages and disadvantages of spontaneous and controlled ventilation during airway foreign body retrieval have extensively been debated, the evidence-based literature has not been able to reach a consensus as to which technique is superior. Proponents of spontaneous ventilation emphasize the reduced risk of converting a partial obstruction to a full obstruction that may occur with the application of positive pressure and the avoidance of lung hyperinflation due to a ball valve mechanism. Supporters of controlled ventilation claim that this technique optimizes the conditions for the endoscopist and decreases the likelihood of injury from patient coughing and bucking.

Litman et al. [2] conducted an analysis of 94 cases of foreign body removal over a period of 18 years and concluded that the type of ventilation technique did not influence the occurrence of adverse events. Of note, 12% of cases required a switch from spontaneous to controlled ventilation, and 5% of cases were switched from assisted to controlled ventilation. Soodan et al. [3] compared spontaneous ventilation and controlled ventilation with paralysis for inhaled foreign body removal in 36 children and reported that 100% of patients in the spontaneous ventilation group needed conversion to assisted ventilation. In addition, the spontaneous ventilation group had a higher incidence of coughing and bucking which led the authors to recommend routine use of controlled ventilation for inhaled foreign body removal. The conclusion drew criticism as multiple reports of successful maintenance of spontaneous ventilation with sufficient blunting of airway reflexes were reported in the literature [4–6]. In addition, it was pointed out that the authors did not use topical anesthesia or intravenous agents to maintain a deeper anesthetic plane.

A large prospective nonrandomized observational study conducted by Chen et al. [7] compared four anesthetic approaches for foreign body removal: controlled ventilation (divided into manual intermittent positive-pressure ventilation [MPPV] and manual jet ventilation [MJV]) and spontaneous ventilation (divided into total intravenous anesthesia [TIVA] and sevoflurane inhaled anesthesia [SIHA]). Major findings included the following statistically significant differences: lower success rate in the TIVA group; more epi-

sodes of body movement, breath holding, and laryngospasm in the TIVA group; and the fewest episodes of hypoxemia in the MJV group. Malherbe et al. [8] critically addressed the poor performance of the TIVA group in a response letter. The authors pointed out that the used doses (propofol infusion at 100–150 mcg/kg/min, remifentanil infusion at 0.1 mcg/kg/min) were low for pediatric patients and reported their positive experience with mean propofol infusion rates of 368 (SD 103) mcg/kg/min and mean remifentanil infusion rates of 0.21 (SD 0.31 mcg/kg/min) [9]. The higher doses have also been successful at our own institution when a TIVA technique is used. When using these high doses with spontaneous breathing, the success rate is enhanced by the prior administration of glycopyrrolate, followed by an increasing titrated dose of propofol and remifentanil, while the anesthesia provider ensures a patent upper airway with a properly positioned shoulder roll and a sustained jaw thrust until laryngoscopy and bronchoscopy are instituted. Even though infants and children will hypoventilate, anesthesia providers can ensure adequate oxygenation using continuous supplementary oxygen delivered at high flow rates via a nasal cannula.

With the increased use of total intravenous anesthesia with agents such as propofol, remifentanil, and dexmedetomidine, practitioners are more frequently successful in obtaining the combination of preserved respiratory drive and adequate blunting of airway reflexes. Nevertheless, the lack of evidence supporting a clear superiority of either spontaneous or controlled ventilation for inhaled foreign body removal, as supported by a meta-analysis from Liu et al. [10], leaves the ultimate anesthetic approach up to the preference of the provider.

Monitoring

Patient monitoring during airway endoscopies should follow the same standard as for any other procedure based on the American Society of Anesthesiologists guidelines: electrocardiogram, noninvasive blood pressure, pulse oximetry, and temperature. End-tidal CO_2 monitoring is very helpful but may need to be adapted to the airway device used. For the spontaneously breathing patient without an airway device, consideration should be given to the use of a nasal cannula with a CO_2 sampling port. A precordial stethoscope can provide invaluable continuous monitoring of respiratory efforts and airway patency. A direct, unobstructed view of the patient's chest can provide valuable information with regard to chest wall movement, breathing patterns, and intercostal retractions.

Pharmacology

The availability of a large selection of anesthetic drugs gives the anesthesia provider the opportunity to tailor the anesthetic to support a specific approach chosen by the otolaryngologist. While some anesthesia providers favor simple regimens that occasionally may only consist of 1–2 agents, others posit that the use of multiple agents in lower doses creates either an additive or synergistic effect and may reduce the occurrence of side effects.

To conceptualize our approach, we will evaluate drugs for their ability to provide the following effects that are important for airway endoscopies.

Anesthesia

This is a basic requirement in pediatric anesthesia practice given the age of most patients and their inability to cooperate with the exam. In adult practice, flexible bronchoscopies are frequently performed under local anesthesia and minimal to moderate sedation. Rigid bronchoscopies require a deeper plane of anesthesia.

Analgesia/Suppression of Airway Reflexes

Many airway endoscopies either do not create significant painful stimuli (flexible bronchoscopy) or lead to transient painful stimuli that resolve after conclusion of the procedure (rigid bronchoscopy). Of more importance is the suppres-

sion of airway reflexes, which can significantly influence length, success, and complications of a procedure.

Immobility

Immobility is important to prevent unexpected movement that may lead to airway injury and displacement of the endoscope. For major organ surgeries, immobility under general anesthesia is typically achieved by neuromuscular blocking agents; the situation is different for airway endoscopy when spontaneous ventilation is the goal. Fortunately, interventions that adequately suppress airway reflexes combined with an agent that provides anesthesia make strict immobility by paralysis unnecessary.

Maintenance of Spontaneous Ventilation

Spontaneous ventilation is dependent on two factors: (1) preservation of the central respiratory drive and (2) maintenance of a patent airway. The latter, as discussed earlier, is achievable as the otolaryngologist serves as an additional team member that can provide help with airway maneuvers such as jaw thrust, chin lift, and two-handed facemask application. Use of a properly positioned shoulder roll and airway adjuncts such as oral or nasopharyngeal airways further improves airway patency. The rigid bronchoscope, when introduced into the airway, serves as a stent and provides an excellent conduit for air exchange. Preservation of the central respiratory drive, and not only the drive itself but also the afferent input that regulates depth of breaths (e.g., tidal volumes), is more difficult to achieve in conjunction with the need for adequate blunting of airway reflexes. This requires skill and expertise along with careful titration of anesthetic agents like propofol, opioids, dexmedetomidine, volatile anesthetics, and benzodiazepines. All of these agents reduce respiratory drive, either by direct action on respiratory centers or a shift in the CO_2 response curve.

In the following paragraphs, we will discuss commonly employed anesthetic agents.

Volatile Anesthetics

Sevoflurane is often chosen to induce general anesthesia for children in whom intravenous access has not been secured. It is not uncommon at our institution to induce with sevoflurane, place a peripheral intravenous cannula, and then switch to a TIVA technique. In addition, volatile anesthetics are unique because they provide a combination of anesthesia, unconsciousness, and suppression of airway reflexes while maintaining spontaneous ventilation. In fact, for brief diagnostic airway endoscopy procedures (including rigid endoscopy), the combination of local anesthetic application to the vocal cords and maintenance with a volatile agent may be sufficient. While multiple studies have confirmed the suppression of laryngeal reflexes with high-dose volatile agents that even allow successful intubation [11, 12], this approach does not reliably protect against laryngospasm. In a study conducted by Erb et al., laryngospasm was encountered in 32% of patients intubated at an end-tidal sevoflurane concentration of 2.5% versus 18% of patients at 4.7% [13]. One problem with using sevoflurane or other inhaled agents for airway endoscopy is contamination of the perioperative zone by the agent. Placing a suction device near the mouth during such instances can scavenge the gas. In addition, the continued maintenance of anesthesia by the inhaled agent requires ongoing delivery using the side arm of the rigid bronchoscope. Sevoflurane may also be provided by continuous insufflation via a small endotracheal tube positioned into the nose or mouth, while the otolaryngologist performs suspension laryngoscopy for brief surgical procedures on the larynx. Again, anesthetic gas scavenging close to the mouth will be required.

Propofol

Propofol provides anesthesia and unconsciousness. In infusion doses of 150–250 mcg/kg/min,

it frequently preserves spontaneous ventilation in children and therefore is commonly used in airway endoscopy. While propofol is known to provide some blunting of upper airway reflexes as observed with LMA placement after a large bolus dose of propofol, the required dose to do the same for insertion of a rigid endoscope approaches the apneic threshold for a significant number of patients. As such, propofol is commonly used in combination with other agents. Malherbe et al. [14] studied the use of total intravenous anesthesia with propofol and remifentanil at doses of 200–500 mcg/kg/min and 0.1–0.2 mcg/kg/min, respectively. Procedures were performed under spontaneous ventilation. Adverse events included apnea in 21% (none of which required controlled ventilation or intubation) and coughing in 27% of patients. No episodes of laryngospasm, stridor, or arrhythmias were noted, and all procedures were completed successfully. Shen et al. [15] also reported the successful use of propofol and remifentanil for inhaled foreign body removal in children presenting with foreign body aspiration-related respiratory impairment (defined as presence of pneumonia, obstructive emphysema, and/or atelectasis confirmed by X-ray). The doses required were propofol at 200 mcg/kg/min and remifentanil 0.05 mcg/kg/min adjusted in 0.05 mcg/kg/min increments to achieve a 50% reduction in baseline respiratory rate.

Remifentanil

The pharmacokinetic profile of remifentanil makes it an ideal agent for airway endoscopy. As a fast-onset, short-duration drug, it provides hemodynamic as well as respiratory stability and blunts airway reflexes after reaching a steady state at the correct infusion dose. During this steady state, when used in combination with propofol, it allows the endoscopist to smoothly perform an airway examination and procedures. Anesthesia providers need to resist the temptation to inject bolus doses; even when used cautiously, this can quickly result in respiratory depression.

Fentanyl

Fentanyl can be used to provide analgesia and blunt airway reflexes. Patience needs to be exerted when it is used for upper airway endoscopy because of its relatively slower onset and comparably longer duration of action. Careful titration needs to be employed to avoid respiratory depression.

Ketamine

Ketamine represents a unique agent as it has combined anesthetic and analgesic effects with a strong preservation of the respiratory drive. One of the main disadvantages, an increase in salivation, can be counteracted by the early administration of an anticholinergic such as glycopyrrolate. Another benefit of ketamine is its hemodynamic stability that makes it an attractive agent for patients with congenital heart disease requiring airway endoscopy. The hallucinatory effects are minimized by the preadministration of a benzodiazepine [16] especially when it is used as monotherapy. While a continuous infusion is possible and this is most often done in combination with propofol, our group mostly uses ketamine boluses during endoscopy procedures. Ketamine has not extensively been studied in airway endoscopy procedures, but a large body of literature exists that reports its successful use in diverse procedures such as upper gastrointestinal endoscopies [17], flexible bronchoscopies [18], and drug-induced sleep endoscopies [19].

Dexmedetomidine

Dexmedetomidine can be considered an adjunct for airway endoscopy and may be employed in a multimodal approach. As a single-agent, it typically does not provide adequate attenuation of airway reflexes or sympathetic responses to the procedure, and despite its ability to induce sleep, patients frequently arouse with the significant stimulus of endoscopy. This limitation may be overcome by increasing the dexmedetomidine

dose at the cost of prolonged recovery times. Cai et al. [6] report successful airway foreign body recoveries in children treated with a 4 mcg/kg dexmedetomidine bolus followed by airway topicalization with lidocaine and a dexmedetomidine infusion at 3 mcg/kg/h. In combination with agents like propofol, volatile anesthetics, and ketamine, it helps to attenuate the sympathetic response and decreases anesthetic requirements. Chen et al. [20] compared the combination of propofol/dexmedetomidine (200 mcg/kg/min propofol, 4 mcg/kg dexmedetomidine loading dose followed by 1–2 mcg/kg/h infusion) with propofol/remifentanil (200 mcg/kg/min propofol, 0.05–0.1 mcg/kg/min remifentanil) for airway foreign body removal procedures under spontaneous ventilation and concluded that both combinations resulted in satisfactory conditions for the endoscopist. There were no significant differences in the incidence of adverse events, and no conversions to controlled ventilations were reported. The propofol/dexmedetomidine combination provided more respiratory and hemodynamic stability but prolonged recovery time significantly.

Benzodiazepines (Midazolam)

Midazolam is typically not used as a main agent in airway endoscopy besides its usual role as a premedication. Typical doses are 0.5–1 mg/kg per OS, 0.1 mg/kg intravenous/intramuscular, or 0.2 mg/kg intranasal.

Local Anesthetics (Lidocaine)

Lidocaine is the most frequently used local anesthetic for airway topicalization in preparation of endoscopy. It has a reasonable safety profile, has a fast onset with a quick effect, and can be administered in doses of up to 5 mg/kg body weight. Careful and targeted lidocaine application is a significant factor in the success of airway endoscopies: a well-anesthetized glottis and trachea reduce the risk of unwanted problems, namely, laryngospasm and excessive coughing/bucking while reducing anesthetic requirements. In fact, recent studies have attested to the efficacy of both topical and intravenous lidocaine for prevention of laryngospasm [21, 22]. One study reported the successful use of an EMLA cream coat applied to the rigid bronchoscope. This approach resulted in significantly less episodes of oxygen desaturation and breath holding in the intervention group; in addition, bronchoscopists were rating their ability for surgical manipulation as excellent in 80% of patients from the intervention group as compared to 13% of patients in the control group [23].

Doxapram

Doxapram is an analeptic agent that stimulates central and peripheral chemoreceptors [24]. The resulting sensitization to hypoxemia and hypercarbia leads to an increase in respiratory rate and tidal volume, with a net positive effect on minute ventilation. In addition, doxapram induces catecholamine release leading to increases in blood pressure and heart rate. It can be used as an intravenous bolus or as a continuous infusion. Due to the rapid disappearance from plasma after an IV bolus, the duration of effect is only 5–12 min. Doxapram may be considered as an option to support ventilation during longer procedures when controlled ventilation is not preferred.

Anticholinergics (Glycopyrrolate)

Traditionally, many pediatric practitioners administer glycopyrrolate prior to start of an endoscopic procedure. The expected benefit is twofold: (1) anticholinergics increase the heart rate, thereby providing a safety margin in the event of hypoxemia, which is not an uncommon occurrence during those procedure, and, more importantly, (2) anticholinergics reduce airway secretions that might increase the risk for airway obstruction and laryngospasm and impair the endoscopist's ability to assess the airway. Opponents of anticholinergics claim that this approach may result in a dry mouth and

thickening of bronchial secretions with limited benefit for the procedure. Double-blinded prospective studies in the pediatric population are lacking, but studies in adults undergoing airway endoscopy did not show any benefit from anticholinergic premedication [1, 25–27]. One study that examined the use of glycopyrrolate in pediatric patients diagnosed with upper respiratory tract infections did not find any benefit in reducing the incidence of perioperative respiratory adverse events [28].

Complications

Inadequate Suppression of Airway Reflexes (Coughing, Bucking)

Inadequate suppression of airway reflexes is commonly seen during airway endoscopy procedures with a spontaneously breathing patient and remains an attestation to the art of providing an adequate balance of anesthesia while preserving ventilatory drive. Even though major complications are rare, on occasion, a patient's movement may cause significant injury from the deployed airway instruments including the rigid bronchoscope or the suspension laryngoscope.

Laryngospasm

Especially in airway procedures that require an unsecured airway with spontaneous ventilation, the threat of laryngospasm is constantly present and should not be underestimated. The reflex responsible for triggering laryngospasm is, in its intended form, protective. Solid objects or liquids that gain entry to the glottis elicit the protective reflex: glottis closure ensues to prevent foreign material entry to the trachea (e.g., aspiration). During airway endoscopy, the endoscope itself is a foreign body. Ways to blunt or abort the reflex include application of topical lidocaine and maintenance of an adequate plane of anesthesia. Many anesthetic agents can contribute to blunting the reflex, but they are also a double-edged sword: volatile anesthetics, for example, can in lower doses increase airway reactivity and may predispose to laryngospasm during light planes of anesthesia. Ketamine, despite its promotion as a dissociative anesthetic that maintains spontaneous ventilation, also maintains airway reflexes. Increased secretions can potentially trigger laryngospasm. Prompt recognition is essential and often aided by the otolaryngologist's direct view of glottic structures. Initial treatment includes placement of an oral airway, application of positive pressure via facemask, and application of pressure to the laryngospasm notch [29, 30]. If laryngospasm persists, the next steps include injection of a propofol bolus; if unsuccessful, the gold standard treatment is paralysis, either with succinylcholine or a non-depolarizing muscle relaxant [31].

Bronchospasm

Bronchospasm is frequently associated with an anaphylactic reaction; in contemporary practice, the major triggers in the perioperative period are antibiotics, non-depolarizing muscle relaxants, and latex [32]. During airway endoscopy, bronchospasm can also be triggered by airway manipulation from endoscopes, aspiration of gastric secretions, and irritation of the carina by an endotracheal tube, fiberoptic bronchoscope, or a rigid bronchoscope [33]. When bronchospasm is suspected, the initial steps should include an increase of the FiO2 to 100%, manual bag-mask ventilation, or ventilation via the side arm of a rigid bronchoscope to assess pulmonary compliance and deepening of the anesthetic with volatile and/or intravenous agents. If possible, administration of a β_2-agonist via nebulizer or breathing circuit can be attempted. For severe episodes of bronchospasm that limit air exchange, the most effective treatment approach is epinephrine with or without the administration of a neuromuscular blocker and ventilation via an endotracheal tube. Additional treatment modalities that typically require some time to reach full effect include corticosteroids, magnesium sulfate, and ketamine [34, 35].

Respiratory Insufficiency (Hypopnea, Apnea, Hypoxemia, Hypercarbia)

The decline in respiratory function based on position, anesthesia, and paralysis has been well described. Functional residual capacity, which serves as an important store for oxygen and prevents formation of atelectasis, becomes progressively impaired. It is therefore important to understand that for a patient who is on significant respiratory support while in the awake state, it may be impossible to maintain adequate oxygenation and ventilation after induction of a sufficient plane of anesthesia that provides adequate blunting of airway reflexes. Healthy patients and patients with mild underlying pulmonary disease typically tolerate hypercarbia well. Hypoxemia can frequently be addressed with intermittent application of supplemental oxygen, assisted breaths, and recruitment maneuvers. If the airway has been secured, the anesthesiologist can be more aggressive with supportive maneuvers (intermittent controlled ventilation, FiO2 increase to 100%, recruitment breaths, application of PEEP). In pediatric patients, particular attention should be paid to changes in heart rate. While intermittent episodes of hypoxemia are tolerated to a certain extent, a drop in heart rate should alert the anesthesiologist to an impeding critical event that requires immediate intervention.

Pneumothorax

The ideal airway endoscopy in a spontaneously breathing patient bears little risk for the development of a pneumothorax. If assisted or controlled ventilation becomes necessary, high airway pressures can result in injuries to the lung. Specific situations require heightened awareness, such as the use of a ventilating rigid bronchoscope in a small infant. If the otolaryngologist places the rigid bronchoscope into a main stem bronchus, it may occlude the bronchus and impede air egress. In addition, when using the ventilating rigid bronchoscope, airway pressures and tidal volumes measured by the anesthesia machine are inaccurate. Occurrence of a pneumothorax should be suspected clinically (decreased breath sounds) and confirmed by ultrasound and/or chest X-ray.

Aspiration

Procedures with an unprotected airway as well as emergent interventions that forego NPO guidelines carry a high risk for aspiration. The final decision about timing of the procedure and airway management strategy needs to take into account the urgency of the case, NPO status, patient comorbidities, as well as the surgeon's assessment and procedural needs. If the anesthesiologist deems it necessary to proceed to the OR with a patient at high risk for aspiration, a frank conversation should be held with the consenting party, which needs to be thoroughly documented in the patient chart. In the setting of a full stomach, it is conceivable that maintenance of spontaneous ventilation might yield a slightly lower aspiration risk compared to controlled positive-pressure ventilation of an unsecured airway. Flexible bronchoscopy via an endotracheal tube placed after rapid sequence induction and the cuff-inflated would be a more suitable option in older children to allow the use of larger flexible bronchoscopes.

Airway Bleeding

Airway bleeding can be the primary reason for the endoscopy (from airway hemangiomas, arteriovenous malformations) or occur during the procedure secondary to injury from the endoscope. It impairs the endoscopist's ability to visualize the airways and impairs gas exchange that may result in hypoxemia. Depending upon the location of the bleeding, a quick decision to advance a cuffed endotracheal tube either distal to the bleed or placement in the opposite unaffected lung may be lifesaving.

Airway Fire

Airway procedures that involve the use of a laser carry a high risk for surgical fires, and precautions need to be taken to prevent this complication.

Airway endoscopies are less risky but still provide all three basic elements of the surgical fire triangle: ignition source (bronchoscope light), oxidizer (supplemental oxygen), and fuel (drapes).

Sepsis

A rare but serious complication that has been reported after bronchoalveolar lavage is sepsis [36–38]. Introduction of lavage fluid can disturb the barrier function of surfactant; dislodged microorganisms can gain entry to the bloodstream and may overwhelm immune defenses. Even if the outcome is not fatal, fevers and hemodynamic instability is not uncommon after bronchoalveolar lavage procedures in the infected patient.

Jet Ventilation in Pediatric Airway Endoscopy

Jet ventilation for pediatric airway endoscopy has multiple appeals. It allows the administration of muscle relaxants, thereby creating complete immobility and ideal surgical conditions. Jet ventilation is applied either via a ventilating laryngoscope or special bronchoscope (Fig. 5.1). A small rigid cannula or a soft cannula is placed alongside of the laryngoscope or bronchoscope. The cannula is connected to a high-pressure oxygen source with a pressure regulator and a manually controlled release valve to allow ventilation utilizing the venturi principle. An endotracheal tube is not required for the procedure, and this allows an unobstructed view for the endoscopist. The key to successful ventilation is to ensure the presence of maximum chest wall compliance (usually achieved by adequate intravenous anesthesia and neuromuscular blockade) and the endoscopist ensuring that the surgical laryngoscope or bronchoscope is optimally positioned as are either the rigid or soft cannula on the side. One needs to begin with lower pressures, and the increase in pressure needs to be adjusted to allow adequate bilateral chest expansion. The rate of ventilation will provide a control of carbon dioxide exhalation. Jet ventilation usually maintains adequate oxygenation throughout the whole procedure and facilitates uninterrupted interventions by the

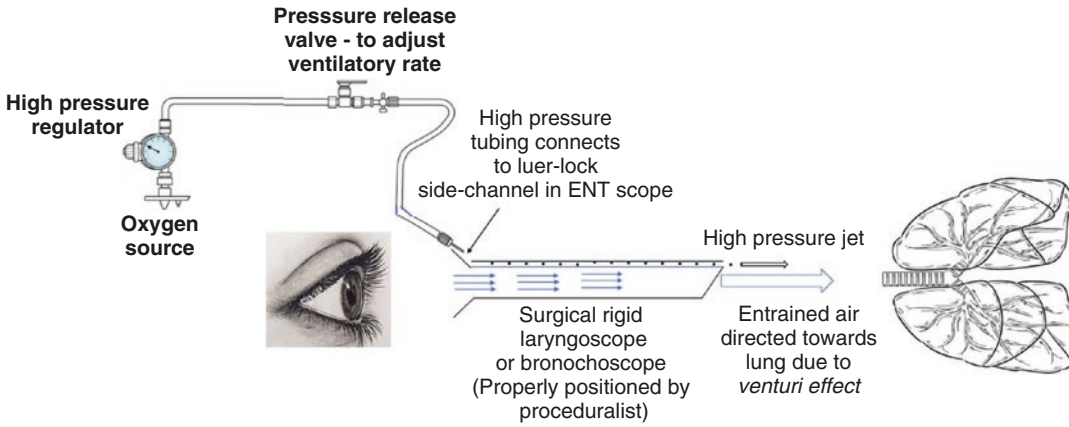

Fig. 5.1 Jet ventilation with a rigid ventilating laryngoscope or bronchoscope. The manual jet ventilator consists of an oxygen source connected via high-pressure tubing to a regulator and pressure release valve. The setup is connected via luer-lock connector to either the side channel of a ventilating rigid laryngoscope or bronchoscope. By operating the lever on the pressure release valve, short bursts of *venturi* breaths can be applied. One should ensure that the patient is satisfactorily anesthetized especially when the scope is above the cords – the use of muscle relaxants will ensure smooth ventilation during the diagnostic or surgical procedure. One should start with low insufflation pressures that can be gradually increased to ensure satisfactory chest expansion. Thus, the anesthesia provider adjusts the rate and chest expansion manually during the procedure while maintaining continuous communication with the proceduralist

endoscopist [39]. Careful patient selection is crucial as restrictive lung disease, obstructive lung disease, and conditions impairing gas exchange at the alveolar-capillary level or obesity may result in inadequate ventilation and/or oxygenation [40].

Monitoring of Anesthetic Planes

A reliable monitor of anesthetic planes can currently be considered the holy grail of anesthetic practice – and unfortunately still needs to be invented. The bispectral index (BIS) monitor has widely been marketed as a direct measure of the effects of anesthetics and sedatives on the brain, but the evidence in pediatric practice (and to some degree also in adult practice) is lacking. Monitoring of end-tidal concentrations of volatile anesthetics can provide some guidance to the anesthesiologist as regards anesthetic depth, but it is (a) inadequate at picking up dynamic changes (rapid changes in end-tidal concentrations do not reflect effect-site concentrations), and (b) it becomes unusable in the setting of an unsecured airway. Lastly, target-controlled infusion systems probably come closest to calculating the amount of drugs needed to achieve a sufficient anesthetic plane, but do not provide feedback or monitoring (in addition, those systems are not commercially available in the USA). As such, monitoring of the anesthetic plane remains part art of anesthesiology practice and is heavily influenced by provider experience. Nevertheless, based on the authors' observations, we will try to provide suggestions:

- Compared to propofol alone, volatile anesthetics have the advantage of not only providing amnesia but also some immobility and blunting of airway and spinal cord reflexes. Brief endoscopy procedures can frequently be performed after an inhalation induction with high-dose sevoflurane if time is provided for the patient to reach a deep level of anesthesia (we recommend topicalizing the vocal cords and subglottic area for added reflex ablation).
- Bolus doses of intravenous anesthetics allow the anesthesiologist to reach a certain anesthetic level faster but carry the risk of "overshooting" which may result in apnea, bradycardia, and hypotension. Despite the emphasis on rapid OR turnover, the author has observed the most satisfactory results if, after anesthesia induction, a TIVA that includes both propofol and remifentanil is started and some time is allowed to pass for the medications to achieve a steady state. As dictated by pharmacokinetics, to reach a certain propofol level just by infusion of a set rate, it may take up to 10–12 min; therefore, IV boluses can be used judiciously to hasten this process, but we favor the approach of rather "undershooting." Our usual endpoints are the presence of steady breathing with slowing of respiratory rate and mild hypercarbia. If the introduction of the rigid bronchoscope results in coughing, bucking, and patient movement, the otolaryngologist can remove the device and apply more lidocaine, while the anesthesiologist can add small boluses of anesthetic agents and possibly modify infusion rates.

Intraoperative Management

At this point, we have provided different management options and discussed approaches and complications. In this paragraph, we will describe how a typical airway endoscopy is performed at our institution.

The initial contact between the anesthesia provider and the patient along with family is established in the preoperative unit. After evaluation, physical exam, and discussion of the anesthetic plan, we frequently administer premedication in form of midazolam (0.5–1 mg/kg per OS). Our facility supports parent-present inductions when indicated and judged safe by the attending anesthesiologist. Anesthesia is induced via volatile or an intravenous agent with the goal of maintaining spontaneous ventilation. At this point, the anesthesia provider can get a feeling for the patient's airway: is spontaneous ventilation via mask easy? Does the patient need significant support – jaw thrust, chin lift, two-handed mask, oral/nasal airway, and CPAP – to maintain the airway? Is assisted bag-valve-mask ventilation possible?

After induction of anesthesia, an infusion system is connected to the intravenous line, and propofol along with remifentanil is started. We frequently start propofol at 200–250 mcg/kg/min and remifentanil at 0.1–0.2 mcg/kg/min and titrate to maintain spontaneous ventilation with an appropriately sized shoulder roll and mild neck extension to overcome upper airway obstruction. At this point, it is important to recognize that medications started as infusions will either require a loading dose or adequate time to reach a level that allows undisturbed airway manipulation. Furthermore, one should be cognizant that if an inhalational induction was performed, the volatile agent will significantly contribute to the plane of anesthesia and additional propofol and/or remifentanil boluses may cause respiratory depression. Given the lack of a monitor that provides a clear quantification of the anesthetic plane and the impairment of respiratory drive, the decision of administering additional drug boluses is driven by vigilant patient observation, evaluation of patient response to stimuli, and experience of the anesthesia provider.

When a sufficient plane of anesthesia has been established, the bed is turned 90 degrees, and the airway is handed over to the otolaryngologist. At this point, equipment and rescue drugs should be placed in a readily accessible area. Depending on the anesthesia team (one anesthesiologist model versus care team of resident/fellow/CRNA and anesthesiologist), it will be critical to have the anesthesia ventilator, rescue/emergency drugs, and airway equipment within reach as one provider can become "trapped" in a position next to the patient without the ability to freely move back to the anesthesia cart.

A sample setup may look like this (Fig. 5.2). The anesthesia provider should ideally be able to access

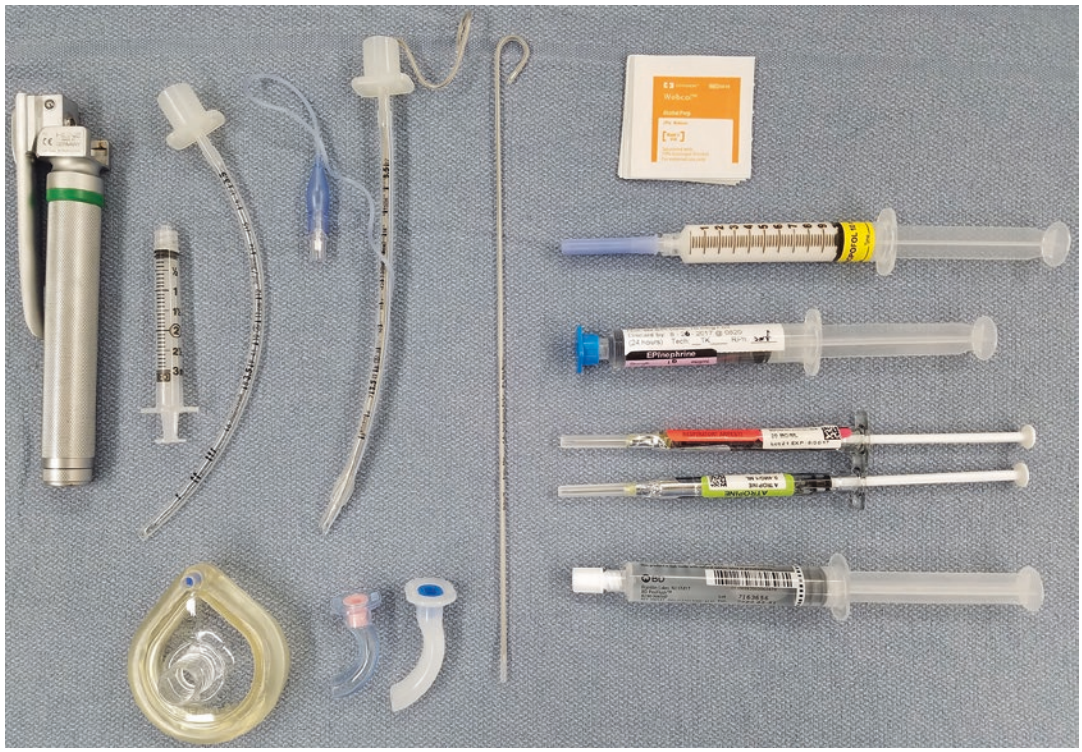

Fig. 5.2 Sample setup during a pediatric airway endoscopy. The authors use this setup during airway endoscopy procedures. The material is either placed in close proximity on the anesthesia workstation or (preferred by the authors) on the lower end of the operating room table. Located on the left side is emergency airway equipment including laryngoscope handle and blade, endotracheal tube with stylet, extra endotracheal tube, extra stylet, mask, and oral airways. The right side has various emergency drugs (atropine, succinylcholine, epinephrine) to which agents can be added to deepen and/or maintain a sufficient anesthetic plane (such as propofol, ketamine, dexmedetomidine, and others)

the ventilator on one side and the patient's airway on the other. Rescue equipment can be placed on a small towel in front of the anesthesia provider (either on the anesthesia workstation or on the end of the operating room table) – typically these consist of emergency drugs (succinylcholine, atropine), propofol, epinephrine, mask, endotracheal tubes with stylet (cuffed and uncuffed in different sizes), oral airways, and laryngoscopy handle with blade.

After taking the airway over, the otolaryngologist proceeds with direct laryngoscopy and application of topical lidocaine to anesthetize the vocal cords and subglottic area. Depending on institutional preferences, this step can also be performed by the anesthesia care team. The advantage would be the ability to get a direct look at the airway, judge one's ability to intubate, and document a Cormack and Lehane view in the anesthesia record, although this information can be solicited from the otolaryngologist. Different approaches to airway topicalization exist; this author favors the use of 2% lidocaine (maximum dose: 5 mg/kg) via a topicalizer, although some institutions use 4% lidocaine. We first spray both vocal cords and the mucosa overlying the cuneiform and corniculate cartilages. We then introduce the topicalizer via the open glottis into the trachea. After positioning the topicalizer tip slightly below the glottis, we spray the subglottic area while pulling the topicalizer tip back out. This procedure is a critical part for two reasons: (1) excellent topicalization will yield superior conditions for endoscopy and blunt airway reflexes and reduce the risk of laryngospasm; (2) care should be taken to perform airway topicalization with the patient at a deep plane of anesthesia as contact of the lidocaine droplets with the vocal cords and trachea may precipitate laryngospasm and/or coughing and bucking in presence of light anesthesia.

The airway endoscopy proceeds with the otolaryngologist performing the required parts. The anesthesia provider is tasked with maintaining an adequate plane of anesthesia by adjusting continuous infusion doses and administering bolus doses as needed to provide ideal operating conditions; in addition, the anesthesia provider is typically the first individual to notice changes in vital signs that may require intervention. Again, close communication with the otolaryngologist can prevent the development of severe complications.

At the conclusion of the procedure, the bed is turned back 90 degrees to the anesthesia provider, and the anesthetic agents are stopped. The patient is monitored during emergence and then transferred to the postanesthesia care unit (PACU) or, in selected cases, the pediatric intensive care unit. Especially in patients with known difficult airways, it is prudent to confirm adequate return of airway reflexes and consciousness while in the operating room with difficult airway equipment on standby as airway complications during transport or in the PACU can be catastrophic. Patients with straightforward airways can be brought to the PACU while still in a deep plane of anesthesia if the nursing staff at the practitioner's institution is experienced in recovering those patients.

Conclusion

Airway endoscopy is frequently performed for diagnostic and/or therapeutic indications. Communication between the otolaryngologist and the pediatric anesthesiologist is of paramount importance to avoid problems and should include specifics about the planned procedure, expected difficulties, desired mode of ventilation (spontaneous, assisted, or controlled), and disposition. It is important to recognize that anesthetics need to be tailored to the unique patient needs and the specific procedures. Even though a well thought-out plan may be devised, airway endoscopy procedures often present with dynamic changes in patient condition and require the pediatric anesthesiologist to be able to rapidly diagnose those changes and adjust the anesthetic approach accordingly. It is helpful to become familiar with the large armamentarium of employable anesthetic agents, the different endoscopy equipment, and the alternative ventilation modes.

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Neonatal Laryngoscopy and Bronchoscopy

6

Claude Abdallah, Jennifer R. White, and Brian Kip Reilly

Introduction

Surgical endoscopy in the neonate is an extremely high-risk procedure. The technical skills, diagnostic acumen, and proper instrumentation are essential for a safe outcome. Direct laryngoscopy and bronchoscopy should only be performed within a hospital setting that possesses an experienced team. Neonates that require airway evaluation may be full term (>37 weeks), moderate to late premature (32 to <37 weeks), very premature (28 to <32 weeks), or extremely premature (<28 weeks) [1]. Thus, the prenatal development and physiological response to anesthetic agents will be dependent on the patient's age and associated medical comorbidities. In addition, specific sizes of the laryngoscopes and bronchoscopes utilized must be available and functioning properly and preferably in at least duplicate sizes.

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Neonatal airway distress is apparent in the first minutes or hours of life. Therefore, the first attempts to secure and maintain the airway in the delivery room or the neonatal intensive care unit (NICU) provide essential information for the airway team (anesthesiologists, otolaryngologists, pediatric surgeons, respiratory therapists, and perioperative nurses). A thorough cardiac and pulmonary evaluation should be performed to assess for congenital abnormalities that may prevent or limit proper oxygenation of the neonate's blood. The heart, lungs, and tracheobronchial system are under increased demand since the heart pumps faster, the tracheobronchial system is smaller, and the thoracic cage is more compliant promoting rapid episodes of hypoxia that can lead to brain damage, if not immediately corrected.

Neonatal laryngoscopy and bronchoscopy can be quite challenging for care providers because of this increased risk of hypoxemia. Neonates requiring bronchoscopy for respiratory failure are innately at higher surgical risk, secondary to possible underlying congenital anomalies and/or the precipitating factors that occur during the endoscopic evaluation of their airway. Hypoventilation may result from combined factors including the primary airway pathology, associated anomalies, anesthesia, airway manipulation, or trauma, in addition to those specific factors related to the physiology of neonates. Premature neonates are even more susceptible and vulnerable to these challenges.

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Airway obstruction secondary to a foreign body is extremely rare in neonates, yet may present unique challenges. The peak incidence of foreign body aspiration is 1–3 years of age [2]. Older children, such as toddlers, tend to aspirate parts of toys and food-related items. However, when airway obstruction from a foreign body occurs in hospitalized neonates, medical devices may be the culprit, or abuse should be suspected [3].

Physiology

The goals of anesthetic management for bronchoscopy in neonates include adequate ventilation while balancing inspired oxygen concentration, peak inspiratory pressures, and preservation of hemodynamic stability, with avoidance of risk factors for intraventricular hemorrhage. There are several important physiological and anesthesia factors that must be taken into consideration.

The neonate is at greater risk of cardiovascular collapse during anesthesia and surgery than older pediatric patients. Neonatal cardiac output depends more on heart rate, and the higher resting heart rate in neonates does not permit an increase in cardiac output. Neonates also have less ability to increase cardiac contractility because of their decreased ventricular compliance. Furthermore, they have a diminished baroreceptor response to hypotension. Bradycardia is particularly dangerous in the neonate, especially if resulting from hypoxia. In addition, neonates have increased pulmonary vascular resistance, which predisposes to right-to-left shunting that worsens with hypoxia, hypercarbia, and acidosis. The ensuing vicious cycle can lead to severe hypoxemia and cardiopulmonary collapse [4, 5].

Neonates, particularly premature neonates, have a biphasic ventilatory response to hypoxia, *i.e.*, increase in ventilation followed by hypoventilation and a decreased response to hypercapnia. This can ultimately result in apneic episodes during acute decompensation. Apneic episodes usually involve both a failure to initiate a breath (central apnea) and a failure to maintain a patent airway (obstructive apnea). An additional factor leading to respiratory decompensation may result from partial occlusion of the small diameter airway of neonates due to secretions and loss of muscle tone. The consequence of this airway narrowing is an increase in the work of breathing. Low lung volumes and poor compliance increase intrapulmonary shunt and ventilation/perfusion mismatch with increased risk of hypoxia, hypercarbia, and acidosis. Small changes in lung ventilation of neonates can lead to shunting and desaturations. Oxygen desaturations can be very rapid because neonatal oxygen consumption (per kg) is 2–3 times faster than that of the adult, yet closing volume is within the range of normal tidal volumes.

Neonates have a lower fraction of type 1 muscle in their diaphragm and chest walls and tend to fatigue more quickly than adults. In addition, their chest walls are highly compliant with decreased recoil. This imbalance ultimately requires them to do more work in order to move a similar tidal volume. This imbalance of chest wall and pulmonary compliance also makes them prone to lung collapse [6–8].

Anesthetic Considerations

One of the major factors leading to optimizing the outcome during the perioperative period for direct laryngoscopy and bronchoscopy in neonates includes preventing uncontrolled displacement of a secured airway during transport or during manipulation at the operative table or bassinette. Avoidance of coughing is also important to prevent total occlusion of the airways from laryngospasm and/or bronchospasm. Avoidance of use of a stylet in intubation may prevent unintentional bleeding from tracheobronchial laceration, which can result in a failed bronchoscopy. Such complications can be life-threatening. Efficient communication between the different teams involved and team readiness is essential throughout the entire perioperative period. This includes the neonatal intensive care team, operating room nursing team, and anesthesia and surgical teams. Possible complications such as complete airway obstruction should be prepared for and discussed prior to the operation.

The anesthesiologist should keep in mind the unique physiology of the premature newborn

including respiratory, cardiac, renal, hepatic, and central nervous system and formulate a plan for induction and maintenance of anesthesia accordingly. The availability of age-appropriate monitors and anesthesia equipment (neonatal size endotracheal tubes and laryngoscope blades) should be ensured prior arrival to the operating room. Adequate intravenous access should also be verified.

Prevention of hypothermia is crucial to avoid hemodynamic, respiratory, and metabolic consequences of hypothermia, such as apnea and metabolic acidosis. The neonate and the premature neonate are extremely susceptible to hypothermia. Evaporative heat loss and insensible fluid loss, as well as conductive and convective heat loss, are increased because there is little fat for insulation and a large surface area to mass ratio. Thermal regulation is not well developed, and non-shivering thermogenesis, which depends on brown fat stores, is decreased in the neonate and the premature neonate. The goal of normothermia is attained by applying an underbody "Bair Hugger" device, heating pads, warming the room and covering the infant as much as possible, and by utilizing and monitoring of core temperature devices.

Prevention of blood glucose fluctuations is also very important since the neonate, particularly the low birth weight and premature neonate, is at risk for both hypoglycemia and hyperglycemia. Decreased glycogen and body fat predispose to fasting hypoglycemia, whereas decreased insulin production with infusion of dextrose predisposes to hyperglycemia. Neonates who have not been fed for hours, those that are small for gestational age, and neonates of diabetic mothers are particularly prone to develop hypoglycemia. Hyperglycemia should be avoided as it causes a hyperosmolar state and can lead to intraventricular hemorrhage (IVH) and osmotic diuresis.

Anesthetic Techniques

Management of the airway during a direct laryngoscopy and bronchoscopy can be a difficult task for both the otolaryngologist and anesthesiologist given the small caliber of the neonatal airway and heightened risk of respiratory decompensation and cardiovascular collapse. There must be constant communication between both parties to ensure safety of the patient. Most of the literature supports the use of spontaneous ventilation throughout airway endoscopy. One of the primary goals of this technique is to maintain adequate oxygenation and ventilation with the ability to provide continuous ventilation even when the bronchoscope is removed. Ideally this would occur with minimal interruptions of the procedure with several episodes of insertion of endotracheal tube and active ventilation. One advantage of spontaneous ventilation is it enables the surgeon to see somewhat of a dynamic function and movement of the larynx. However, it is also important to maintain a depth of anesthesia that will prevent chest "bucking" or coughing during instrumentation as this could result in injury and rapid desaturation. At the same time, rapid emergence from anesthesia at the end of the case is often desired [9].

Achieving both general anesthesia and spontaneous ventilation can be a challenging task and requires a fine balance between titration of the anesthetic medications and use of oxygen supplementation with different techniques, such as through a nasal cannula or insufflation of oxygen through the nose or mouth. The anesthesiologist should also be careful in titrating the fraction of inspired oxygen (FiO2) as acceptable and tolerated to achieve adequate oxygenation. Atelectasis and different associated pathologies may impede ventilation and make the neonate more vulnerable to apnea and hypoxemia. Arterial oxygenation variations are important since they may play a role in retinopathy of prematurity. Another potential risk throughout the ventilation process is barotrauma, which can be life-threatening [10, 11].

Different techniques are used to achieve an adequate level of anesthesia, taking into consideration age-specific physiological and pharmacological factors while administering inhalation or intravenous medications. Inhalational agents are often used during airway endoscopy cases. The MAC (minimal alveolar

concentration) of inhalation anesthetics is lower in neonates, especially in those who are low in birth weight and premature. Another option includes intravenous ketamine, supplemented with application of topical local anesthesia (lidocaine) on the laryngeal structures and tracheal mucosa in order to suppress airway reflexes to prevent coughing and laryngospasm.

Total intravenous anesthesia (TIVA) technique allows for a steady level of anesthesia that is independent of ventilation and does not expose the operating room personnel to exposure of inhalational anesthetic agents. Infusions of propofol and remifentanil are commonly used intravenous anesthetic agents. Remifentanil, an opioid, has the advantage of antitussive properties, which is an ideal property for airway endoscopy. Opioids decrease airway reflexes, which is why it is often used for endotracheal intubation in neonates and children. Lastly, it has a short half-life, making it easily titratable. Studies have also shown that the use of propofol as compared to inhalational sevoflurane decreases the risk of apneas and laryngospasm. For these reasons, TIVA can be a great anesthetic option for airway endoscopy cases [9]. Dexmedetomidine use has the risk of hemodynamic perturbations such as bradycardia, hypo-, or hypertension and therefore is avoided in neonates.

Performing an "awake laryngoscopy" with the neonate may be necessary but can be risky because of movement of the neonate (oftentimes requires swaddling). There is also risk of potential increase in intracranial pressure, intraventricular hemorrhage, and prolonged episodes of breath holding. The potential lack of autoregulation of cerebral blood flow and fragile cerebral blood vessels may be important factors leading to the development of intraventricular hemorrhage. Several risk factors, which have been described in intraventricular hemorrhage [12, 13], include fetal distress, low Apgar score, seizure, pneumothorax, metabolic acidosis, hypoxia, hypo-/hypercapnia, acidosis, the need for mechanical ventilation, and severe blood pressure fluctuation or vasopressor infusion.

On the contrary, there are circumstances where the neonate requires deeper anesthesia, yet an endotracheal tube may interfere with access to the surgical sites during the operation. Such cases include suspension laryngoscopy cases with use of a laser. Jet ventilation via a laryngoscope or bronchoscope is an option for achieving ventilation in these cases, but this is traditionally reserved for older children and adults given the increased risks associated with this technique. Those risks include barotrauma, air trapping, cervical emphysema, and pneumothorax. A technique of alternately high-/low-frequency jet ventilation via a laryngoscope has been described by Mausser et al. reporting promising and safe outcomes, but further studies are needed to validate the safety of this technique in this patient population [14].

The anesthesiologist must also take into consideration that the neonate's kidneys are less mature, which can play an effect on their processing of anesthetic agents. Neonatal kidneys have fewer nephrons and smaller glomerular size, leading to a decreased kidney function. Baseline plasma creatinine levels are higher with increasing prematurity and remain elevated until 3 weeks of age. The increase in creatinine clearance seen in term neonates occurs more slowly. Hyponatremia and hyperkalemia are also more common in low birth weight, premature neonates. Immature hepatic function leads to decrease in drug metabolism. Reduced albumin synthesis leads to low albumin levels, thus enhancing the "free" concentration of anesthetic drugs that are highly bound to albumin. For a given dose of fentanyl, higher plasma fentanyl concentrations and a slower clearance of the drug will occur in the neonate and the premature neonate when compared to older infants. This ultimately leads to prolonged analgesia effects and respiratory depression, which increases the risk of postoperative apnea and delayed return to consciousness. For this reason, the neonate must be carefully assessed at the end of anesthesia and in the postoperative period. If the patient is to remain intubated after the operation, the anesthesiologist may elect to administer sedation in combination with opioids and muscle relaxants.

Lastly, recent reports in the immature animal model showed that prolonged exposure to several

anesthetic agents might affect brain development. General anesthesia precipitates apoptosis in many regions of the brain [15–17]. The neurotoxicity is highly dependent on the developmental age. Extrapolating the results to human neonates and infants is not yet evident, but there are ongoing research projects that may help delineate with more precision this problem in the future. Keeping up with the latest recommendations of anesthesia practice are suggested when anesthesia is administered for a needed surgical procedure.

Intraoperative Airway Management

Selecting the proper endotracheal tube (ETT) is a critical part of the operation. The inner diameter of the uncuffed ETT is calculated using the following formula from the American Heart Association: uncuffed ETT inner diameter size = (age in years/4) + 4. Premature infants usually take a 2.5–3.0 mm ID tube, while 12-month-old infants usually accommodate a 3.5 mm–4.0 mm ID tube. It is appropriate to check for a leak between 10 and 20 cm H_20 pressure to reduce the tube pressure in the infant's cricoid and subglottic region. The smallest cross-sectional area in an infant's airway is the cricoid ring within the upper trachea. Reduced or minimal cuff pressures in this region should be as low as tolerated to prevent mucosal edema, ulceration, and inflammation, which can lead to narrowing or stenosis in the subglottic trachea [18]. Being properly prepared also includes having at least one endotracheal tube that is a ½ size smaller than expected and loaded with a stylet that is placed to overcome resistance from regional stenotic areas of the airway.

The type of laryngoscope selected during the operation should suit the user's preference. The child's laryngeal anatomy should be taken into consideration during the selection process, as well. The three main types of laryngoscopes are the (1) standard, (2) subglottic, and (3) anterior commissure. The Miller blade (0 or 1 smaller to larger) is often selected by the author (BKR) and is successful to either suspend or lift the epiglottis when visualizing the vocal folds (Fig. 6.1). The Macintosh blade is designed with a greater curve and is used to engage the vallecula region of the epiglottis during intubation. On the contrary, the Miller Blade is straight and is designed to lift off the epiglottis directly, although it can also reach and engage the vallecular and tilt the epiglottis upward to visualize the vocal folds. Tooth guards in the neonate or infant are usually not necessary. Instead, the gums may be protected with use of moist gauze soaked in saline or with nothing at all so long that gentle technique is used throughout the procedure. Placement of the neonate into suspension should be achieved expediently thus to minimize oxygen desaturations and prevent hypoxia or ischemia. In addition, all parts of the bronchoscope should be present and assembled prior to the start of the operation (Fig. 6.2).

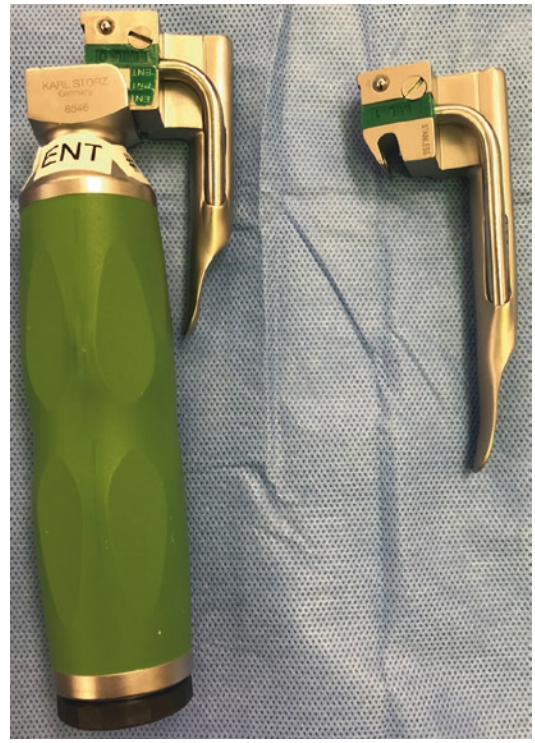

Fig. 6.1 Size #0 and #1 Miller laryngoscopes

In the premature infant, the larynx is at the highest position, approximately at the level of the second or third cervical vertebrae and tilted more anteriorly [18]. In fact, ten tracheal rings

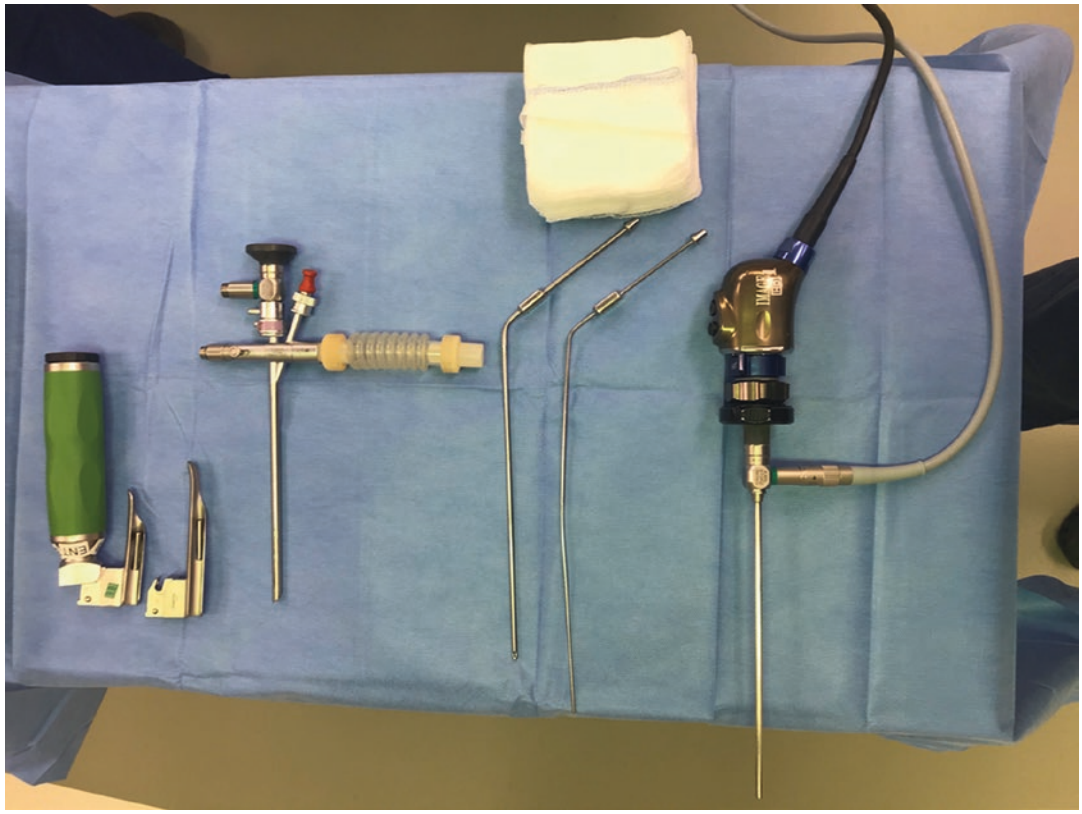

Fig. 6.2 Bronchoscopy setup

are usually above the sternal notch. The larynx then begins to descend at 2 years of age to the sixth or seventh vertebra by adult age. The hyoid and cricoid bone can both be palpated, and anterior pressure may be applied to facilitate tracheal intubation in an anterior larynx. Difficult airways can present themselves unexpectedly, so it is critical to anticipate difficulties with mask ventilation. The glidescope and fiberoptic equipment should be readily available in the room for intubation in patients with micrognathia, retrognathia, and extremely premature neonates.

Uncuffed tubes should be encouraged when long periods of ventilation are required, as 90% of acquired airway conditions involve subglottic stenosis (SGS). SGS is most commonly a result of prolonged intubation. The otolaryngologist should be consulted after a failed extubation attempt following an endotracheal intubation period for further evaluation of the airway, which will include a direct laryngoscopy and bronchoscopy and possible tracheostomy.

If a neonate is found to have a difficult or tenuous airway, alerting the NICU team is critical and it is imperative to identify their airway status (a note "CRITICAL AIRWAY" posted above the patient's bed). Any neonate who has a challenging tracheal intubation should have the parents, caregivers, and team made aware so as to avoid future problems. The infant's tongue is proportionally larger, and in cases of severe macroglossia, such as Beckwith-Wiedemann syndrome or Down's syndrome, the tongue can obstruct the newborn's airway making tracheal intubation quite challenging. When performing laryngoscopy, it is important to gently sweep the infant's tongue to the side to ensure proper exposure.

Knowing when to safely extubate the trachea of a neonate can reduce the need for an urgent airway. An endotracheal tube air leak test (ALT) can be performed prior to extubation. The ALT

identifies the pressure that is required to produce an audible leak between the endotracheal tube and the tracheal wall when the larynx is auscultated with a stethoscope. If the pressure is high (generally greater than 30 cm H_2O), this may suggest that the endotracheal tube is "tight." This could be indicative of airway edema, although this is assuming the endotracheal tube in place is in fact the correct size for the patient. Some studies have shown an association between high ALT pressure (>30 cm H_2O) and post-extubation failure and/or stridor [19]. It is also important to note that direct laryngoscopy and bronchoscopy can also induce some airway edema from sheer manipulation, especially if any intervention is done during the operation. In such circumstances, endotracheal intubation may be required postoperatively with administration of intravenous steroids until the airway edema resolves.

Airway Management in Other Hospital Settings (Outside the Operative Suite)

When a neonate emergently develops respiratory distress, the primary goal is to secure the airway through endotracheal intubation. Airway distress can develop in the delivery room, NICU, or emergency department. A readily available and fully stocked "Emergency Airway" cart with a wide array of endotracheal tubes sizes, tracheostomy tube sizes, and even bronchoscopes in these locations is critical.

Emergency medical personnel, rapid response teams, surgeons, and anesthesiologists should refer to a chart prepared and located on the "Emergency Airway" cart detailing the appropriately sized corresponding endotracheal tubes, tracheostomy tubes, and rigid bronchoscopes to ensure that they can quickly respond in an emergency situation, as well as making "real-time" assessments to pick the most appropriate-sized instruments. Operative direct laryngoscopy and bronchoscopy do not necessarily need to occur immediately, unless the infant cannot be stabilized and ventilated.

Summary

Neonatal direct laryngoscopy and bronchoscopy should be performed rapidly when indicated for diagnostic purposes to fully assess a newborn's airway. The primary goal during the procedure is to maintain a safe and secure airway while the patient undergoes assessment. Diagnostic airway endoscopy includes airway measurements, photo-documentation, gentle probing to rule out tracheoesophageal fistulas and laryngeal clefts, biopsies of rare neoplasms, and cultures. Therapeutic interventions include securing the airway in advance of tracheostomy, mucous plug removal, airway cast debridement, foreign body removal, and surgical excision of cysts/tumors. One of the major benefits of using the rigid bronchoscope is the ability to ventilate and oxygenate the patient throughout the procedure.

In order to safely and properly evaluate anatomical structures, the procedure should be performed in the operating room or procedure suite with an airway emergency cart present and dedicated pediatric anesthesiologist. All required instruments including the proper laryngoscopes should be readily available. Lastly, constant communication should be maintained throughout the perioperative period between the entire team including the nurses, surgeons, and anesthesiologist to ensure the best possible surgical outcome.

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7 Difficult Airway Management of Neonates, Infants, and Children with Syndromes Involving the Airway

Grace Hsu and John E. Fiadjoe

What Does a Pediatric Difficult Airway Entail?

The difficult pediatric airway is a challenge even for the experienced pediatric anesthesiologist. Children have a higher rate of oxygen consumption than adults leading to a shorter apnea time [1]. There is no standard definition of a difficult airway; however, there are key characteristics of difficult airways found across all practice guidelines [2]. A difficult airway is the situation in which an anesthesiologist has difficulty with face mask ventilation, tracheal intubation, or both. With recent advances in airway technology, descriptions of difficult airways are more detailed, including whether a patient will be difficult to ventilate with a supraglottic airway (SGA), difficult laryngoscopy, difficult tracheal intubation, or difficult front of neck access (FONA). The focus of this chapter will be on anticipated or known difficult airways. Some of the principles discussed may apply to unanticipated difficult or emergency airway management.

Respiratory critical events remain a significant cause of morbidity and mortality in children. A recent study from 261 participating centers across 33 European countries reported an incidence of respiratory critical events of 3.1% (2.9–3.3) in 30,874 children undergoing anesthesia with a mean age of 6.35 years [3]. Airway management in children with difficult airways is associated with an even higher incidence of complications and respiratory critical events. The Pediatric Difficult Intubation (PeDI) multicenter registry is a prospectively collected dataset of difficult tracheal intubation in children from institutions all over the world. A recent analysis of the PeDI registry data showed that out of 1018 children with difficult airways, 204 (20%) had at least one complication, the most severe being cardiac arrest which occurred in 15 (2%) children. The most common overall complication of hypoxemia (oxygen saturation <85%) occurred in 94 (9%) children [4]. Risk factors for complications included more than two tracheal intubation attempts, weight less than 10 kg, a short thyromental distance, and three direct laryngoscopy attempts prior to an indirect technique. One of the key take-home messages from these data is that intubation attempts should be considered critical events and clinicians should do their best to minimize laryngoscopies in this population. Furthermore, indirect laryngoscopy should be

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considered early in the airway management plan. Additionally, infants are a particularly vulnerable group as they had almost three times the complications of older children. Valois-Gomez et al. looked at risk factors for difficult bag-mask ventilation (DBMV) in children ages 0–8 years old. They found that there is an inverse relationship with age and DBMV [5].

Risk factors for difficult intubation in children include congenital craniofacial pathology, cervical spine instability, neck immobility, presence of a mass compressing the neck micrognathia, macroglossia, facial asymmetry (especially abnormalities of the ears), limited TMJ mobility, and severe subglottic or tracheal stenosis.

Despite advances in difficult airway management, failure to predict difficult oxygenation or ventilation remains a major cause of failed airway management [6]. The National Audit Project of The Royal College of Anaesthetists and the Difficult Airway Society (DAS) in the United Kingdom looked at major complications in airway management and found that human factors contributed to a majority of serious adverse outcomes [7]. Human factors included deficits in communication, judgment, planning, and fixation errors, such as perseverance with intubation attempts despite patient desaturation, perseverance with the same intubation technique despite failure of that technique, and perseverance of intubation despite multiple failed attempts [8]. Although rarely discussed, cognitive biases can play a significant role in outcomes of difficult airway management. These biases include anchoring, loss aversion, overconfidence, and framing effects. The first step to countering these biases is to understand when they are occurring. Loss aversion is the tendency to view a loss as having more impact than an equivalent gain. An example of this would be a clinician who fails to perform an awake fiber-optic intubation because of concerns of appearing incompetent if they fail. The loss of reputation is seen as being worse than the gain of a successful intubation. Anchoring occurs when one is fixated on an initial condition. If a patient becomes difficult to ventilate, the clinician may perseverate because they are anchored to the prior condition of easy ventilation and believe the airway obstruction will resolve without needing a surgical airway since it was easy before. Overconfidence occurs when a clinician has an inaccurately high self-assessment – this could lead them to proceed to secure a tenuous airway under general anesthesia rather than with a sedated or awake fiber-optic intubation. Framing a clinical situation changes the perception of the situation without altering the facts. For example, a difficult airway patient in extremis can be thought of as needing a life-saving tracheostomy, in contrast to the situation being thought of as being bad and dire and likely to result in a lawsuit if surgical access is performed. The first frame encourages the right action, while the second does not [9].

Syndromes That Involve the Pediatric Airway

Although specific syndromes have been associated with a difficult airway, the common characteristics in these patients are anatomically based. Conditions that affect the oropharyngeal space, the anterior mandibular space, the maxilla, the temporomandibular joint, and the vertebral column are associated with difficult intubation.

Oropharyngeal Space Patients with tumors of the airway and lymphatic malformations may have very little pharyngeal space making intubation challenging. Beckwith-Wiedemann syndrome is associated with an enlarged tongue which rarely presents challenges during intubation. The laryngoscopist may need an assistant to retract the tongue to facilitate tracheal intubation. Ventilation may be difficult and should be considered during the airway management plan. Children with mucopolysaccharide disorders such as Hunter and Hurler syndromes have poor pharyngeal and laryngeal tissue compliance making these patients some of the most difficult to intubate. Patients who have had radiation treatment to the head and neck may also present with poorly compliant airway structures and can be extremely difficult to intubate.

Anterior Mandibular Space Pierre Robin sequence, Goldenhar syndrome, trisomy 13, trisomy 18, and cri-du-chat syndrome all present with micrognathia which limits the anterior mandibular space available to displace the tongue.

Temporomandibular Joint Temporomandibular joint ankylosis may severely limit mouth opening making intubation difficult.

Maxilla/Midface Apert syndrome, Crouzon syndrome, and Pfeiffer syndrome all have midface hypoplasia. Many of these disorders are associated with small nasal passages and a high arched palate making them prone to upper airway obstruction. Patients with Treacher Collins syndrome have both maxillary and mandibular hypoplasia and are prone to severe upper airway obstruction.

Vertebral Column Patients with Goldenhar syndrome may have fused *vertebrae* or hemivertebrae, limiting their cervical neck range of motion. Klippel-Feil syndrome is associated with severe restriction in neck movement due to fusion of cervical vertebrae and atlanto-occipital abnormalities. VACTERL association includes vertebral anomalies that may make tracheal intubation difficult [10].

Best Location for the Management of These Children

Airway management of children with difficult airways outside the operating room (OR) is associated with worse outcomes. Emergency intubation in children by pediatric anesthesiologists in the emergency department (ED) or inpatient units are associated with a significantly higher rate of difficult intubation and intubation-related adverse events, compared to those intubated in the OR [11, 12]. In general, children in extremis should be managed at their bedside location, though moving the child may be appropriate if the necessary equipment or personnel support are not available at bedside. This decision should not be made lightly as many of these patients often have comorbidities that are unrelated to the airway that need special consideration. If transport to the OR is deemed necessary for airway management, a member of the child's primary care team should accompany the airway managing team to the OR. The child's primary team can be invaluable in managing non-airway-related medical issues. Children who are stable should be managed wherever the care team feels is safest. Clinicians should be mindful that the most important goal in airway management is to maintain adequate oxygenation and ventilation.

Team Approaches

As with any high-risk situation, teamwork is imperative in pediatric difficult airway management. Schmutz et al. found through a systematic review that training teams in process behaviors were associated with an improvement in clinical performance [13]. Qualities of high-functioning teams include clear closed-loop communication, understanding of roles, mutual trust among members, a culture of no blame, collaboration, and having a shared goal.

For anticipated difficult airways, it is important to have a preinduction time-out to introduce team members, discuss the plan and potential challenges, and identify key roles. Each member needs to trust and respect the other members. We have found that an a priori plan of who will make the first, second, and third tracheal intubation attempts is important for successful airway management with the least number of attempts.

Another important aspect of teamwork is that all team members must feel empowered to speak up when they see something they disagree with and not be afraid of the authority gradient or decision-making power hierarchy. Protocols such as Co-PILOT (Co, confirm failure; P, propose other equipment; I, immediate senior anesthesiologist assistance to be called; L, laryngeal mask airway – second generation; O, oxygenate; and T, tracheal access) have been developed to help groups improve teamwork. These protocols include the participation of an anesthesia assistant and employ decision-making tools such

PACE (Probe, Alert, Challenge, Emergency) that involves increasing levels of assertiveness for team members as the urgency of a situation increases [14].

It is important to note that when a patient enters the can't intubate, can't oxygenate (CICO) emergency scenario, front of neck access (FONA) should be attempted. In this chapter, FONA refers to all cannula and scalpel emergency airway rescue techniques via the cricothyroid membrane or anterior tracheal wall. Preparation for CICO is crucial since it is rarely performed by anesthesiologists. Outcomes are very poor in children, and therefore a surgical tracheostomy by an ear, nose, and throat (ENT) surgeon is preferred. In the setting that an ENT surgeon is not immediately available, the clinician can perform a cannula or scalpel FONA, although there is not enough literature to support one as the first-line technique over the other. The Association of Paediatric Anaesthetists of Great Britain and Ireland (APAGBI) recommends percutaneous cannula cricothyroidotomy as the first FONA to be attempted in children 1–8 years old as it can be performed quickly and is relatively noninvasive [15]. Holm-Knudsen showed that scalpel FONA was more successful than cannula FONA using piglets as a pediatric model; however it was associated with significant rates of posterior tracheal wall damage [16]. With current evidence, it is likely more important that an institution chooses one technique and provides adequate training and familiarity with that technique and equipment than which technique is chosen. Once FONA has been obtained, adequate oxygenation can be provided using an Enk Flow Regulator (Cook Medical, Bloomington, IN, USA) [17]. The Ventrain (Ventinova Medical B.V., Eindhoven, the Netherlands) is a new device designed to ventilate through a small lumen tube in patients with difficult airways. It is unique in that it uses suction in the expiratory phase, thereby making expiration an active rather than a passive process as it is with other devices. This may reduce the risk of barotrauma seen with jet ventilators and other devices [18]. A team at the Royal Children's Hospital in Melbourne, Australia, developed an institutional approach to the CICO scenario that includes a CICO pack with two separate pouches containing equipment needed for either a cannula or scalpel FONA technique [19]. Other considerations for a CICO bundle include human factors such as the person performing FONA should be different from the person who failed to intubate or oxygenate the patient, to avoid task fixation [20].

How to Best Sedate/Induce a Child with an Anticipated Difficult Airway

Awake intubations are rarely performed in children because of difficulty with patient cooperation and will not be discussed in this chapter. A controversial topic in management of the difficult pediatric airway is whether to use muscle relaxants or to maintain spontaneous ventilation. In infants without difficult airways, it has been shown that the addition of muscle relaxants during intubation to sevoflurane induction improved intubating conditions when compared to placebo or alfentanil and was associated with fewer adverse respiratory events [21]. Further work needs to be done to determine the effect of muscle relaxants in difficult pediatric airway management.

Spontaneous ventilation should be maintained in patients with difficult mask ventilation. This can be achieved either by volatile anesthetics or via intravenous hypnotics. Airway adjuncts such as nasopharyngeal or oropharyngeal airways, two-handed and two-person face mask ventilation, or supraglottic airways may improve mask ventilation.

The challenge of keeping a patient spontaneously ventilating during airway management is the ability to instrument the airway without including coughing, bucking, laryngospasm, bronchospasm, or vomiting. Sevoflurane alone may not provide adequate conditions for intubation of a pediatric difficult airway in a spontaneously ventilating patient. Erb et al. showed in a study that defensive airway reflexes including cough, expiration reflex, and spasmodic panting were almost completely suppressed with high concentrations of sevoflurane (sevoflurane

4.7% = $MAC_{ED95Intubation}$) as compared with sevoflurane 2.5% (= 1 MAC). However, the incidence of laryngospasm is only partially reduced even with high concentrations of sevoflurane [22]. We have found a 5 s jaw thrust to be a reliable test of adequate depth of anesthesia for airway instrumentation in a spontaneously ventilating patient. The clinician should look for increases in respiratory rate and heart rate and body movement as signs of inadequate depth of anesthesia.

Total intravenous anesthesia with propofol with or without remifentanil is a common technique in a spontaneously ventilating patient. Propofol acts via the inhibitory neurotransmitter GABA and causes muscle relaxation and suppresses respiratory drive. Ketamine has also been used as an adjunct for a spontaneously breathing patient and works on blocking *N*-methyl-D-aspartate (NMDA) receptors and preserves ventilation. However, ketamine activates cholinergic systems and leads to hypersalivation – an antisialagogue may help reduce this side effect.

Dexmedetomidine has many properties that are advantageous for anesthesia for a spontaneously ventilating patient, including anxiolysis, analgesia, and sympatholysis. Dexmedetomidine is an α2-adrenoceptor agonist and causes sedation by acting in the locus coeruleus. It has also historically been viewed to cause minimal respiratory depression. However, Lodenius et al. showed that sedation with dexmedetomidine significantly reduced hypoxic and hypercapnic ventilation in healthy male volunteers, to a similar extent as sedation with propofol [23]. They induced sedation in ten patients with a bolus over 10 min of dexmedetomidine up to 1.1 μg/kg or propofol 750 μg/kg, followed by an infusion of dexmedetomidine 0–1 μg/kg/hr. or propofol 0–75 μg/kg/min. Conversely, other case reports demonstrate dexmedetomidine attenuates airway reflexes while maintaining stable respiratory profiles in spontaneously ventilating children [24], particularly when combined with another intravenous anesthetic, such as propofol [25]. It is likely that combining two intravenous anesthetics decreases the doses of both drugs needed to provide adequate intubating conditions while preserving spontaneous ventilation.

When dexmedetomidine/propofol (DP)-total intravenous anesthesia (TIVA) was compared to remifentanil/propofol (RP)-TIVA for rigid bronchoscopy for foreign body removal in 77 children, both groups had similar incidence of desaturation, coughing, and breath-holding rates. However, DP-TIVA patients had respiratory rates closer to baseline and an Et_{CO2} closer to baseline, suggesting it didn't impair respiratory drive as much as RP-TIVA [26].

Dexmedetomidine has a biphasic effect on blood pressure. There is an initial hypertensive response caused by peripheral vasoconstriction, followed by a sympatholytic effect leading to a decrease in blood pressure. At lower bolus doses (0.5 μg/kg), the hypertensive response is minimized [27]. Another hemodynamic effect of dexmedetomidine is bradycardia – up to a 30% decrease from baseline. Though at a lower bolus dose of 0.49 μg/kg over 5 s, there isn't significant hemodynamic compromise. Mason et al. report extreme hypertension in response to the administration of glycopyrrolate to treat dexmedetomidine-associated bradycardia and caution treating bradycardia in a normotensive patient [28]. We have achieved very good intubating conditions by combining dexmedetomidine with inhaled sevoflurane in spontaneously ventilating patients with difficult airways. Other combinations have been described including dexmedetomidine with ketamine.

There is increasing awareness that passive oxygenation during intubation is useful for reducing complications and increasing the desaturation free time available to secure the airway. This can be done using a nasal cannula, supraglottic airway, modified nasopharyngeal airway, and modified oral RAE endotracheal tube or through the working channel of a fiber-optic scope. It is important to note the risk of delivering *O*xygen *T*hrough the *W*orking *C*hannel (OTWC) of a fiber-optic scope, including the risk of tension pneumothorax if it is delivered without allowing gas egress. We recommend using this technique only when the scope is outside the trachea and suggest oxygen flows of 2 L/min in infants and 3 L/min for all other ages. Oxygen insufflation can be helpful to blow away secretions and blood. If used in the trachea, it is

important to not wedge the scope, as this can lead to pneumothorax [29]. A prospective randomized controlled trial in 48 healthy children compared passive oxygenation using transnasal humidified rapid-insufflation ventilatory exchange (THRIVE) to standard practice in paralyzed children and demonstrated that THRIVE prolongs the apnea time in children [30]. Steiner et al. examined the use of deep laryngeal oxygen insufflation during laryngoscopy. In one condition they used a laryngoscope with an oxygen cannula attached to the blade and concluded that laryngeal oxygen insufflation increases the time to 1% desaturation and reduces the overall rate of desaturation during lower endoscopy in children [31]. Oxygenation during intubation of the child with a difficult airway is beneficial and should be performed whenever possible.

The application of topical lidocaine to the larynx is a common practice in pediatric anesthesia. Some studies have shown that it decreases perioperative respiratory adverse events, while other studies have shown an increased incidence of complications such as laryngospasm and bronchospasm [32–35].

Newest Gadgets for Difficult Pediatric Airways

Since its advent in the 1970s, the fiber-optic bronchoscope (FOB) has been the gold standard for intubation in difficult airway management. Despite a plethora of new devices and technologies, it still remains the gold standard. Newer devices include video laryngoscopes and second-generation supraglottic airway devices (SGAs).

Video Laryngoscopes

Video laryngoscopes (VLs) have become very popular in difficult airway management. They can be classified as angulated or non-angulated devices. Although they look similar, angulated and non-angulated VLs are very different. The angulated devices are most helpful for difficult airways, while non-angulated devices are useful for routine intubations. VLs require dedicated practice to master. Although the glottic view is almost always excellent, the clinician has to learn the new skill of inserting the tracheal tube indirectly. Counterintuitively, a grade II view of the airway makes it easier to insert the tracheal tube than a grade I view as there is usually more length in the oropharynx to advance the tracheal tube. Other maneuvers to improve the ease of insertion of the endotracheal tube include rotating the tube, external laryngeal manipulation, and reverse loading the tube onto the stylet. Reverse loading refers to bending the styletted tube at 60 or 90° against its natural concave curve [36]. VLs are associated with longer intubation times than traditional laryngoscopy because of the indirect manipulation of the tracheal tube. The GlideScope VL is the most commonly used VL in children with difficult airways. Park et al. performed the largest study of children with difficult airways comparing the GlideScope to standard direct laryngoscopy. They found that the GlideScope was successful in 82% of patients vs. 21% with direct laryngoscopy [37]. Other VL options for the child with the difficult airway include the Airtraq, the TruView EVO2, and the C-MAC D-blade. Almost all the evaluations of these devices were done in manikins or children with normal airways [38–40].

VLs fail when there is limited space in the oropharynx, limited mouth opening, macroglossia, or large masses in the oropharynx. Visualization of the airway may also be compromised by fogging, secretions, vomitus, or blood.

Fiber-Optic Intubation

Fiber-optic intubation remains the most versatile technique to secure the airway of a child with difficult intubation. Newer fiber-optic bronchoscopes integrate a camera in the tip, thereby enhancing the quality of the image produced. Fiber-optic intubation can be performed freehand or through a laryngeal mask. Burjek et al. compared fiber-optic intubation through a supraglottic airway in children to videolaryngoscopy and found that first attempt success rates were similar; however, fiber-optic intubation through a

supraglottic airway had a higher first attempt success in infants. Furthermore, ventilating continuously through a SGA was associated with a lower incidence of hypoxemia. The Air-Q is the most commonly used SGA for fiber-optic intubation in children. This is because it is designed with a wide airway tube that facilitates the placement of a cuffed tracheal tube.

Supraglottic Airway Devices

SGAs can be used as the primary airway management technique in children with difficult airways. Technical difficulties with using SGAs are inversely proportional to the age of the child. Newer SGAs incorporate a gastric access channel that allows the stomach to be emptied of gastric contents and helps in confirming the SGA is in the correct position. Clinicians should be prepared to secure the airway in the event of any technical issues. Two simple tests can be used to confirm that the second-generation SGA is in good position. First, a small amount of lubrication is placed on the orifice of the gastric access channel – pressing a finger slightly in the suprasternal notch should cause the lubricant to move in and out if the tip of the mask is in the upper esophageal sphincter. This maneuver compresses the esophagus and sends a slight amount of air up the drain tube causing the lubricant to move slightly. The second test involves placing a small amount of occlusive lubricant on the gastric drain tube while giving a tidal volume breath through the airway tube of the mask. Disruption of the lubricant from the drain tube suggests inadequate separation of the airway and the esophagus – this may occur if the mask is underinflated, inappropriately sized, or sitting too high. Second-generation SGAs with pediatric sizes include the LMA Supreme, Igel, and the Ambu AuraGain.

Summary

Children with difficult airways are particularly vulnerable. Preparation is the key to caring for them successfully – a simple checklist can help optimize care. Introduce all team members, and review the induction and intubation plan with the entire team, including identifying the clinician making each intubation attempt. Identify an individual who is available to assist before beginning airway management. The following principles should guide the care of these patients.

1. Limit the number of tracheal intubation attempts.
2. Know your equipment. Be prepared.
3. Always attempt to oxygenate during intubation.
4. Ensure an adequate depth of anesthesia before instrumenting the airway.
5. Be wary of cognitive biases that may delay action.

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8 Anesthesia Maintenance During Endoscopic Airway Surgery

Sharon H. Gnagi, Michel J. Sabbagh, and David R. White

Introduction

The management of pediatric airway pathology can be challenging from both an anesthetic and surgical standpoint. There are a wide variety of conditions managed endoscopically and a large range of pediatric patients that may undergo surgery. This requires close coordination between the anesthesiologist and surgeon for successful intervention and is especially highlighted during endoscopic airway surgery when the airway must be shared to optimize both visualization and delivery of anesthesia. As technology and surgical instrumentation improve, endoscopic procedures of the airway have become increasingly common, and indications for endoscopic airway surgery continue to grow. There is currently no consensus regarding anesthetic management during these surgeries, and a large variety of anesthesia and ventilation techniques exist to provide quality anesthesia during endoscopic surgery. This chapter aims to review the large variation of airway pathology managed endoscopically, anesthesia delivery mechanisms, and anesthetic agents available.

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Communication

Communication between all members of the airway team is essential for safe, efficient, and quality surgical care. This is highlighted by discussing the preoperative airway management plan. Intraoperatively, clear communication of changing stimulation and altering steady state is necessary to anticipate possible needs of changing the current anesthetic. Similarly, communicating signs of inadequate anesthesia is necessary to provide adjustments in anesthetic depth. This communication ultimately helps to minimize complications and medical errors and expedite surgery. Communication extends to the postoperative time period which may include the postanesthesia care unit or intensive care unit depending on the airway pathology and intervention.

Creating a culture of safety and teamwork includes allowing all members to voice concerns at any time. Mutual respect for all involved disciplines emboldens all to speak up when issues arise. Checklists and team briefings and debriefings additionally foster open communication and greater understanding of the patient and surgery at hand [1].

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The Pediatric Airway

The pediatric airway has several unique features that must be considered prior to surgical intervention. First and most obvious, the pediatric airway dimensions are small with the typical diameter of the subglottic neonatal airway ranging from 3 to 4 mm in size [2]. Stenoses in this area exponentially increase the resistance of airflow, as described by Poiseuille's law. This law describes the relationship between a decrease in radius leading to an inverse increase in resistance to the fourth power, quickly leading to obstruction with small changes in the diameter of the airway. Anatomically, the larynx sits higher in the infant with the lower border of the cricoid at the lower border of the fourth cervical vertebrae [3]. The more superior location of the larynx in children may create difficulty in visualizing the larynx because of the more acute angulation between the base of the tongue and the laryngeal opening [4]. Children have a relatively larger tongue, and therefore mask ventilation may be difficult without an oral airway. During laryngoscopy a neck or shoulder roll will relieve the hyperflexion of the infant's neck caused by the relatively large occiput [3]. The cartilage of the pediatric airway is more malleable and may present with tracheo-, broncho-, or laryngomalacia leading to increased ability of the airway to collapse secondary to pressure changes in the airway during respiration.

Diseases of the Pediatric Airway

Airway Masses

Masses within the pediatric airway may range from benign to malignant and can present in a variety of ways including hoarseness or abnormal cry, stridor, or respiratory distress. Lesions that are frequently managed endoscopically include saccular cysts, laryngoceles, subglottic cysts, subglottic hemangiomas, granulation tissue, and recurrent respiratory papillomatosis (RRP) among other less common etiologies. These lesions may be marsupialized or removed Airway Masses endoscopically utilizing several different methods including microdebrider, laser, coblator, or cold steel technique.

Functional Pathology of the Airway

Laryngomalacia and tracheomalacia describe the flaccidity of the airway leading to collapse, especially during the increased exertion of coughing, feeding, or crying. Laryngomalacia is characterized by inspiratory stridor and collapse of the supraglottic tissue during inspiration seen on flexible laryngoscopy. Late-onset laryngomalacia is becoming increasingly recognized in association with OSA, exercise-induced stridor, and dysphagia and therefore may be treated in older patients. Supraglottoplasty is the treatment of choice for severe laryngomalacia and can be done using a variety of methods. Tracheomalacia is the abnormal collapsibility of the trachea accentuating the physiological airway narrowing that occurs during expiration [5]. Patients with tracheomalacia present with a barking cough and expiratory stridor. More severe cases may present with recurrent respiratory distress, wheezing, cyanosis, or acute life-threatening events (ALTE). Localized tracheomalacia may be secondary to extrinsic compression including vascular rings or prior surgery including tracheostomy, laryngotracheal cleft repair, or tracheoesophageal fistula repair. Endoscopic treatments are limited as stenting has been previously shown to be fraught with problems. However, with new absorbable stents on the horizon, this may emerge as a temporizing or improved treatment method. Endoscopy performed concurrently during open procedures has been shown to improve outcomes.

Vocal fold immobility (VFI) may be unilateral or bilateral. VFI may be congenital or arise as a complication from cervical or cardiothoracic surgery or pathology. Unilateral VFI presents with a hoarse breathy voice, while bilateral VFI presents with stridor and intact phonation. Unilateral VFI is typically treated with injection laryngoplasty in efforts to medialize the affected vocal fold. Bilateral VFI may be treated endoscopically

with arytenoidectomy, vocal fold lateralization, cordotomy, posterior cricoid grafting, anterior posterior cricoid split, or a combination of these therapies.

Airway Stenosis

Stenoses of the airway can occur anywhere along the respiratory tract from the oropharynx to the pulmonary bronchi. The etiology of stenosis is most commonly a consequence of trauma, surgery, intubation, or congenital anomaly. The majority of intubation-related injuries are due to use of an endotracheal tube (ETT) being too big for the infant airway.

For anterior glottic stenosis, techniques include removing the superior epithelium of the glottic web, cutting the web on one side of the glottis and suturing it to the contralateral side, lysis with keel placement, buccal mucosal or perichondrium grafts, or an epiglottic flap for large anterior commissural defects [6]. For posterior glottic stenosis, most treatments are similar to those for bilateral VFI. Endoscopic resection with flap reconstruction is another option described in recent literature.

For subglottic stenosis, endoscopic options include lysis of stenosis (sharply or via laser) with dilation by bougie or balloon and grafting procedures. Anterior and/or posterior cricoid split with or without cartilage grafting has been the mainstay of airway reconstruction with a more recent trend toward endoscopic performance. Posterior cartilage grafting has been performed endoscopically since it was first described with reproducible success [7]. Anterior cricoid split has been performed for early subglottic stenosis to successfully facilitate extubation and avoid tracheostomy and has been performed endoscopically in conjunction with balloon dilation [8].

Congenital Anomalies

The range of other congenital abnormalities is large, and many are mentioned above. Congenital anomalies of the airway that may be managed endoscopically may include laryngeal webs, laryngeal clefts, and tracheoesophageal fistula. Many congenital anomalies may coexist with additional or multilevel airway pathology.

Preoperative Assessment

Prior to any airway intervention, a thorough preoperative assessment of the child is paramount. This begins with a full history of the child, planned operation, and past medical history. Assessing current respiratory status, feeding, phonation, and cough may help anticipate the degree of airway compromise. A list of preoperative considerations and their anesthetic implications can be found in Table 8.1. Many children with airway pathology may have significant comorbidities and sequelae of prematurity, prolonged intubation, and/or tracheostomy; therefore this information is critical to review as anesthesia-related risks are commonly predicted by concurrent disease. In some instances, patients may present in acute distress and require urgent surgery necessitating an efficient evaluation, or there may be minimal opportunity to review history and modify anesthesia-related risks.

After a thorough history, an evaluation of the airway and physical examination follows. The general appearance of the child, body mass index, and work of breathing are immediately assessed. Any evidence of prior trauma, burns, or surgery to the neck, dysmorphic features, neuromuscular disease, or congenital abnormalities should be noted. Specifically, abnormalities of the bony structures of the mandible and/or midface, mouth opening, microstomia, or redundant soft tissues of the upper airway should be noted and included in proper planning of airway intervention. Physical examination features that may result in a difficult airway include, but are not limited to, obesity, facial trauma, retro- or micrognathia, intraoral pathology such as infection or tumor, trismus, microstomia, or poor dentition**.** Loose dentition is especially important to note prior to endoscopic airway surgery, as instrumentation can lead to tooth loss. Preoperative assessment includes evaluation of craniocervical

Table 8.1 Significant preoperative considerations before pediatric airway surgery

Organ system	Comorbid conditions	Preanesthetic implications	Intraoperative adjustments to consider
Cardiac history	Structural heart disease	Assess risks of cardiac arrest, significant dysrhythmia, shunt physiology, paradoxic embolism, response to hypercarbia or hypoxemia	Maintain normocarbia
	Cardiac surgery		Filter intravenous fluids
	Dysrhythmia history		Consider need for ionotropic support
	Acute life-threatening events		
	Medications		
Pulmonary history	Chronic lung disease	Assess risk of adverse respiratory event	Consider risk/benefit of Fio_2 options
	Pulmonary hypertension		Consider effects of spontaneous vs controlled ventilation
	Recent respiratory infection		
	Chronic aspiration		
Airway history	Difficult ventilation, intubation	Assess risk of unexpected difficult mask ventilation or intubation, adverse airway event, desaturation	Prepare for difficult airway
	Syndrome associated with airway difficulty		Consider surgical airway options
	Microstomia, macroglossia, ptossoglossis		Maintain spontaneous ventilation
	Retrognathia, temporomandibular joint disease		
Neurologic history	Seizure disorder	Assess risk of hypercarbia on autoregulation	Consider intravenous vs inhalational induction
	Intracranial pathology	Assess risk of induction techniques	Consider risks of drug interactions assess seizure risk
Neuromuscular disorders	Hypotonia	Assess risks of malignant hyperthermia, sensitivity to anesthetics and analgesics, postoperative respiratory embarrassment	Consider need for clean technique
	Mitochondrial myopathies		Consider postoperative ventilation
			Consider increased response to analgesics, neuromuscular blocking drugs
Birth history	Prematurity and associated sequelae	Chronic pulmonary disease, developmental delay, history prolonged intubation	Increases risk of respiratory events, difficult intravenous access
Social issues	Guardianship	Assess resources needed to assist family and child	Need for social-work assistance, interpreters
	Behavioral issues		
	Consent		Consider ability of guardian/child to comprehend planned surgery and risks
	Language barriers		

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movement, Mallampati scoring, thyromental distance, and prognostication. These characteristics are also considered by the surgeon as the same factors necessary for exposure during endoscopic airway surgery. For further description of management of the difficult airway, please refer to Chap. 6.

If preoperative imaging or flexible laryngoscopy images obtained during clinic or prior surgeries are available, these are helpful to review. Some patients may have concurrent obstructive sleep apnea (OSA), and therefore being familiar with any prior sleep study and the severity of their OSA is also crucial for perioperative planning.

Adherence to strict NPO guidelines is paramount in this patient population as they may spend part or all of their procedure without a secured airway. Strategies to improve outcomes in patients who may suffer from gastroesophageal reflux disease, gastroparesis, or acute intra-abdominal processes include a reduction in gastric volume through the use of a promotility agent such as metoclopramide (0.15 mg/kg) preoperatively and gastric emptying through the use of an orogastric tube following induction, as well as pH-modifying agents such as ranitidine (1.5 mg/kg intravenously) and sodium citrate (1 mL/kg up to 30 mL, orally) preoperatively [9].

Additional considerations include the use of an anticholinergic agent. Glycopyrrolate or atropine is used to minimize reflex bronchoconstriction through the cholinergic receptors during airway manipulation and vagal-induced bradycardia from insertion of laryngoscope or bronchoscope. These agents are also useful as antisialagogues, reducing secretions to improve surgical visualization intraoperatively. In an acute airway situation, requiring urgent or emergent surgery with a full stomach may alter clinical decision-making. The risks of operating on a full stomach must be weighed against the current clinical status of the patient. Prior studies have found that the morbidity risk for pediatric aspiration with anesthesia induction is low, and experience with foreign body removal suggests that inhalational techniques may be safely used with a full stomach [10, 11]. These patients typically require intravenous access preoperatively and may be induced through rapid sequence following preoxygenation. Following intubation, the stomach is emptied using an orogastric tube, and the endotracheal tube may be removed by the surgeon to allow for surgical exposure.

Anesthesia Delivery

Anesthesia delivery during endoscopic airway surgery is a delicate balance between adequate depth and delivery of anesthesia and proper access and visualization of the airway to perform surgery.

Spontaneous Ventilation

Spontaneous ventilation without intubation avoids restriction of visualization and combustible material during laser surgery and is often preferred by the surgeon. Additionally, during diagnostic portions of the procedure, positive pressure ventilation may prevent adequate visualization of some pathologies such as the collapse of tracheomalacia. Spontaneous ventilation may be maintained through inhalational or intravenous anesthesia, and specific agents will be further discussed below. Oxygen +/− inhalational gas may be delivered via an endotracheal tube in the hypopharynx via the mouth or nose or connected directly to the laryngoscope.

Apneic Ventilation (Intermittent Apnea/Intubation)

This technique provides intermittent ventilation and oxygenation with an endotracheal tube and periods of apnea that allow the surgeon to work. Paralytics can be utilized to establish apnea which creates the added benefit for the surgeon of no vocal fold motion. This technique provides shorter windows of punctuated working time and is typically only suitable for short procedures. Maximum operative time vary from 90 s up to 6 min in prior literature [12, 13]. Preoxygenation is key in this technique as it carries a risk of

hypoxemia associated with episodic desaturations during the working window. Desaturation and hypoxemia can occur very quickly as infants have a higher rate of O2 consumption and loss of as much as 45% of their functional residual air capacity during general anesthesia [14]. Additionally, the patient may become hypercarbic with arterial CO2 rising by 11 mmHg in the first minute and by 4.5 mmHg in each subsequent minute [15]. This is exhibited clinically by an increase in heart rate and blood pressure. There are typically no deleterious effects, but may lead to respiratory acidosis and have a negative impact on pulmonary vascular resistance and intracranial pressure. Multiple intubations and extubations also carries risk of swelling, mucosal trauma, and laryngospasm. Lastly, this technique may not be possible in a severely compromised airway as an endotracheal tube may be unable to pass.

Endotracheal Intubation with Conventional Ventilation

The airway may be managed with an age-appropriate or intentionally smaller endotracheal tube for optimal surgical exposure. This is likely the safest technique, but typically limits visualization necessary for performing endoscopic airway procedures. While particularly limiting for procedures involving the vocal folds, subglottis, and trachea, it may be the anesthetic delivery system of choice for select procedures. For example, this would be the ideal choice for procedures of the upper airway, including vallecular or thyroglossal duct cyst excision at the base of tongue. When operating in the posterior oropharynx, a nasotracheal intubation may be preferred to maximize exposure of the operative field.

Patients undergoing endoscopic airway surgery may have a pre-existing tracheostomy. These children may undergo several endoscopic airway procedures while moving toward decannulation including balloon dilation, grafting procedures, removal of laryngeal stents, and debridement of suprastomal granulation tissue among others. In this case, anesthesia may be delivered through the patient's pre-existing tracheostomy tube or exchanged if necessary to a cuffed tracheostomy tube or endotracheal tube through the stoma. If the stoma needs to be completely unobstructed, as in the removal of suprastomal granulation tissue through the stoma itself, a ventilating bronchoscope may be used to maintain oxygenation and anesthetic depth.

Jet Ventilation

Jet ventilation is the delivery of high-flow, high-pressure gases to the airway to entrain ambient air to supplement the delivery of a tidal volume [16]. It can be administered through a variety of ways: a small diameter catheter, specially designed jet laryngoscopes, or a transtracheal cannula. These delivery systems are then connected to either manually controlled jet ventilation or to a jet ventilation machine.

The small diameter catheters utilized are typically placed in a transglottic fashion to deliver airflow. These are not laser-safe and would need to be used in an intermittent apneic fashion if used during a laser procedure. While commonly used in adults, even a small 2–3 mm jet ventilation catheter may obstruct visualization of the surgical field in an infant or neonate. Additionally, partially obstructing the small airway of an infant may increase the likelihood of barotrauma and air-trapping. Newer jet ventilation machines may offset this risk with built-in safety switches that turn off delivery automatically when a threshold pressure is reached to allow for egress of air. Another option described uses a small modified suction catheter with an internal diameter of 1.5 mm passed through the nose into the trachea to deliver oxygen. In this study, they used a manually controlled jet ventilator to deliver oxygen at 15–35 psi (usually 25 psi) at a frequency of 16–20 bpm [17].

Transtracheal ventilation is invasive and requires transcutaneous puncture of the airway, typically at the cricothyroid membrane to deliver anesthesia with a 14G or 18G cannula. This delivery method is difficult in infants and has been associated with a higher complication rate related to barotrauma [18].

Supraglottic jet ventilation is typically delivered via a jet laryngoscope and connected to either manual jet ventilation or a jet ventilation machine. Jet laryngoscopes typically have attachments with integrated nozzles into the wall of the laryngoscope as opposed to within the lumen so as to not impair visualization. One benefit of this configuration is that disconnection or accidental removal of a catheter, endotracheal tube, etc. is not possible. Proponents also advocate that this method is minimally invasive, offers excellent visualization, and is unlikely to cause barotrauma as the delivery is above any potential area of stenosis.

Superimposed jet ventilation involves both a high- and low-frequency jet ventilation stream that is "superimposed." This augments tidal volume without increasing driving pressure, resulting in better elimination of CO2 and increased velocity of inspiratory gas so that ventilation is possible even in examples of severe stenosis [14]. The high-frequency portion produces positive end-expiratory pressure prevents alveolar collapse and results in better oxygenation [14, 19]. Studies have demonstrated that supraglottic, superimposed high-frequency jet ventilation via this method is safe and effective in pediatric patients ranging from 3 weeks to 14 years and 2.4 kg to 50 kg [14, 20]. The jet ventilation machine (Bronchotron-1G Respirator, C. Reiner Corp., respectively, its successor TwinStream™, C. Reiner Corp.) was set with a driving pressure of 0.03 bar•kg-1 in the low-frequency part of jet ventilation and 0.02 bar•kg-1 in the high-frequency part with an inspiratory/expiratory ratio of 1:1 [14].

While the methods described above offer excellent visualization, jet ventilation is less commonly used in pediatric airway surgery, and its current use is controversial. The risk of barotrauma and resultant complications such as pneumothorax justly create concern, and some studies have shown an increased incidence of barotrauma and laryngospasm when compared with other anesthetic techniques, specifically with a transtracheal approach [18]. Some worry that jet ventilation use in the treatment of RRP may propagate seeding of the lower respiratory tract by carrying HPV particles; however, other studies have shown that this is not the case [21]. Many studies have demonstrated jet ventilation as a safe and effective method with less risk of hypoxia [14, 17, 19]. This positive pressure ventilation may be particularly helpful for obese children where insufflation may not be adequate. Modifications of adult administration techniques have been shown to be effective and useful adjuncts in endoscopic airway surgery in children [22]. Gas insufflation into the stomach is an additional consideration with supraglottic jet ventilation in the pediatric patient as increased intra-abdominal pressure may reduce pulmonary compliance and tidal volumes. A red rubber catheter readily available to decompress the stomach in the event that this occurs offers a quick and easy solution.

Anesthetic Agents

Premedication

Benzodiazepines are agents that produce amnesia and sedation that are commonly used in pediatric anesthesia practice. Midazolam is most frequently used [9], due to its multiple routes of administration (oral, intravenous, intramuscular, and intranasal), which gives the practitioner options in more complex situations. It is a particularly good agent due to its lack of pain on injection from its water-soluble properties, as well as reliability and rapidity of onset. Midazolam 0.5–0.7 mg/kg orally 30 min prior to surgery is typically employed. Its half-life is much shorter than other options in its class, and it can be reversed with the use of flumazenil if required intraoperatively or postoperatively. There is a ceiling effect to its respiratory depression. Patients should not become apneic if it is used as a solo agent for sedation, unless a known respiratory depressant is added, most commonly an opioid such as fentanyl.

Induction

Inhalational or intravenous inductions are both options for endoscopic cases, the former being the preferred method for many anesthesiologists

[23]. This technique allows a slow, smooth loss of consciousness while maintaining the airway under close observation, especially when the extent of airway pathology is unknown [24]. Following successful induction of anesthesia, the anesthesiologist must take care in maintaining spontaneous respiration. Most endoscopic procedures require maintenance of spontaneous ventilation as there is often a need for providing the anesthetic without a secured airway for at least part of the procedure if not the entirety. Anesthetics are therefore built around this principle, and agents are titrated to both respiratory rate and lack of response to the surgical stimulus. The primary inhalational agent used in children is sevoflurane as it is the least pungent in this class. Although desflurane may have a better blood/gas partition coefficient, its pungency and demonstrated increased airway irritation have led to incidence of airway problems when used in conjunction with a laryngeal mask airway upon deep removal [25]. Thus, desflurane does not lend itself well to inhalation inductions.

If an IV line is already in place, it can be used for induction of anesthesia, which may include a combination of intravenous medications such as propofol, lidocaine, fentanyl, and dexmedetomidine. Although propofol may be the anesthesiologist's preferred induction agent, its effect on respiratory response is highly variable in children and may cause apnea or obstruction in patients with an already compromised airway on induction. A slow infusion during induction and maintenance has been shown to have a lower risk of respiratory depression while allowing spontaneous respiration when titrated appropriately, though may not inhibit the cough reflex at this concentration [13, 26]. Depending on the surgical plan, a muscle relaxant may also be administered after positive pressure ventilation is ensured via facemask.

Sugammadex is gaining acceptance as a nondepolarizing neuromuscular blocker which acts as a noncompetitive antagonist and has been used as a reversal agent with good results in the pediatric population [27, 28]. It allows for rapid reversal of agents such as rocuronium without having to wait for return of neuromuscular function as monitored through the response to the train-of-four stimulation. Pediatric bronchoscopy especially and some endoscopic procedures may require rapid increase and maintenance of anesthetic depth followed by an abrupt end to the procedure. In these instances sugammadex is revolutionizing anesthetic strategies without the sometimes controversial use of succinylcholine bolus or infusion to achieve similar results in a pediatric patient.

Ketamine 2–3 mg/kg IV can also be used for induction secondary to its properties of preserving respiratory drive and maintenance of sympathetic tone in circumstances when the child has a difficult airway, reactive airway disease, or an uncooperative child that requires intravenous access [29]. Ketamine's psychotomimetic properties may limit its use by other providers.

Intraoperative Maintenance of Anesthesia

Inhalational agents can be used successfully for bronchoscopies and endoscopic procedures. The main concerns in these cases occur when an endotracheal tube is not used for the duration of the procedure. When there is absence of a secured airway, the practitioner is unable to accurately monitor the delivered and expired concentrations. In these cases where the circuit is either attached to a side port on a bronchoscope or an airway is inserted blindly into the posterior hypopharynx, greater amounts of inhalational agent are used due to high fresh gas flows through the vaporizer and occupational exposure for the operating room personnel can be above safe limits [30, 31]. If necessary, briefly obstructing the laryngoscope can be performed to allow for better delivery of inhalational agents to the patient. Helium may be a useful adjunct for endoscopic airway surgery, especially in the partially obstructed airway. Helium's lower density improves turbulent airflow, oxygen delivery, and gas exchange and may be fitted to the anesthetic machine to facilitate oxygenation in select circumstances [32].

Total intravenous anesthesia (TIVA) offers a solution to the issues experienced with inhalational agents. TIVA along with the maintenance

of spontaneous respiration offers significant advantages. Here, there is unobstructed surgical access, optimal conditions for dynamic function assessment, minimized risk of airway fire, as well as the absence of environmental pollution [33]. TIVA does require careful titration of infusions and can be difficult to manage with rapidly changing clinical stimulation. It requires simultaneously avoiding both apnea and light anesthesia and may lead to higher rates of rescue maneuvers such as intubation, interrupted bronchoscopy, or administration of paralytics [16].

Opioids such as remifentanil can be used by bolus or infusion to aid anesthesia. Remifentanil has an ultra-short elimination half-time and has been described as a major step forward in airway surgery in children [14, 34]. It provides a quicker recovery, decreased postoperative delirium, and reduced postoperative nausea and vomiting when compared to inhalational agents [13, 35–37]. Total intravenous anesthesia with both propofol and remifentanil is feasible and useful in an older child and may be titrated to effect with avoidance of apnea [16, 33]. A respiratory rate of ≤10 breaths/min predicts a higher risk of subsequent apnea [38]. Doses in the literature range from 150–250 μg/kg/min with remifentanil 0.05–0.1 μg/kg/min [16] to higher doses reported by Malherbe at 200–500 μg/kg/min and remifentanil 0.1–0.2 μg/kg/min [33]. Younger children, especially less than age 3, tolerate higher doses of remifentanil combined with propofol infusion while maintaining spontaneous respiration [38]. Specific dosing strategies for remifentanil to determine age-specific dosing to facilitate the avoidance of neuromuscular blocking agents have been previously described [39]. It is also possible to combine inhalational and intravenous techniques and may allow fine-tuning by combining the agents. Often, the addition of sevoflurane can provide rapid additional anesthetic depth when surgical stimulation changes to minimize the inherent delay of IV infusion pharmacodynamics until the infusion can be adjusted [16].

Dexmedetomidine, an alpha-2 agonist, has the unique ability to provide sedation and analgesia while maintaining spontaneous respiratory drive [17, 40]. It can be used as simple boluses throughout the procedure (0.3–0.7 mcg/kg) or as an infusion (0.5–1.0 mcg/kg/h) for procedures of varying lengths of time. It has been used successfully in larger doses: a bolus dose up to 4 mcg/kg and infusion dose up to 2 mcg/kg/h [17]. Especially at the higher dosing range, practitioners should expect to see some degree of bradycardia as well as variations in blood pressure (both hypo- and hypertension).

The variety of options that exist to provide excellent anesthesia care highlight that each patient and surgical encounter differ and ultimately provider experience, the individual patient, and their response to the anesthetic will guide the intraoperative plan.

Monitoring

Monitoring during endoscopic airway surgery consists of continuous pulse oximetry, electrocardiogram, blood pressure monitoring, and body temperature. If an endotracheal tube is in the airway, end-tidal CO2, tidal volumes, and respiratory rate during spontaneous ventilation may be monitored. Another option includes attaching the standard sampling line directly to the Luer fitting on a Lindholm laryngoscope sideport [16] or transcutaneous carbon dioxide monitoring. Ventilation is observed clinically by exposing the chest to allow visualization of chest rise, chest auscultation, precordial stethoscope, observance of skin color, or a monitoring hand on the abdomen, especially when end-tidal CO2 is difficult to obtain when an endotracheal tube is placed blindly in the hypopharynx. When utilizing jet ventilation, integrated airway pressure cannulas detect elevated pressures and alarm and shut off to aid in the prevention of barotrauma.

Intraoperative Considerations

After initial induction, all endoscopic airway surgeries begin with topical application of lidocaine to the larynx +/− trachea to minimize sensitivity to manipulation. Anesthetizing the airway is best achieved through the use of topical lidocaine.

One - Four percent lidocaine used with an atomizer in a dose of 3–4 mg/kg [12, 16] is effective when sprayed onto the glottic opening as well as directly onto the tracheal mucosa, past the vocal cords. This ensures that laryngospasms do not occur during the procedure by blunting the afferent limb of the reflex arc. The surgeon and anesthesiologist must take great care in redosing the topical lidocaine either at regular intervals for longer procedures, or as the patient starts to exhibit the return of laryngeal sensitivity to surgical manipulation. Less commonly, especially for shorter procedures, the airway can be anesthetized directly through the use of nerve blocks. For a complete review of anatomy and techniques, please refer to additional readings from Benumof [41].

Dexamethasone (0.5 mg/kg up to 10 mg IV) given at the outset of the procedure is the steroid of choice to combat airway swelling. On initial stimulation and/or instrumentation, it is important to closely observe the child for any movement or response and respond appropriately by removing equipment until an adequate depth of anesthesia is obtained to proceed. Some instrumentation such as vocal cord spreaders may be especially stimulating, and introduction or removal of these instruments may induce laryngospasm. Communication with the anesthesiologist regarding these maneuvers is helpful in efforts to anticipate potential treatment necessary.

Potential complications include laryngospasm, bronchospasm, airway trauma, cardiac dysrhythmia caused by enhanced vagal tone, cardiac events caused by occult or concurrent structural cardiac disease, or aspiration of pulmonary contents [16]. Maneuvers to decrease events include careful preoperative planning, team communication, and anticipation of potential complications for appropriate prompt intervention. A video monitor, now commonly used as part of endoscopic airway surgery, allows simultaneous visualization for both the anesthesiologist and surgeon for both understanding the modifications of the airway at hand and allowing early detection in changes in the depth of anesthesia.

Periods of apnea resulting in desaturation are typically managed either by removing the suspension and laryngoscope and offering positive pressure ventilation via facemask or intubating through the laryngoscope with an endotracheal tube. The latter avoids the time required to re-establish optimal surgical exposure. Laryngospasm may occur with or without desaturation and can be managed with positive pressure ventilation or administering a small dose of propofol or paralytic to break the spasm.

Barotrauma from jet ventilation is important to suspect and recognize early. If any concern exists, a chest X-ray is warranted. A large or tension pneumothorax is a clinical diagnosis and may present with decreased chest motion, diminished breath sounds, and hyperresonant percussion progressing to tachycardia, hypotension, and hypoxia. This requires urgent needle decompression followed by chest tube placement.

Laser Use in Endoscopic Surgery

Laser use in endoscopic airway surgery requires additional safety considerations. Airway fire is always a risk with the use of a laser. For a fire to be created, three elements are necessary: a source (drapes, endotracheal tube, etc.), oxygen (from anesthesia), and a source of heat (laser, cautery). Laser safe endotracheal tubes may be used if the patient is intubated; however, they are not available in all pediatric sizes. The provider must be cautious in using the “standard” internal diameter (ID) sizes, as the laser safety precautions of the tube create a significantly larger outer diameter (OD), resulting in an inappropriately sized endotracheal tube. For example, a typical uncuffed 3.5 ETT has a 4.9 mm OD, while a laser-safe uncuffed 3.5 ETT from the same company has a 5.7 mm OD. Exact OD sizes may vary between different producers. Metal tracheostomy tubes may be used for patients that have a tracheostomy in place for laser-safe ventilation. As discussed above, other anesthetic delivery options are available as an alternative to endotracheal intubation.

Laser plume is an important and potentially more commonly overlooked consideration. A suction catheter may be inserted into the nose or mouth or directly connected to a laryngoscope to suction laser plume. Protective masks to filter particulate material as well as viral particles present in vaporized tissue are advised for operating room personnel.

Lastly, eye protection is also crucial for both the patient and OR personnel. Laser beams can be focused onto the retina via the lens causing a small but intense area of damage [12].

Prior to use of a laser in the airway, a laser safety timeout should be performed to ensure the following: (1) All operating room personnel are wearing appropriate laser-specific eye protection. (2) The patient's eyes are covered with saline-soaked gauze, and moist towels are used to protect the skin of the face, neck, and upper chest. (3) All OR windows are covered, and entrances are marked to notify that laser use is in progress with glasses available to incoming personnel. (4) No flammable anesthetic gas is being used. (5) The oxygen concentration should be <30%.

Endoscopic Airway Procedures

There are many endoscopic surgical options currently available to treat a multitude of pathologies as mentioned above. The treatment is typically determined by the underlying pathology, patient-specific factors, and physician preference. In general, endoscopic techniques offer many advantages: fewer complications, shorter hospital stays, faster recovery, lower costs, and less need for pain management and scar revision. A few of these surgical cases with their specific anesthetic management considerations are highlighted below.

Balloon Dilation

Balloon dilation is increasingly common for the treatment of subglottic stenosis due to its safe and efficacious nature. It typically requires repeat procedures, therefore knowing the last procedure's pre- and post-dilation airway size as well as balloon size used is helpful in anticipating the degree of stenosis for future procedures. It may also be used as a postoperative adjunct to open airway reconstruction to optimize surgical results. Anesthesia for balloon dilation of subglottic, laryngeal, or tracheal stenosis follows similar guidelines as for endoscopy with the major difference being that the airway will be completely occluded during the dilation for a period of time. The senior author typically uses 2 min or desaturation to 92% as an endpoint. Every effort must be made to optimize preoxygenation as well as increasing anesthetic depth prior to the dilation [42]. This is usually accomplished by hyperventilating the patient and administering an anesthetic bolus before the dilation. Balloon dilation may be coupled with topical mitomycin C application or intralesional steroid injection. One rare complication, when used in higher concentrations, of topical mitomycin C application includes excess fibrin formation resulting in acute dyspnea 24–48 h after the procedure. Knowledge of this complications and its treatment of prompt endoscopic removal is an important consideration.

Papillomas

Laryngeal papillomatosis is usually caused by HPV types 6 and 11. It has a bimodal distribution with peaks at ages 2–5 and then again between 20 and 30 years of age [43–45]. Patients will present with some degree of airway obstruction, especially during the first surgery. Goals during the procedure should be to maintain airway patency and adequate ventilation, optimize surgical exposure, and minimize any further seeding. Anesthetics should focus on the degree of obstruction and the patient's ability to follow directions. For minor debulking, often a natural airway and TIVA will be sufficient. Often, intermittent apnea followed by intubation may be necessary depending on the level of obstruction, or conversely intubation with a

laser safe tube and spontaneous ventilation may be an alternative [44]. Given the concern for a reduced airway, it is useful to have a selection of endotracheal tubes in sizes smaller than would be expected based on standard parameters. Jet ventilation has been used for these procedures, but it may be avoided by some practitioners as described above for concerns of seeding the virus further into the tracheobronchial tree. These patients may have had a tracheostomy, in which case inserting a cuffed endotracheal or tracheotomy tube allows for oxygenation and ventilation. Induction of anesthesia should be mindful for the risk of transitioning from a partial airway obstruction to losing the ability to ventilate the patient. Thus maintaining spontaneous respiratory drive and preparation for emergent intubation or surgical airway is paramount [43]. These patients should be monitored closely during emergence as the presence of residual bleeding and secretions puts them at high risk for laryngospasm.

Laryngeal Cleft Repair

Laryngeal clefts are a congenital anomaly characterized by a fissure between the airway and the esophagus. They are divided into four types based on the depth or length of the cleft. Most type 1 and 2 and selective type 3 cleft can undergo endoscopic repair [46–47]. Laryngeal cleft repair success is similarly hinged on surgical exposure and the lack of endotracheal intubation [47]. Avoiding endotracheal intubation also allows for easier surgical instrumentation as well as spares any endotracheal tube related suture line damage or dehiscence. Maintenance of general anesthesia is best achieved through the use of a TIVA while maintaining spontaneous ventilation. The anesthetic should be titrated to obtund airway reflexes and minimize the response to surgical stimulus. Severe type 3 and 4 clefts may present a management dilemma, with little distal posterior tracheal wall to allow separation from the esophagus, making ventilation difficult during repair. Cardiopulmonary bypass with an open approach may be necessary for these more severe laryngotracheoesophageal clefts.

Postoperative Considerations

After surgery, most children remain spontaneously breathing; however, an endotracheal tube is occasionally required during emergence. Pain management may be accomplished with topical anesthetic and low-dose morphine (0.05–0.1 mg/kg IV) [16] or hydromorphone (3–5 mcg/kg IV). Other options may include ketorolac (0.5 mg/kg) if bleeding is not a concern with the surgeon or acetaminophen in either an oral, rectal, or intravenous formulation (10–15 mg/kg).

Postoperative stridor may be seen following endoscopic airway procedures. Management may include expectant observation with full monitoring, oxygen by facemask, and elevating the head of bed (e.g. 45–90°), or placing a shoulder roll. Persistent or worsening stridor requires prompt evaluation. Airway edema, hemorrhage, aspiration, or reflux should be considered and treated appropriately. Medical treatments may include nebulized racemic epinephrine or administration of IV steroids such as dexamethasone. Helium-oxygen therapy may also be helpful in the setting of airway obstruction. Continuous positive airway pressure ventilation or endotracheal intubation should be performed if necessary.

It is crucial that the postoperative recovery from anesthesia is not neglected as the anesthetic does not end with surgery [24]. Recovery staff should be knowledgeable in recognizing complications that may arise as the patients wake up from endoscopic airway surgery. Particularly in patients with a previously obstructed airway, providers should be knowledgeable regarding post-obstructive negative pressure pulmonary edema. Communication with the recovery room, intensive care unit, or floor should include ease of mask ventilation, laryngoscopic view on initial intubation, recommendations for how to replace a secured airway if necessary and appropriate size, intraoperative response to medications, and

intraoperative challenges including desaturation, dysrhythmias, high peak inspiratory pressures, and peripheral venous access [16].

Pearls for Success

- *Good communication between the anesthesiologist, operating surgeon, and nursing staff is imperative to provide quality care during and after endoscopic airway surgery.*
- *Creating an airway plan prior to surgery and involving all team members ensure appropriate anesthesia and surgical equipment, and team members will be ready to execute plan.*
- *Airway surgery, including induction of anesthesia, should not proceed until all involved are satisfied that everything is ready.*

Conclusion

Pediatric endoscopic airway surgery is common, and indications will likely grow with technology and instrumentation advances in the future. Quality maintenance of anesthesia is crucial for a successful endoscopic airway intervention. Due to the multitude of pathologies and associated surgical interventions, the diversity of the patients, and the variety of anesthetic techniques available, gaining a familiarity with several different techniques described in this chapter will be advantageous to providing the best care for this patient population.

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9 Anesthesia Maintenance During Open Airway Reconstruction

Bobby Das and Catherine K. Hart

Introduction

Successful open airway surgery requires not only good surgical technique but also well-executed anesthetic technique. Anesthesia for open airway surgery is challenging and requires consideration of numerous patient-specific and procedure-specific factors. In all open airway surgery, the airway must be jointly managed by the surgeon and the anesthetist, which requires close communication and collaboration between the two. In this chapter, we will discuss preoperative, intraoperative, and postoperative considerations for sedation, pain control, and airway management.

Preoperative Considerations

During the preoperative period, respiratory status, prior airway management history, and advanced airway assessment should be emphasized to assess fitness for surgery and to formulate an anesthetic and airway management plan [1, 2]. Lung sounds should be auscultated, and a baseline oxygen saturation (SpO2) is necessary to assess adequate ventilation and oxygenation. The respiratory baseline should be documented prior to surgery noting any signs of respiratory distress like nasal flaring, retractions, wheezing, stridor, or tachypnea. Especially during the winter, it is crucial to check for signs of upper or lower respiratory infection, fever, or signs of reactive airway disease, which should be optimized prior to surgery. The preoperative airway assessment should include the Mallampati score, mouth opening, thyromental distance, the presence of micrognathia, range of motion of the neck, dental abnormalities, signs of airway obstruction, tongue size, and facial malformations.

Review of prior anesthetics can give valuable insight into managing the airway. If available, the previous records should be assessed for difficulty to mask ventilate, the need for an oral airway, whether a stylet in the endotracheal tube was required to successfully intubate, size and type of endotracheal tube used, oral versus nasal intubation, number of attempts at direct laryngoscopy required, level of experience of laryngoscopist, and whether advanced airway equipment is needed (glidescope, fiberoptic, or rigid bronchoscopy). Prior issues or complications can indicate the need for advanced airway management and the need for additional anes-

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thesia staff and/or the need for otolaryngology staff to assist with rigid bronchoscopy. Equipment should be prepared prior to start of the case and an intensive care unit (ICU) bed with ventilator reserved if needed.

Patients undergoing open airway surgery often have a preexisting tracheostomy. Prior to the case, it is important to assess the status of the tracheostomy. It is important to identify changes from baseline, specifically whether there are increased or thickened secretions, increased oxygen requirement, or increased ventilator requirements for ventilator-dependent patients. Baseline ventilator settings should be noted. Spare tracheostomy tubes of the same size and one size smaller should be on hand in case of mucous plugging.

Prior to the beginning of the case, it is essential that the surgeon and anesthetist discuss the plan for airway management. This discussion should include the specific plans for establishing the airway during induction and maintaining the airway during the procedure, as well as the plan for postoperative airway management, keeping in mind that one of the primary anesthetic goals is to maintain airway patency while maximizing surgical exposure during the procedure.

Intraoperative Considerations

When possible, a peripheral intravenous (IV) line should be placed prior to surgery to allow for an expedient, safe, and controlled induction. If the patient has a tracheostomy, induction can be done by connecting the anesthesia ventilator directly to the tracheostomy and using an inhaled anesthetic agent. An inhalation induction allows the patient go to sleep while breathing spontaneously [1–3]. It is important to note that the speed of induction will be inversely proportional to the size of the leak present at the level of the larynx. If there is a large leak around the tracheostomy tube, an inhalation induction may take longer and it occluding the mouth and nose may speed induction. If a tracheostomy is not present, a mask induction using an inhaled agent allows for maintenance of spontaneous respiration. If an inhalation induction is not possible, a mixed IV induction using propofol and a short-acting opiate like fentanyl can be used. In nearly all cases, the use of a paralytic during induction should be avoided in order to maintain spontaneous respiration. Anesthetizing the vocal cords with 1% or 4% topical lidocaine at a dose of 3–5 mg/kg facilitates intubation without the use of paralytics. If needed, a short-acting depolarizing muscle relaxant like succinylcholine can be used, although this is not optimal. Alternately, a bolus of remifentanil can be used in lieu of paralytics. Once the airway is secure, the ventilator should be set to pressure support to propagate spontaneous respiration if possible. If the ventilator does not have this setting, manual bag ventilation can be used until the patient is breathing adequately on his or her own. If a tracheostomy is present, a cuffed, reinforced endotracheal tube (either the same size or a half size smaller than the tracheostomy tube) can be placed through the tracheal stoma with the cuff inflated as needed to minimize the leak within the circuit and maximize ventilation. Care should be taken to avoid having the end of the endotracheal tube abutting the tracheal wall as this can result in partial obstruction and impede ventilation. Care must also be taken to avoid positioning of the tube into either of the mainstem bronchi. The surgeon or anesthesiologist then sutures the endotracheal tube to the anterior chest wall.

For maintenance of anesthesia, a total intravenous anesthesia technique (TIVA) has several advantages [1]. Since the surgeon will likely be intermittently removing and replacing the endotracheal tube in the airway, and thus disrupting airflow and any anesthetic gases used, the patient may enter a lighter plane of anesthesia if only inhalation agents are being used. This can disrupt the surgery and potentially compromise the airway due to bucking of the patient, laryngospasm, or bronchospasm. A TIVA technique using propofol combined with remifentanil infusion allows for delivery of anesthetic during removal or disruption of the airway while still allowing spontaneous respiration. An additional benefit of the TIVA technique is that it avoids the complica-

tions associated with inhaled anesthetic agents in patients with muscular dystrophy or malignant hyperthermia.

Open airway surgery cases usually do not require central venous or arterial access. Two peripheral IVs should be sufficient along with standard ASA monitors. Many of these patients have had multiple previous procedures and blood draws and can, therefore, present a challenge for obtaining adequate intravenous access. Using ultrasound can greatly increase speed and success of IV placement in such patients. Consideration should be given to placement of a peripherally inserted central catheter in patients with a history of difficult IV access or in patients who may require a prolonged period of postoperative sedation.

Maintaining adequate oxygenation and ventilation is essential during open airway surgery. After induction, the patient is placed on the operating table in the supine position with a shoulder roll and the head extended. As mentioned above, if a tracheostomy is present, a cuffed endotracheal tube is placed through the stoma and secured to the anterior chest wall. If the patient does not have a tracheostomy, the airway is secured orally via endotracheal intubation. Once the trachea is opened, the oral endotracheal tube is withdrawn and the distal trachea is intubated from the surgical field. In order for the surgeon to have adequate access to the trachea, the endotracheal tube must be intermittently removed [2, 3]. Each time the endotracheal tube is replaced, it is necessary to verify adequate ventilation. This portion of the surgical procedure requires very close communication between the surgeon and the anesthetist [1, 3, 4]. While the trachea is open, there is often a large leak in the anesthetic circuit. To maintain adequate oxygenation during this time, it is often necessary to administer 100% oxygen. It is also sometimes necessary to rely on hand ventilation during this portion of the procedure. It is important to note that if high levels of inspired oxygen are being used, care must be taken to avoid the use of electrocautery as this can lead to an airway fire. The importance of communication between the anesthesia and surgical teams during this portion of the procedure cannot be overstated.

Open airway surgery can be performed using a double-stage or single-stage approach. In double-stage approach, a tracheostomy tube is replaced through the stoma at the conclusion of the procedure. In many double-stage procedures, a suprastomal stent is left in the airway to support the reconstructed area, which obstructs the airway proximal to the tracheostomy tube rendering such patients entirely tracheostomy tube dependent for ventilation. While a suprastomal stent is in place, a patient cannot be intubated or mask-ventilated via the upper airway. The majority of patients who undergo a double-stage procedure will be awakened from anesthesia in the operating room and then transferred to the recovery room postoperatively. In a single-stage approach, there is no tracheostomy in place at the end of the procedure regardless of whether a tracheostomy was present at the beginning of the procedure [5, 6]. In most cases, the patient is nasotracheally intubated prior to completing the airway surgery. This nasotracheal tube is left in place at the conclusion of the procedure and will remain in place for anywhere from a few hours to 14 days postoperatively [5, 6]. Following open airway surgery, nasotracheal intubation is generally preferred over orotracheal intubation. This preference is guided primarily by expert opinion as there is no evidence in the literature comparing the differences between the two approaches. However, it is intuitive that having the endotracheal tube passing through the nasopharynx down into the airway is more comfortable than having the tube passing through the mouth and oropharynx into the airway. This theoretically reduces the amount of sedation necessary to tolerate the endotracheal tube. Additionally, it is felt that a nasotracheal intubation keeps the tube more secure and minimizes the movement of the tube at the level of the larynx. This theoretically decreases the amount of mechanical trauma at the level of the larynx and at the site of repair in the airway and decreases the risk of disturbance of the graft and/or anastomosis as well as minimizing the formation of granulation tissue.

Postoperative Considerations

In patients who remain intubated following surgery, maintaining adequate analgesia and sedation is necessary to ensure a smooth transfer from the operating room to the ICU at the conclusion of the procedure [1]. This is best accomplished with a propofol or dexmedetomidine infusion. Once in the ICU, one of the primary treatment goals is to maintain adequate analgesia and sedation to both minimize the risk of accidental extubation as well as movement of the endotracheal tube while avoiding excessive sedation [6]. Excessive movement of the tube can traumatize the fresh anastomosis and/or grafts and irritate the airway mucosa leading to granulation tissue formation. Excessive sedation, including the use of paralytics, can increase patient morbidity by increasing the risk of withdrawal, atelectasis, neuromuscular weakness, and exacerbation of underlying pulmonary disease.

There is a high degree of variability in postoperative sedation routines with little standardization either within or across institutions although it is generally accepted optimal outcomes are achieved when sedation is administered at the lowest amount tolerated to keep a patient quiet and comfortable [7]. Generally, this is accomplished using an opiate infusion, most commonly fentanyl or morphine, in combination with a midazolam infusion. Alternately, infusions of ketamine, dexmedetomidine, or a combination of both can be used separately or adjunctively to maintain adequate sedation. Paralytics are used only as a last resort in cases in which the child cannot be kept adequately sedated. In some patients, use of a paralytics or excessive sedation may necessitate use of vasoactive agents to maintain adequate blood pressure. Many patients, particularly those over the age of 3 years, can be allowed to wake up and in some instances come off the ventilator despite being intubated. [5] These patients are managed with intermittent doses of a sedative with adequate pain control.

Once the patient is nearing the time of extubation, sedation should be weaned to maximize spontaneous ventilation and adequate minute ventilation and to optimize the conditions for extubation [8]. The patient should also be transitioned from mandatory pressure or volume-controlled ventilation to pressure support ventilation and finally unsupported spontaneous respiration as tolerated. Paralytic infusion should be off, and remifentanil or propofol can be used temporarily in lieu of paralytic infusions while optimizing the patient for extubation. If the patient has a difficult airway, the anesthesia and/or otolaryngology team should be present for extubation in the ICU. Once extubated, a pain consult maybe useful to oversee postoperative pain management. An opiate-based patient-controlled analgesia (PCA) can be used with a demand dose if age appropriate with or without a continuous infusion. Pulmonary toilet, early ambulation, and proper nutrition will decrease recovery time and likely help with postoperative pain. Once PCA usage is low enough, the patient can be transitioned to intermittent IV opiates every 3 h as needed and then oral opiates like oxycodone. Patients who have required extensive sedation may require a prolonged wean of sedatives and opioids.

Conclusions

Anesthesia for open airway surgery is challenging. Awareness of the unique anesthetic considerations, careful planning, and clear communication between the surgical and anesthesia teams are essential to provide safe and effective anesthesia for open airway cases.

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10 Optimal Sedation Protocol After Single-Stage Open Airway Reconstruction

Hoyon Lee and Sophie R. Pestieau

Content

Acquired laryngotracheal stenosis is defined as a narrowing of the airway most often caused by repeated intubation, prolonged intubation, or intubation with a large endotracheal tube. Pressure necrosis from the endotracheal tube causes mucosal edema and ulcers, which causes granulation tissue formation. The overall incidence of post-intubation laryngotracheal stenosis in neonates is about 1% [1].

Other causes of laryngotracheal stenosis include airway trauma, previous airway surgery including high tracheostomy or cricothyroidotomy, burns, infection, chronic inflammation, and tumors. Intubation with an appropriately sized endotracheal tube with a leak at 20 cm H_2O decreases the risk of stenosis.

The Myer-Cotton grades of laryngotracheal stenosis are the most commonly used tool to measure the severity of stenosis and predict clinical outcomes [2]. The degree of narrowing is calculated by comparing the diameters of the endotracheal tube that can be inserted with a leak between 10 and 25 cm H_2O to the age-appropriate endotracheal tube. Grade I ranges from no obstruction to 50% narrowing, grade II ranges from 51% to 70%, and grade III ranges from 71% to 99%. Grade IV is an airway with complete stenosis without any lumen [2].

Options for management of laryngotracheal stenosis range from conservative medical treatment, endoscopic surgery with lasers or dilation, anterior cricoid split, laryngotracheal reconstruction, partial cricotracheal resection, slide tracheoplasty, and tracheostomy. Of these options, laryngotracheal reconstruction with cartilage grafts is the workhorse for management of subglottic stenosis, especially when there is posterior glottic involvement [1]. Multistage laryngotracheal reconstruction was first introduced in 1970s and still performed today for grades III or IV stenosis, multilevel stenosis, or decreased pulmonary reserve. After opening the stenosis, costal cartilage is grafted, and an intraluminal stent may be inserted to stabilize the newly reconstructed airway to allow for epithelialization and healing. The tracheostomy remains in place postoperatively, and decannulation occurs several months postoperatively. Potential complications of long-term tracheostomy in the pediatric population include unintentional decannulation, infection, hemorrhage, obstruction, granulation tissue, failure to decannulate, and post-cannulation respiratory failure. In addition to the risks of tracheostomy, long-term airway stenting also carries the risk of infection, granulation tissue, stent migration, and dysphagia [1, 3, 4].

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In the 1980s, the first single-stage laryngotracheal reconstruction was first performed. The overall surgical technique is similar to that of multistage reconstruction, except for stenting and postoperative airway management. In patients with pre-existing in situ tracheostomy, decannulation and closure are done in the same procedure. In patients without an in situ tracheostomy tube, cannulation is avoided altogether. The nasotracheal tube remains in place postoperatively and acts as a temporary stent for the newly reconstructed airway to heal. Single-stage reconstruction is usually optimal for patients requiring an anterior graft, but single-stage reconstruction has been done in patients requiring posterior grafts. Despite the advantages of lower duration of stenting and decreased dependence on tracheostomy, single-stage reconstruction carries the risk of unintended extubation and post-extubation respiratory failure. Reintubation of the newly reconstructed trachea could cause damage to the cartilage graft and require tracheostomy. *Because of the risk of difficult reintubation, single-stage reconstruction is relatively contraindicated in patients with craniofacial or vertebral defects, neurologic defects, and chronic lung disease* [1, 3].

Postoperative management of patients after single-stage laryngotracheal reconstruction is complex due to prolonged intubation, risk of airway compromise, and sedation requirements. Other potential postoperative complications include atelectasis, pneumonia, anastomotic leaks, withdrawal from sedation, and neuromuscular weakness. The length of intubation, rate of reintubation, and rate of tracheostomy vary widely by center. In 1 retrospective study of 190 patients who underwent single-stage reconstruction, the mean length of intubation was 3.4 days, 29% required reintubation, 52% of those who required reintubation required tracheostomy (overall 15% of the total cohort), and an overall decannulation rate of 96% at 1 year follow-up [3]. Reasons for reintubation included granulation tissue or airway edema, recurrent laryngotracheal stenosis, secretions, prolapsed graft, self-extubation, poor pulmonary reserve, and anxiety [3].

Strategies for sedation vary by institution and can vary from complete immobilization to minimal to no sedation. Arguments against postoperative sedation include increased length of stay in the pediatric intensive care unit (PICU), increased length of hospitalization, risk of withdrawal from benzodiazepines and opioids, and pulmonary complications. In a study analyzing 34 patients who underwent single-stage laryngotracheal reconstruction, there were no significant differences in accidental decannulation between the sedation and paralysis, sedation only, and awake groups [5]. Both the sedation and paralysis group and the sedated group had significantly higher rates of withdrawal ($p < 0.0001$) with number of days sedated as the most significant predictor for withdrawal ($p = 0.003$). The duration of stay in both the PICU and the hospital were significantly prolonged in both sedated and paralyzed patients as well as sedated patients when compared to the awake patients, with days sedated as the only significant predictor of prolonged stay in the PICU. 73.7% of sedated patients had pulmonary complications compared to 26.7% of awake patients ($p = 0.008$). Though these results favor keeping patients awake in the ICU postoperatively, an important factor to consider is the age of the patients and their ability to follow instructions. In this study, the mean age of the sedated group was 16 months vs. 39 months in the awake group [5].

In another retrospective study of 133 patients who underwent tracheal surgery, 54 patients who were intubated but awake and unrestrained were compared with 79 intubated, sedated, and restrained patients [6]. Rates of atelectasis, pneumonia, post-extubation stridor, withdrawal, and unintended extubation were compared. The group with awake patients had significantly lower rates of atelectasis ($p < 0.001$), post-extubation stridor ($p < 0.001$), and withdrawal ($p < 0.001$) compared to the sedated group. There were no significant differences in the incidence of pneumonia, aspiration, or unplanned extubation between the two groups. Similarly to the study by Powers et al., age and size of patients were a confounding factor in the significant differences between the two groups with a mean age of 113 months in the awake group of vs. 33 months in the sedated

group [6]. Results from these two studies indicate that older children who are able to follow instructions and communicate may tolerate the endotracheal tube without sedation and restraints without an increased risk of unintended extubation [6]. For younger patients who are unable to follow instructions or patients who are at risk for post-extubation respiratory failure, sedation is critical for patient safety. Commonly used agents for sedation include benzodiazepines, opioids, α2 agonists, and N-Methyl-D-aspartate (NMDA) antagonists. Neuromuscular blockade is sometimes added for patients with complex sedation regimens and to facilitate mechanical ventilation.

The most frequently used sedatives in the PICU are benzodiazepines such as midazolam and lorazepam [7]. Benzodiazepines bind to the α subunit of the GABA receptor to produce amnesia and anxiolysis. Midazolam has a faster onset and shorter duration of action than lorazepam. A standard bolus dose of 0.05–0.1 mg/kg IV has an onset of action of 1–2 min, peak effect at 5 min, and an elimination half-life of 2 h. As an infusion, doses can be started at 0.05 mg/kg/h and titrated up to 1 mg/kg/h as needed. Midazolam undergoes hepatic metabolism through the cytochrome P450 CYP3A enzyme to an active metabolite and renal excretion. In infants with immature cytochrome P450 enzymes, duration of action may be prolonged. Adverse effects include hypoventilation, hypotension, prolonged context-sensitive half-life, tolerance, and withdrawal [7].

Lorazepam is an intermediate-acting benzodiazepine with slower onset and longer duration of action than midazolam [7]. Bolus doses range from 0.025 to 0.05 mg/kg, while infusion doses range from 0.025 to 0.05 mg/kg/h. Lorazepam's metabolites are inactive, but its context-sensitive half-life and emergence course are significantly prolonged compared to midazolam. In addition to hypoventilation and hypotension, other adverse effects include delirium, propylene glycol toxicity, tolerance, and withdrawal. Propylene glycol is an additive to increase drug solubility. Because propylene glycol is metabolized to lactate and pyruvate, long-term use of lorazepam can lead to metabolic acidosis, hyperosmolarity, cellular toxicity, and acute tubular necrosis. Serum osmol gap higher than 10–15 may be a sign of propylene glycol toxicity. Most cases can be treated by discontinuing lorazepam, but in emergent cases, dialysis may be used to clear propylene glycol [7].

Diazepam is a long-acting benzodiazepine that is rarely used for sedation in the PICU due to its prolonged half-life [8]. Bolus doses range from 0.05 to 0.1 mg/kg. Diazepam is hepatically metabolized to active metabolites that account for its long duration of action. Like lorazepam, diazepam also has propylene glycol as an additive. Prolonged use increases the risk of propylene glycol toxicity and thrombophlebitis [8].

Propofol is another sedative that acts on the GABA receptors for amnesia and anxiolysis. For non-procedural sedation, bolus doses range from 0.5 to 2 mg/kg, and infusion doses range from 20 to 70 mcg/kg/min, however for procedural sedation and anesthesia infusions can range from 50 to 300 mcg/kg/min [7, 9, 10]. Advantages of propofol include short onset of action of 15–30 s, ease of titration, and short recovery. Adverse effects include hypotension from decreased systemic vascular resistance and direct myocardial depression. Propofol infusion syndrome (PRIS) is a rare but lethal metabolic disruption of mitochondrial fatty acid oxidation. Currently propofol is not FDA approved for sedation in critically ill pediatric patients due to an increased risk of PRIS. Risk factors for developing PRIS include prolonged use greater than 48 h and infusion rates greater than 4 mg/kg/h. PRIS usually presents as hyperlipidemia, metabolic acidosis, rhabdomyolysis, hyperkalemia, arrhythmias, and cardiac failure.

Dexmedetomidine is a α2 agonist that acts as both a sedative and analgesic by inhibition of noradrenergic activity [11]. Advantages of dexmedetomidine include natural sleeplike sedation without respiratory depression and a decrease in opioid requirement due to its analgesic properties. Loading dose of dexmedetomidine is usually 1 mcg/kg, while infusion doses range from 0.2 to 1.5 mcg/kg/h. Distribution half-life is 5–6 min while terminal half-life is about 2 h. Adverse effects include bradycardia, hypotension, and withdrawal. Dexmedetomidine is not currently

approved by the FDA for use in children, but there have been many reports of its utility in sedation for critically ill children especially when tachyphylaxis to benzodiazepines and opioid infusions develops.

In the setting of postoperative laryngotracheal reconstruction sedation, the evidence for the use of dexmedetomidine is mixed. One retrospective study of 24 patients who underwent laryngotracheal reconstruction or laryngeal cleft repair revealed fewer respiratory interventions and decreased requirements for other sedatives when dexmedetomidine was used for less than 7 days [11]. However in a more recent study of 50 postoperative single-stage laryngotracheal reconstruction patients comparing those who received dexmedetomidine as the primary sedative versus another sedative regimen, there were no differences found between the 2 groups in length of hospitalization or complications [12]. More interestingly, this study found that dexmedetomidine did not decrease requirements for additional sedatives.

Among opioids, the most commonly used for sedation in critically ill children include fentanyl, morphine, and methadone. Opioids provide analgesia via μ receptors but are not useful for anxiolysis or amnesia. Like benzodiazepines, there is a risk of tachyphylaxis and withdrawal with prolonged use. Fentanyl is a lipid-soluble opioid that has a fast onset of action of 5–6 min. Bolus doses range from 0.5 to 2 mcg/kg and infusion doses range from 0.5 to 2 mcg/kg/h [7]. Duration of action of single boluses are short, but repeat doses or infusions may result in prolonged duration of action due to redistribution to peripheral compartments resulting in a longer context-sensitive half-life. Fentanyl does not cause histamine release or hypotension, but it can cause bradycardia. In addition, large bolus doses may cause chest wall rigidity resulting in difficulty ventilating [7].

Morphine is a hydrophilic opioid with a slower onset of action with peak effect approximately 20 min after administration [7]. Bolus doses range from 0.05 to 0.1 mg/kg and infusion doses range from 0.05 to 0.1 mg/kg/h. Morphine is hepatically metabolized to morphine-3-glucuronide and an active metabolite morphine-6-glucuronide. Because morphine-6-glucuronide is renally excreted, patients with chronic kidney disease or renal failure are at risk of respiratory depression after morphine administration. Due to stimulation of histamine release, morphine can cause vasodilation, hypotension, pruritis, and nausea.

Methadone is a lipophilic opioid that antagonizes both μ and NMDA receptors for analgesia [7]. It is equipotent to morphine with a slower onset of action and longer half-life of approximately 19 h. Due to its long half-life, it is given with longer interval dosing with typical loading doses of 0.1–0.2 mg/kg and can be given intravenously, orally, or through a feeding tube due to high bioavailability. Methadone undergoes hepatic metabolism through cytochrome P450 CYP3A4 so caution must be taken when used in neonates and concurrent use of other drugs undergoing the same metabolism. Adverse effects include respiratory depression and QTc prolongation [7]. In addition to analgesia, methadone has been useful for weaning children from opioid infusions though there is a wide range of doses and protocols between institutions. In a systematic review of 12 studies examining methadone use for opioid weaning, initial doses were found to be 0.15–1.8 mg/kg/day with the most common taper strategy of 10 days [13]. Overall, a methadone protocol was associated with a decrease in the number of patients with withdrawal [13].

Ketamine is an NMDA antagonist and produces analgesia and a state of dissociation without respiratory depression [7]. It is often used in conjunction with opioids to decrease the risk of tolerance due to its opioid-sparing analgesic effects. Through its sympathomimetic effects, it often causes tachycardia, hypertension, and bronchodilation. Bolus doses range from 0.5 to 2 mg/kg, while low-dose infusion doses range from 0.1 to 0.2 mg/kg/h. Patients are at significant risk of hallucinations with ketamine use, which may be prevented by pre-treatment with benzodiazepines. The increase in oral secretions can be treated with an anticholinergic such as glycopyrrolate [7].

Neuromuscular blockade can be used in conjunction with sedatives to prevent movement and facilitate mechanical ventilation in patients with

inadequate sedation or analgesia. In postoperative laryngotracheal reconstruction patients, movement of the endotracheal tube may result in inadvertent extubation or disruption of fragile surgical anastomoses which could have devastating consequences. When using neuromuscular blockade agents, patients should be assessed with a train of four to ensure the lowest effective dose is given. Infusions should be titrated to a train-of-four response of one to two twitches. Intermittent paralysis has been shown to decrease the risk of atelectasis and length of intubation without an increase in self-extubation [14]. After long-term use of neuromuscular blockade agents, patients may have prolonged weakness even after the infusions are discontinued due to accumulation of metabolites and muscle atrophy. For long-term neuromuscular blockade in critically ill patients, nondepolarizers like rocuronium and vecuronium are the drugs of choice [7, 15].

Rocuronium is an intermediate acting nondepolarizer with a rapid onset of action [7]. Maximum neuromuscular blockade is often achieved in 2–3 min after an intubating dose of 0.6–1 mg/kg. Continuous infusions of rocuronium start at 10 mcg/kg/min and titrated to effect. Rocuronium is eliminated through hepatobiliary excretion and has duration of action of 20–35 min. Because there are no active metabolites, rocuronium is an ideal choice for infusions in the ICU.

Vecuronium is also an intermediate-acting nondepolarizer with an onset time of 3–5 min and duration of action of 20–35 min [7, 15]. Bolus doses of vecuronium range from 0.08 to 0.1 mg/kg, while infusion rates range from 0.8 to 1.2 mcg/kg/min. Vecuronium undergoes hepatic and renal excretion, and its active metabolite 3-desacetylvecuronium has 50–80% of the potency of vecuronium. Patients who have organ dysfunction and continuous infusions of vecuronium may have prolonged blockade if dose adjustments are not made.

Tolerance in the pediatric ICU leads to increasing medication requirements to produce the same sedative or analgesic effect. Tolerance usually occurs after patients receive greater than 72 h of sedation. Abrupt cessation of benzodiazepines and opioids could lead to withdrawal, especially in postoperative laryngotracheal reconstruction patients who may require prolonged intubation and sedation. Withdrawal from benzodiazepines and opioids presents as agitation, hallucinations, seizures, respiratory distress, tachycardia, and hypertension [13]. The risk of withdrawal is determined by the length of exposure to sedatives. The withdrawal assessment tool-1 (WAT-1) is used in many pediatric ICUs to assess a patient's risk of withdrawal. It uses 11 items on a 12-point scale including loose or watery stools, vomiting or retching, fever, mental state, tremors, sweating, uncoordinated or repetitive movements, yawning or sneezing, startle to touch, muscle tone, and time to return to calm state after stimulus [16]. A WAT-1 score >3 has 87% sensitivity and 88% specificity for predicting withdrawal. To decrease the risk of withdrawal, gradual weaning of benzodiazepines and opioids should be implemented, usually decreasing the daily dose by 10–20% [17]. A written standardized wean protocol of medications and dosages allows for a smoother transfer of care from the PICU to the floor, decreases length of sedation wean by nearly 50%, and decreases the number of patients who require a continuation of their sedation wean after discharge [18]. There are several agents that can be used in conjunction with opioid and/or benzodiazepine taper to decrease the risk of withdrawal. One study examined the efficacy of prophylactic transdermal clonidine in ten patients who received opioids and benzodiazepines after single-stage laryngotracheal reconstruction [19]. Transdermal patches were applied prior to discontinuation of infusions and extubation. There were no severe symptoms of withdrawal observed, and no more than two minor withdrawal symptoms of lethargy and tachypnea occurred in any patient. Another example protocol outlined in a study of 16 patients involved starting all postoperative laryngotracheal reconstruction patients on morphine and lorazepam infusions at 0.03 mg/kg/h with additional boluses if necessary [20]. In addition, dexmedetomidine infusion was started if morphine and lorazepam infusions needed up-titration and neuromuscular blockade was maintained with vecuronium

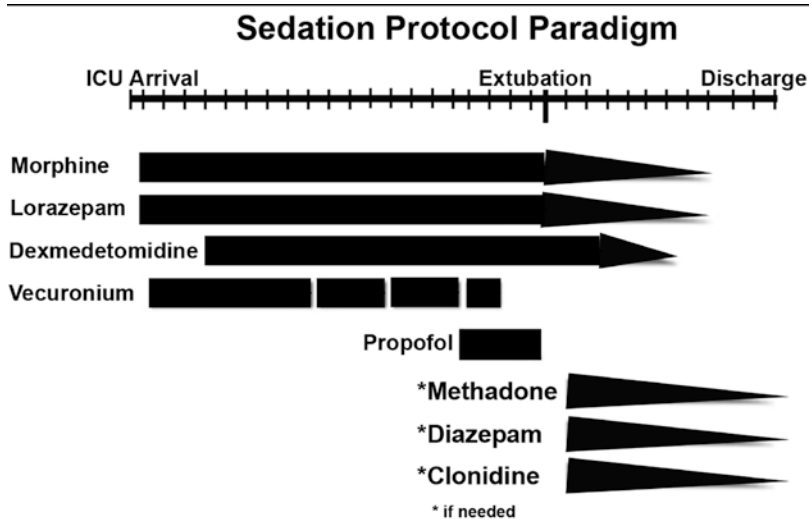

Fig. 10.1 Diagrammatic representation of the timeline for sedation agents used in this protocol. ICU, intensive care unit; OR, operating room. (Adapted from Fauman et al. [20])

at 0.1 mg/kg/h, titrated to train of four response of 1, and discontinued 4–6 h prior to extubation. After vecuronium was discontinued, the patient was temporarily maintained on a propofol infusion of 30 mcg/kg/min until residual neuromuscular blockade wore off and discontinued prior to extubation. Dexmedetomidine was continued after extubation for all patients. If patients were intubated for more than 5 days, a morphine and lorazepam wean was implemented with a 20% decrease daily. If additional agents were necessary for withdrawal, methadone, diazepam, or transdermal clonidine was added (Fig. 10.1) [20].

In summary, postoperative care for patients undergoing laryngotracheal reconstruction is complex due to prolonged intubation, difficult airway, and sedation requirements. There is no universally accepted protocol for postoperative sedation for these patients, but the options range from no sedation to pharmacologic sedation with or without neuromuscular blockade. Commonly used sedatives include benzodiazepines, dexmedetomidine, propofol, opioids, and ketamine. The risks and benefits of sedation must be weighed along with consideration for the individual patient. Prolonged use of sedatives increases the risk of tolerance and withdrawal. Slow weans with a written weaning protocol is recommended to decrease the risk of withdrawal and ensure smooth transition out of the PICU.

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11 Anesthetic Management in Emergent Pediatric Foreign Bodies

Suresh Thomas and Nikhil Patel

Introduction

Foreign body aspiration (FBA) is one of the most challenging and emergent situations in the pediatric population. It is a cause of significant morbidity and mortality. In the United States, FBA was responsible for about 4800 deaths in 2013, or about 1 death per 100,000 children 0–4 years [21].

As infants and children develop and grow, it is inevitable they will place things in their mouths, nose, or ears. Ingestion and/or aspiration of foreign bodies (FB) is relatively common in children between 1 and 3 years for many reasons: exploration of the environment through the mouth, lack of molars which decreases their ability to properly chew food, lack of cognitive capacity to distinguish between edible and inedible objects, and tendency for distraction and to perform other activities, like playing while eating [21].

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Most FBs are expelled spontaneously, but a significant percentage impacts the upper aerodigestive tract. Most studies show that fewer than 15% of foreign body aspirations occur among children older than 5 years of age. Boys comprise more than 50% of all cases of foreign body aspiration. By far, the objects aspirated most frequently are organic or food matter. In North America, peanuts are most common [24].

Approximately 80% of children's choking episodes are evaluated by pediatricians. The symptoms of aspiration or ingestion of FBs can mimic or simulate different pediatric diseases such as asthma, croup, or pneumonia, delaying the correct diagnosis.

Foreign body ingestion and subsequent retrieval is commonly encountered by the pediatric anesthesiologist. In this chapter, we will explain the types of foreign bodies ingested, location, and the urgency/emergency of removal and retrieval. Furthermore, we will describe, in detail, the most appropriate means of anesthetic induction and maintenance during these procedures. Additionally, we will describe outcomes for these routine procedures encountered by the pediatric anesthesiologist.

Presentation and Pathophysiology

Most children following ingestion and/or aspiration of foreign bodies (FB) present initially – acute phase – with choking, gagging, and

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paroxysms of coughing, leading to partial or potentially fatal complete obstruction of the airway, occurring at the time of aspiration or ingestion (witnessed first stage of impaction of FB). These signs may calm down – subacute phase – when the FB lodges and the reflexes grow weary but could present with noisy breathing, drooling, and difficulty with swallowing and poor feeding. Chronic or later phase complications occur depending on the type of FB and where it is located and when the obstruction, erosion, or infection cause pneumonia, atelectasis, abscess or fever (FB in AW), or dysphagia, mediastinum abscess, perforation, or erosion of the esophagus (FB in the esophagus). Occasionally the first symptoms to receive medical care may actually represent a complication of impaction of FB.

Any item coming across the hands of an infant or child has the potential to be ingested and/or aspirated. Commonly ingested/aspirated foreign bodies include coins, magnets, batteries, small toys, food particles, and caustic substances. Ingested batteries and sharp items are removed urgently due to damage that may occur internally to the GI tract, leading to erosion or perforation. Aspirated FB within the respiratory tract requires urgent removal and can become emergent should the patient deteriorate clinically, i.e., extreme cough, wheeze, dyspnea, cyanosis, or respiratory failure.

Ingested Foreign Bodies

Types and Presentation

FBs can be in the ears, nose, nasopharynx, oropharynx, glottis, trachea, bronchus, or esophagus. The esophagus is the most common site of foreign body impaction. Food impactions cause most esophageal foreign bodies. Large, smooth food pieces (steak, hot dogs) are particularly easy to swallow inadvertently before being chewed sufficiently. Bones, particularly fish bones, may be swallowed if the meat in which they are embedded is not chewed sufficiently. Bones were the commonest retrieved food FB encountered, while nuts seem to be the FB most frequently associated with complications [3].

Infants and toddlers do not have fully mature oropharyngeal coordination and often inadvertently swallow small, round foods like grapes, peanuts, and candies, which may become impacted. In addition, infants and toddlers often swallow a wide variety of inedible objects (like coins, batteries), some of which become impacted in the esophagus [30]. Impacted disk batteries are particularly worrisome because they may cause esophageal burns, perforation, or tracheoesophageal fistula.

Not all ingested FB require removal and/or retrieval. In fact, most ingested FBs in the pediatric population are passed through the GI tract with minimal or no damage. Foreign bodies in the esophagus usually lodge in areas where physiologic or pathologic luminal narrowing exists. The esophagus has three areas of narrowing where foreign bodies are most likely to become entrapped: the upper esophageal sphincter (UES), which consists of the cricopharyngeus muscle; the crossover of the aorta; and the lower esophageal sphincter (LES) [29]. Structural abnormalities of the esophagus, including strictures, webs, diverticula, and malignancies, increase the risk of foreign body entrapment, as do motor disturbances such as scleroderma, diffuse esophageal spasm, or achalasia [1, 30].

After reaching the stomach, a foreign body has greater than a 90% chance of passage. Coins reaching the stomach are very likely to pass into the small bowel. Objects larger than 2 cm in diameter are less likely to pass the pylorus, and objects longer than 6 cm may become entrapped at either the pylorus or the duodenal sweep. Objects reaching the small bowel occasionally are impeded by the ileocecal valve. Rarely, a foreign body may become entrapped in a Meckel diverticulum [13].

Swallowed magnets from toys and household items have become a serious health hazard in children. Bucky ball magnets are small round magnets in the shape of ball bearings that are especially strong and are used to make toys of various shapes. If these small magnets are ingested, they can adhere across layers of bowel

and lead to pressure necrosis, fistula, volvulus, perforation, infection, or obstruction [12]. If one magnet is ingested, the risk is lower, but because even single magnets have some risk, endoscopic removal should be considered if the magnet is accessible. If two or more magnets are ingested, there is a risk that the magnets may be in different loops of bowel and become attached via magnetic attraction. If there are more than one ingested magnets in the esophagus or stomach, emergent endoscopic removal is indicated to prevent passage into the intestines. If radiographs show the magnets are past the pylorus, they may be already adherent to each other, or in a worst case, separate, and become adherent across loops of bowel wall. In this case, necrosis, perforation, and peritonitis may occur.

In recent years, children have been increasingly exposed to electronic technology containing button batteries. Button battery ingestion continues to be a problem in the United States, with increasing frequency, most commonly in children with an average age of around 4 years [25]. These may be potentially inhaled or ingested. The presence of a button battery in the esophagus is a medical emergency because necrosis of the esophageal wall may occur within 2 h. Batteries consist of two metal plates joined by a plastic seal. Internally, they contain an electrolyte solution (usually concentrated sodium or potassium hydroxide) and a heavy metal, such as mercuric oxide, silver oxide, zinc, or lithium. If ingested, these batteries often lodge in the esophagus and cause injury by electrical current, electrolyte leakage, or pressure necrosis. If they break in the GI tract, they can cause heavy metal poisoning. These batteries range from 7 to 25 mm and are radiopaque. It is important to distinguish between a coin and a battery because button batteries must be expeditiously removed.

Management of Ingested Foreign Bodies

Management depends upon on the symptoms and progression [4, 13, 14]. Asymptomatic patients who have swallowed multiple magnets should be admitted and monitored closely with serial radiographs and physical examination every 4–6 h. Whole bowel irrigation is a consideration. Alternatively, magnets can be removed by enteroscopy or colonoscopy if accessible. Symptomatic patients or any patient with multiple magnets that do not progress on serial radiographs should have a surgical consult for possible operative removal of the magnets.

Button batteries lodged in the esophagus must be removed immediately. Removal options include endoscopy, Foley catheter removal, esophageal bougie, or Magill forceps removal.

Upon identification of FB ingestion, it is important to gauge if an intervention is necessary as well as the urgency of the procedure. Indications for urgent intervention include airway compromise, esophageal obstruction leading to drooling, disk battery or magnet ingestion, symptoms of peritonitis, or prolonged FB impaction (>24 h) [6, 30].

Initial evaluation by the anesthesiologist includes a history and physical, including allergies, medications, and underlying medical conditions. Although it is important to note NPO status, in an urgent or emergent situation, all infants and children should be considered full stomachs and an aspiration risk. Ideally, these children should have peripheral intravenous access. Pre-procedure sedation should be carefully used in this population; although it may alleviate anxiety and help with separation anxiety, excess sedation can increase the potential for aspiration.

Anesthetic management begins with appropriate monitoring (EKG, pulse oximeter, and noninvasive blood pressure). In an urgent/emergent esophagogastroduodenoscopy, the safety, ideal anesthetic induction would be rapid sequence induction. One, this would limit the potential for aspiration and, two, would provide a secure airway in a patient. However, many infants/children may present in an emergency. With this in mind, the anesthesiologist needs to balance the risk or aspiration versus retrieval of the foreign body without the presence of IV access in a patient who is clinically deteriorating. This can pose a significant challenge, and

although there is no correct method, safety of the child in any scenario should be the utmost importance.

Aspirated Foreign Bodies

Pathophysiology and Presentation

Foreign bodies in the airway are potentially life-threatening emergencies. These interventions, involving the otolaryngologists, are a significant challenge to the clinical anesthesiologist, one, because they occur urgently and two, can have dire consequences if not addressed in a timely fashion. A balance between spontaneous ventilation and general anesthesia is a challenging goal intraoperatively. During these highly stressful procedures, communication between the anesthesiologist and surgeon is essential for a safe, optimal outcome.

A majority of the children presenting with AFB (airway foreign bodies) are less than the age of 3. Tendencies for aspiration in this population are due to incomplete dentition, immature swallow reflex, and distracted eating habits [20]. Aspirated items include food to nonorganic, nonedible items. Symptoms for presentation depend on the location in the airway and include acute respiratory distress, wheezing, hoarseness, and choking.

Even those with minor symptoms require removal of the FB given complications of atelectasis, bronchiectasis, pneumonia, or granulation tissue that may develop. Local inflammation, edema, cellular infiltration, and ulceration may contribute to airway obstruction while making bronchoscopic identification and removal of the object more difficult [22]. Mediastinitis or tracheoesophageal fistulas may result. Distal to the obstruction, air trapping may occur, leading to local emphysema, atelectasis, hypoxic vasoconstriction, post obstructive pneumonia, and the possibility of volume loss, necrotizing pneumonia or abscess, suppurative pneumonia, or bronchiectasis.

It is important to determine the type of foreign body: organic materials can absorb fluid and swell, oils from nuts cause localized inflammation, and sharp objects can pierce the airway. The time since the aspiration should be established because airway edema, granulation tissue, and infection may make retrieval more difficult with delayed presentations. A recently aspirated object may move to a different position with coughing. Cough, wheeze, stridor, dyspnea, cyanosis, and even asphyxia might ensue. The likelihood of complications increases after 24–48 h, making expeditious removal of the foreign body imperative.

Special Considerations Regarding Timing of Anesthesia for Aspirated Foreign Bodies

The presenting symptoms of foreign body aspiration range from none to severe airway obstruction and may often be innocuous and nonspecific. In the absence of a choking or aspiration event, the diagnosis may be delayed for weeks to months and contribute to worsening lung disease [32]. Witnessed events are easier to diagnose with a history of sudden onset of choking, gagging, or coughing in an otherwise healthy child.

The 1995 American Heart Association revision of pediatric basic life support included management of an aspirated foreign body [2]. When the airway obstruction is mild (the child can cough and make some sounds), no active management is indicated. The child should be allowed to clear the obstruction by coughing and observed for worsening of airway obstruction. If the airway obstruction is severe (the child is unable to make a sound), the child should receive subdiaphragmatic abdominal thrusts (Heimlich maneuver) until the object is expelled or the child becomes unresponsive. Infants should receive five back blows followed by five chest thrusts repeatedly until the object is expelled or the infant becomes unresponsive. Abdominal thrusts in infants are not recommended because of the possibility of damage to the relatively large liver.

The urgency for surgical and anesthetic management is dependent on the presentation – most

importantly the degree of airway compromise, the type of suspected FB, and its position. If symptoms of asphyxiation and laryngeal obstruction develop or persist and the child is in a facility with trained staff, a temporary cricothyrotomy can be performed by inserting an 18-gauge needle or catheter to allow for oxygen and positive pressure ventilation en route to the operating room (OR) for more definitive intervention under controlled conditions.

Location of the foreign body can be affected by coughing or positive pressure ventilation resulting in its dislodgment, leading to further pulmonary compromise. If the foreign body is located in the trachea, the child is at risk for complete airway obstruction and should be taken urgently to the operating room. Conversely, the risk of complete airway obstruction is less if the object is firmly lodged beyond the carina.

The time of the last meal should be established to assess the risk of aspiration. There are no reports of aspiration of gastric contents in a recent review article, although fatal progression of obstruction has been reported [16]. In acute cases, therefore, the dangers of delayed removal appear to outweigh the risk of a full stomach in a well-conducted anesthetic. In urgent cases, the stomach can be suctioned through a large-bore gastric tube after induction but before the bronchoscope is inserted to minimize the risk of gastric aspiration. In delayed presentations in which bronchoscopy is not urgent, a pre-anesthetic fast is appropriate.

Aspirated Foreign Bodies: Locations and Management

Urgently determining the site of the FB is important to managing the problem. The location of the FB depends on its characteristics and also on the position of the person at the time of aspiration. Because the angles made by the main stem bronchi with the trachea are identical until the age of 15 years, foreign bodies are found on either side with equal frequency in persons in this age group [7]. With normal growth and development, the adult right and left main stem bronchi diverge from the trachea with very different angles, with the right main stem bronchus being more acute and therefore making a relatively straight path from the larynx to bronchus. Objects that descend beyond the trachea are more often found in the right endobronchial tree than in the left [11].

The larynx and trachea have the lowest prevalence, except in children under 1 year. These are linked with the most dangerous outcomes, complete obstruction or rupture. Bronchus is the preferred location in 80–90% of AW cases.

Evaluation of these infants and children with AFB must be prompt. Similarly with GI foreign bodies, the anesthesiologist should obtain a history and physical, focusing the clinical symptomology requiring an urgent/emergent bronchoscopy. Healthcare providers, including anesthesiologists, should guide initial therapy for severe FB airway obstruction with the Heimlich maneuver and PALS algorithm, as mentioned previously. At the same time, the patient should be monitored and intravenous access must be obtained. The OR should be preparing an emergency direct microlaryngoscopy/bronchoscopy and have a cricothyrotomy tray available should the patient become unresponsive.

Although evaluation of AFB must be prompt, when appropriate, there may be times to delay bronchoscopy. A study also found no increase in morbidity in stable patients, when appropriate, by delaying bronchoscopy for a suspected foreign body until the next available elective daytime slot so that bronchoscopy may be performed during normal daytime operating hours to ensure optimal conditions with an experienced bronchoscopist and anesthesiologist [5, 20, 21].

Perioperative preparation by the anesthesiologist includes obtaining intravenous access as a priority, especially urgent and emergent cases. Administering anticholinergics, such as glycopyrrolate or atropine, can reduce excess secretions, reduce vagal-induced bradycardia, and reduce cholinergic-induced bronchoconstriction that can ensue during the procedure. Anxiolytics, such as midazolam, can be carefully titrated to provide sedation; however, the risk of upper airway obstruction and hypoxemia is possible [33].

Induction of general anesthesia can be accomplished using inhaled sevoflurane or an intravenous hypnotic agent, with or without maintenance of spontaneous ventilation, depending on the anesthetic and surgical plan.

There is no single method of anesthetizing a child for an urgent/emergent airway FB removal. The anesthetic is tailored to the patient's clinical condition and specific location of FB. Traditionally, the ideal scenario includes general anesthesia in a child that is spontaneously ventilating. In fact, a retrospective study by Chai et al. concluded that the group of spontaneously ventilating children who received sevoflurane and propofol maintenance had fewer adverse events than the TIVA group that had propofol and remifentanil infusions [8]. However, another study, although with fewer patients, showed ideal conditions with a TIVA technique, using both propofol and remifentanil infusions. Nevertheless, this study did have increased adverse events including breath holding and hypoxemia [26]. Both these studies, however, showed judicious application of topical local anesthesia reduced the likelihood of laryngospasm, bronchospasm, and airway irritation leading to coughing or bucking. Lastly, a review of 94 cases of pediatric foreign body aspiration suggested that there was no increased incidence of adverse events related to either spontaneous or controlled ventilation, but that prospective studies are needed to ascertain the outcomes related to each mode of ventilatory support [18].

There has been debate on whether the infant or child should have spontaneous or controlled ventilation. Advantages of a spontaneously ventilating patient include better V/Q matching, alveolar ventilation, and no barotrauma. Disadvantages include difficulty in reaching an adequate depth of anesthesia, suppressing airway reflexes, and preventing patient movement during the procedure [32]. In a control ventilated patient, the patient may receive a neuromuscular blocker and will rely on positive pressure breaths between periods of apnea. Advantages include an ideally anesthetized child for an airway procedure, optimal ability to provide oxygenation and ventilation, and lack of patient coughing and movement [19]. Disadvantages of positive pressure ventilation entail possible movement and dislodgment of FB distally, periods of significant oxyhemoglobin destruction at times of apnea, and increased risk of barotrauma, especially with the use of high-frequency jet ventilation [17, 26, 33].

Anesthetic choice, administration, and ventilation technique vary among all anesthesia personnel. Each option should be discussed with the otolaryngologist or proceduralist since the plan has the potential to change during the procedure. Emergent pediatric tracheobronchial FB retrieval needs a coordinated effort among the surgeon, anesthesiologist, and nursing team and requires an adequately anesthetized, immobile child who has blunted airway reflexes [15].

Miscellaneous Foreign Bodies

Other foreign body retrievals encountered by the pediatric anesthesiologist include nasal and otological FBs. Although these may be fewer than GI or airway FBs, these can remain asymptomatic for weeks, months, or even years [4]. Specific anesthetic concerns for FB in the nose or ears are similar to other FBs: NPO times, presenting clinical symptoms and urgency of procedure.

In regards to nasal FBs, more urgent/emergent FB retrievals occur should the FB migrate into the airway, cause significant uncontrolled epistaxis, or cause excessive mucosal erosion results in severe symptoms of a systemic infection, i.e., sinusitis or meningitis [31]. Anesthetic considerations include close communication with the one performing the procedure and an appropriate level of sedation or general anesthesia. Minimally symptomatic children who are adequately NPO can receive either inhalation or intravenous sedation, titrated to their respiratory rate. Otherwise, general anesthesia with an endotracheal tube is warranted, especially those who are not NPO, vomiting, or have concerns for aspiration.

Infants and children who may present with otological FBs can be anesthetized similarly. A majority of this patient population may present

with minimal symptoms of ear discomfort or pain. Sedation or general anesthesia with inhalation or intravenous usually will suffice for FB retrieval in this population.

Expected Outcomes

Following completion of the surgical procedure, after consultation with the ENT surgeon, emergence of the child is performed with or without the presence of an endotracheal tube, usually depending on the personal preference of the anesthesiologist and on if there are complicating medical or surgical factors. However, as the child emerges, there is a possibility of laryngospasm; thus, secretions should be cleared often. Some patients may require elective intubation and post-op ventilation depending on the complexity of the case and associated injury and airway edema.

Early discharge after uncomplicated bronchoscopy is reasonable. In one study, 187 (65%) children were discharged home within 4 h after rigid bronchoscopy [28]. In another study, 82 (60.7%) children had a hospital stay <1 day [27]. Prolonged pulmonary recovery may prevent early discharge. Predictive factors of prolonged recovery included evidence of inflammation on preoperative radiographs, aggravation of pulmonary lesions on postoperative films, and a prolonged duration of bronchoscopy [9, 23]. Ciftci et al. found bronchoscopy time (57 ± 2.9 min vs. 23 ± 1.2 min) to be prolonged in children with postoperative complications in comparison with those without complications [10]. Chen et al. found that postoperative hypoxemia was associated with prolonged emergence from anesthesia and with foreign bodies that were plant seeds [7].

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12 Anesthetic and Reconstructive Considerations in Major Head and Neck Trauma

Sean W. Gallagher and Andrew R. Scott

Introduction

Patients of all ages experience head and neck trauma; however, mechanisms of injury may vary widely based on geographical location, population density, and cultural influences [1]. Differences in the flexibility and physical characteristics of bones in children impart specific patterns of maxillofacial and laryngotracheal injuries in this population as compared to adults. The initial evaluation of pediatric trauma patients may be complicated by numerous factors. The physical exam can be limited by pain, blood, secretions, tissue distortion, and stranger anxiety. Classification and understanding of facial injuries will impact the management of the airway during treatment [2]. Stable patients will benefit from diagnostic imaging, especially when the location of injury involves the head and neck area, while unstable patients may require immediate intervention to secure the airway and remedy hemodynamic instability [3].

This chapter will focus on potential airway challenges and highlight anesthetic considerations encountered during operative procedures for head and neck trauma in children. A thorough understanding of the affected anatomy and the goals and challenges of surgical repair informs the pediatric anesthesia provider in choosing the appropriate definitive airway and anticipating potential difficulties that may arise during induction, maintenance, and emergence from anesthesia in maxillofacial trauma cases.

Anatomy

The anatomical boundaries that define the midface, mandible, and neck help to organize appropriate airway management during the surgical repair of trauma in these areas.

The horizontal thirds of the face can be summarized as the upper face or forehead area, the midface, and the lower third of the face or mandibular area (Fig. 12.1a). The upper face is composed of the frontal bone and includes the superior orbital rims. The midface is bounded superiorly by the zygomaticofrontal suture lines/inferior orbital margin, inferiorly by the maxillary teeth, and posteriorly by the sphenoethmoid junction and the pterygoid plates. The bones of the midface are paired and include the

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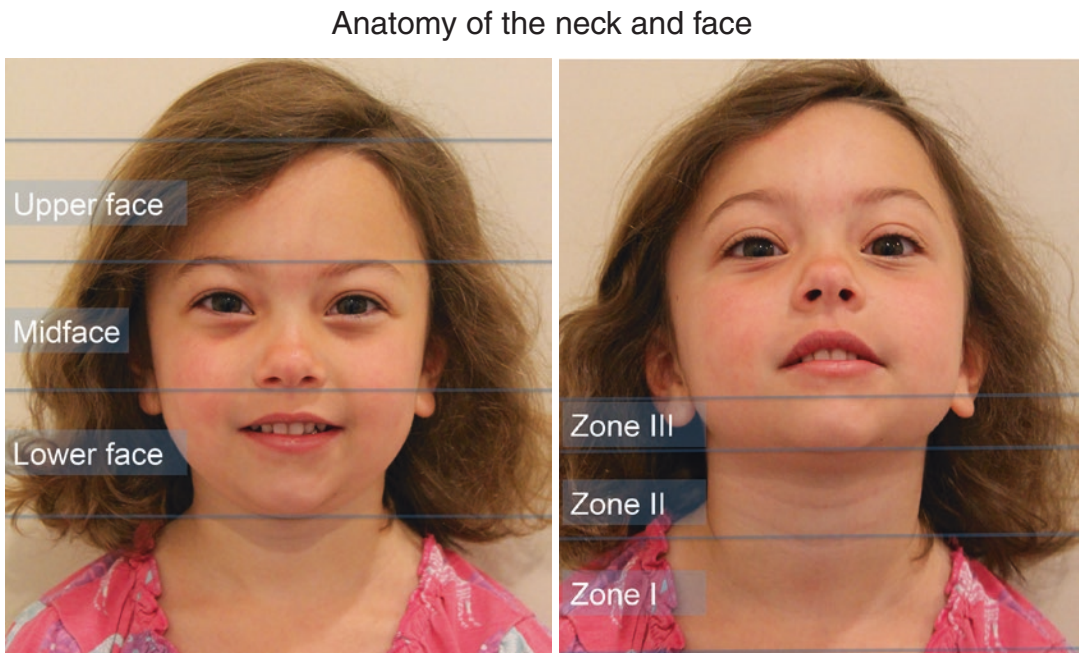

Fig. 12.1 (**a**) The horizontal thirds of the face, defining upper face, midface, and lower face. (**b**) The levels of the neck used for trauma classification: Level I is defined by the clavicles below and cricoid cartilage above; level II exists between the cricoid cartilage and the level of the mandibular angle; level III extends from the mandibular angles to the skull base. Note how the size of a child's head shields the anterior neck from exposure when the head is in a neutral or flexed position

maxillae, the turbinates, and the zygomatic, palatine, nasal, lacrimal, and ethmoid bones. The mandible forms the lower part of the face. In the midline, the mental protuberance gives anterior projection to the overlying soft tissues. Laterally, the ramus of the mandible underlies the masseter muscle and continues superiorly to articulate with the cranium through the condylar process of the mandible.

The neck area is composed of the cervical vertebrae, muscle, and soft tissue that support the cranium. The visceral compartments of the neck contain both highly-vascularized structures (the thyroid gland) and the great vessels themselves, which surround the cartilaginous midline structures of the larynx and trachea. The thyroid, epiglottic, arytenoid, and cricoid cartilages compose the framework of the larynx, which serves as a vital conduit for air exchange between the pharynx above and the lungs within the thorax. The levels of the neck in children may be divided into three zones, identical to those used for classification of neck injury in the neck in adults (Fig. 12.1b).

In infants and children, the size of the head as it relates to the size of the neck and torso is different than that of adults [4, 5]. In newborns, the larynx is positioned higher in the neck at the level of the C3 vertebral body and is often located behind the hyoid bone rather than below it [6]. Starting in early childhood and continuing into puberty, the larynx descends to approximately the C6 level. At this point the length of the neck is longer as it relates to the size of the head.

Upper Face Trauma

Trauma limited to the forehead and upper face does not carry with it the inherent danger of imminent airway obstruction; however, intracranial injury and subsequent alterations in mental status may precipitate aspiration and airway

compromise. The specific anesthetic considerations related to intracranial injury are numerous and beyond the scope of this chapter. Soft tissue injuries and fractures limited to the frontal bone without intracranial pathology may be managed with considerations routine for any surgical procedure on a child. If facial nerve identification is required during the procedure, the use of long-acting paralytics should be avoided. If significant amounts of local anesthetic with epinephrine are utilized in the brow region, some diffusion inferiorly may occur, leading to pupillary changes (ipsilateral mydriasis) that may be detected upon emergence. In such cases, documentation of underlying anisocoria and an accurate preoperative pupillary exam is advisable and may avoid unnecessary panic in the recovery room.

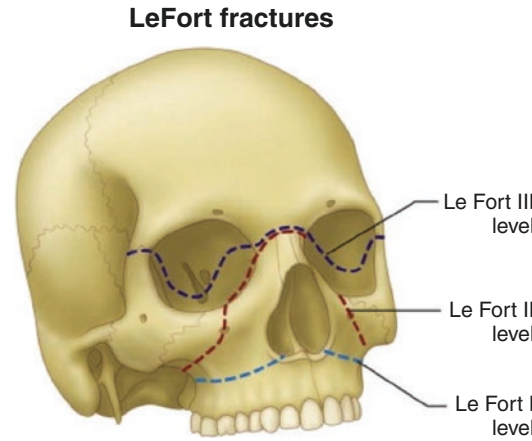

Fig. 12.2 The Le Fort patterns of injury: (**a**) Le Fort 1 fractures effectively separate the palate from the remainder of the skull; (**b**) Le Fort 2 fractures extend medially along a diagonal that terminates in a midline apex at the nasofrontal junction, this amounts to a mobile midface; (**c**) Le Fort 3 fractures amount to craniofacial separation, in which the fracture lines separate the midface through fractures at the zygomaticofrontal sutures laterally, thereby destabilizing the face from the remainder of the calvarium

Midface Trauma

The skeletal manifestations of midfacial trauma may include partial or complete separation of the midface from the skull base. The Le Fort system of classification summarized below is typically used to describe the most common patterns of injury, which occur along predictable planes within the midface [7–9].

Le Fort Type 1

Fracture Involvement

Also known as a floating palate, transverse maxillary fracture, or a Guérin fracture, this fracture pattern involves a horizontal maxillary fracture that leads to the separation of upper teeth from the upper face. This is a fracture that involves the pterygoid plates and passes through the alveolar ridge, lateral nasal wall, and inferior lateral wall of the maxillary sinus (Fig. 12.2).

Le Fort Type 2

Fracture Involvement

Also known as a pyramidal maxillary fracture, this pattern of injury is best described as a triangular fracture with its apex at the nasofrontal suture line, with the maxillary teeth at the base of this triangle. The fracture passes through the posterior alveolar ridge, lateral walls of the maxillary sinuses, inferior orbital rim, and nasal bones (Fig. 12.2).

Le Fort Type 3

Fracture Involvement

The fracture line of a Le Fort 3 injury passes through the nasofrontal suture, maxillofrontal suture, orbital wall, and zygomatic arch, leading to craniofacial disjunction or separation (Fig. 12.2).

Unique Considerations

With the alveolar process of maxilla horizontally separated from the base of the skull, the maxillary arch is destabilized within the oral cavity. The nasopharyngeal airway may be compromised when the unopposed force of soft tissue contraction prompts the mobilized palate to retract posteriorly. Prolapse of the maxilla and attached soft palate tissue leads to upper airway obstruction,

which is exacerbated when the patient is in a supine position (Video 12.1). In such instances, obligate nasal breathers, such as neonates, infants, and toddlers, are at significant risk for obstruction during induction. Trialing various positions prior to the induction of anesthesia may help predict loss of airway patency prior to intubation. Finally, repair of Le Fort 1 fractures requires intraoperative restoration of occlusion with mandibulomaxillary fixation (MMF). Therefore traditional methods for securing oral endotracheal tubes are contraindicated. Nasal intubation may be required but can prove difficult given the issues described above. Alternative methods, such as retromolar and submandibular endotracheal tube placement, will be discussed later.

Orbital Fractures

Fractures of the orbital floor may also involve injury to the globe or entrapment of extraocular muscles. Children and young adults may display a robust oculocardiac reflex, a primitive pathway in which pressure or stimulation of the globe leads to an increase in vagal tone [10]. In fact, recalcitrant hypotension, arrhythmia, and/or bradycardia in the setting of orbital trauma are indications for urgent intervention. Techniques used for repair of orbital floor fractures require significant retraction of the globe and periorbital tissues as well, which may lead to continued hemodynamic variability throughout the repair (Fig. 12.3). Intraocular pressure may be significantly elevated preoperatively, affecting choice of agents selected for induction and maintenance of anesthesia [11, 12]. Similarly the use of intraocular and systemic agents, such as diuretics, may factor into the anesthetic plan for a particular patient. Finally, corneal shields may be utilized by the surgical team as a means of protecting the eye during oculoplastic repair of the orbit. Generous use of lacrimal lubrication and subsequent irrigation is recommended to limit the potential for corneal abrasion. In addition, the plastic shield used for this purpose, which is

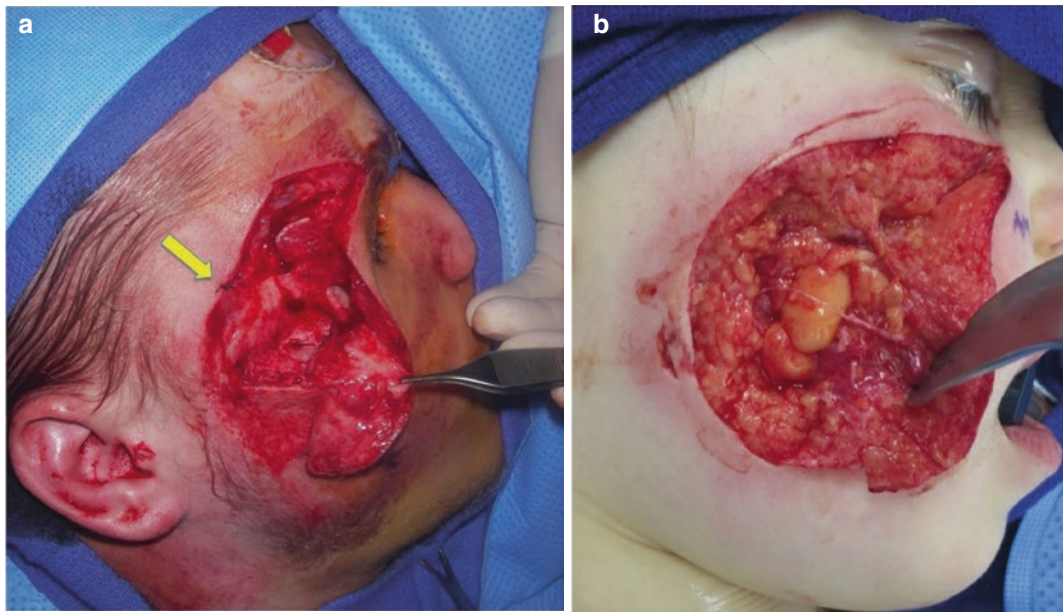

Fig. 12.3 Two representative cases that benefitted from immediate wound exploration with intraoperative facial nerve monitoring: (**a**) Avulsion injury involving the cheek and temple in a teenager. Arrow points to a hemostatic stitch placed in the trauma bay of the emergency room to control bleeding. During subsequent wound exploration in the operating room, the stitch was noted to be strangulating the temporal branch of the facial nerve. Following release of this stitch and bipolar control of the vessel, forehead movement was restored. (**b**) Dog bite involving the cheek and buccal branches of the facial nerve in an 8-year-old girl resulting in immediate midfacial paralysis. Six months after repair with end-to-side nerve grafting, she regained symmetry at rest and a symmetric smile, but demonstrated persistent weakness of the nasalis muscle

sometimes black, should be included in the surgical count, as failure to remove this foreign body will certainly prompt an urgent page from the recovery room, when the nurse notes a "blown pupil" and/or the patient displays an afferent pupillary defect with a total lack of light perception!

Soft Tissue Injury

Soft tissue injuries involving the midface are relatively common. Laceration and avulsion trauma involving the cheek may be complicated by injury to branches of the facial nerve, requiring urgent operative exploration and subsequent grafting. Deep soft tissue injuries involving the cheek may involve the salivary duct of the parotid gland, and injuries to the eyelids may necessitate repair of the lacrimal system. In cases of nerve injury, operative exploration must take place within 48–72 h, prior to the onset of Wallerian degeneration or demyelination injury to the axons of the involved nerve, distal to the site of injury. In such cases, short-acting paralytics or no paralytics at all should be used during induction, intubation, and subsequent maintenance of anesthesia (Fig. 12.4). In cases of salivary or lacrimal duct injury, antimuscarinics such as glycopyrrolate should be avoided, as some degree of basal salivary and lacrimal flow through these systems helps the surgeon find and repair these delicate structures within traumatized tissue.

Soft tissue injury involving the nose may require operative debridement or immediate skin or composite grafting to minimize subsequent scar contracture. Oral intubation with an oral right angle endotracheal (RAE) tube taped to the chin allows for unfettered access to the nose and upper lip and does not impart any distortion to the adjacent soft tissues frequently referenced or utilized in soft tissue repair of these structures. Alternatively, a straight endotracheal tube can be secured near the mentolabial sulcus.

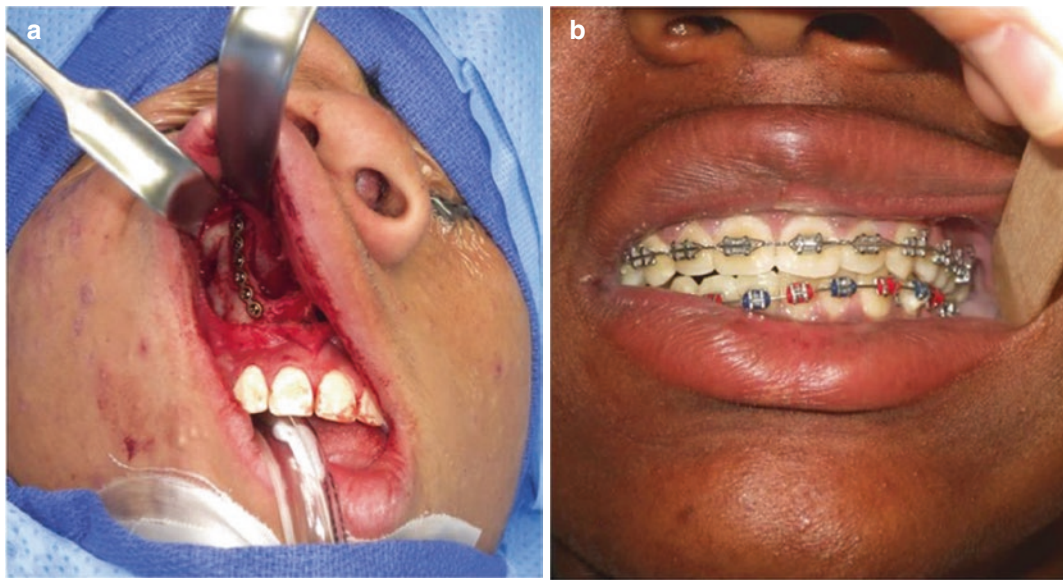

Fig. 12.4 In instances when fractures of the midface do not interfere with occlusion, a transoral intubation is sufficient. If access to the upper gingiva or nasal cavities is required, an oral right angle endotracheal (RAE) tube taped to the lower lip only may be utilized (**a**). In cases requiring intraoperative mandibulomaxillary fixation to restore occlusion (**b**), the endotracheal tube must be positioned outside the path of occlusion. This is most easily accomplished through a nasal intubation. If trauma to the skull base, nasal cavities or nasopharynx prevents safe nasal intubation, alternative methods (submandibular or submental tunnels or tracheotomy) may be considered

Induction of Anesthesia

The presence or absence of IV access, and the need to observe full stomach precautions, will help direct the optimal induction strategy for patients with midface injuries. The majority of these repairs will be elective cases that can follow NPO guidelines. Patients with signficant medical comorbidity should have an IV placed prior to the cessation of PO intake and given appropriate maintenance fluids. Standard, age-appropriate inductions should be safe for isolated Le Fort fractures, orbital fractures, and soft tissue injuries. Inhalational inductions are ideal for neonates, infants, and young children primarily for preservation of spontaneous ventilation. Older pediatric patients can safely be induced with IV medications, with the usual medication contraindications considered. Upper airway obstruction during induction can be overcome with an oral airway. Nasopharyngeal airway placement can be attempted in the absence of skull base fractures, but nasal manipulation may precipitate epistaxis depending on the location of injury. When planning for a nasal intubation, older, cooperative patients should receive nasal oxymetazoline prior to the induction of anesthesia to decrease nasal congestion [13]. For younger or uncooperative patients, oxymetazoline can be administered after the induction of general anesthesia. (Note: the authors favor the use of oxymetazoline in infants and children of all ages over phenylephrine ("pediatric Afrin"), as the latter may induce changes in blood pressure, or cause tachycardia, or arrhythmia through systemic absorption [14, 15]; ironically "adult Afrin" or oxymetazoline is a much safer drug in infants and children.)

The induction plan changes when pediatric patients present for urgent or emergent intervention (usually for the management of airway injury, concomitant neurological, and/or concomitant orthopedic injuries). Induction can proceed as outlined above if the patient is NPO. However, when full stomach precautions are needed, a rapid sequence induction should be used. Prior to induction the anesthetist should communicate with the remainder of the team in regard to whether cricoid pressure will be used given the conflicting data supporting this intervention's effectiveness in minimizing emesis versus possible exacerbation of additional head and neck injuries. Minimizing neck motion is advised when there is concern for an unstable cervical spine or trauma to the trachea.

Airway Management

During induction it may be difficult to obtain a tight seal with the face mask due to pain and edema related to concomitant facial injuries. A larger face mask can overcome seal challenges. Positive-pressure ventilation through a face mask carries a unique risk in this patient population. There exists the potential for dislodging preformed clots in the nasal cavities or nasopharynx, which can lead to renewed bleeding and subsequent aspiration. Such bleeding unnecessarily increases difficulty with endotracheal tube (ETT) placement and may precipitate bronchospasm or laryngospasm, which is otherwise avoidable [16]. Troubleshooting upper airway obstruction can prove difficult in these patients. Typical external airway maneuvers, such as jaw thrust, mouth opening, and atlanto-occipital flexion (when safe to do so), can be used to increase airway patency [17]. An oral airway can be used to help relieve obstruction; nasopharyngeal airways should be avoided in the setting of nasal and/or skull base fractures if possible due to the risk of precipitating epistaxis and a potential for malposition of the airway device in the setting of skull base fracture [18].

The goal of surgical repair for Le Fort fractures, a procedure that requires intraoperative mandibulomaxillary fixation, is to correct malocclusion (Fig. 12.5). Because the occlusal plane must be reestablished, with all teeth in contact with one another, traditional means of securing oral endotracheal tubes cannot be utilized. A number of alternatives exist to secure the airway [19]. When there is a patent nasopharyngeal passage, a nasal endotracheal tube can be placed. This route should be avoided if there is concern for skull base fractures, congruent nasal injuries, or in the setting of maxillary prolapse. A traditional or flexible endotracheal can be placed transorally, with subsequent tunneling in a submandibular or submental position.

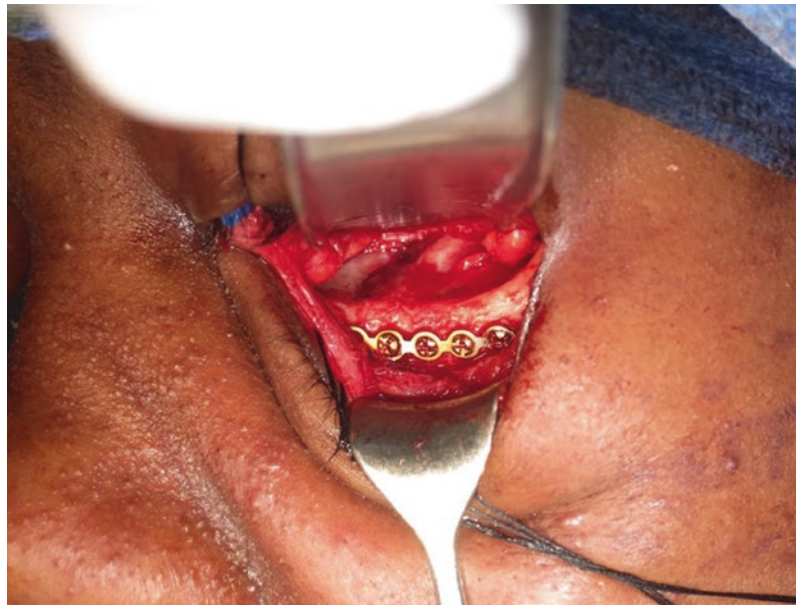

Fig. 12.5 A mini-plate on the inferior orbital rim overlying a fracture extending to the orbital floor posteriorly in a teenager

Submental intubation, first described by Hernández in 1986, was conceived to reduce the need for tracheostomy in patients undergoing maxillofacial surgery [20]. First, the patient is orally intubated with a reinforced tube. A skin incision is then made in the submandibular or submental triangle, one fingerbreadth below the mandibular border, ideally on the side opposite any fractures. Blunt dissection is carried through the mylohyoid and along the lingual surface of the mandible in either a subperiosteal or supraperiosteal plane into the floor of mouth. The pilot balloon and endotracheal tube without a connector are subsequently delivered through the incision without causing inadvertent extubation. Stay sutures are then placed through the soft tissue and endotracheal tube to prevent retraction of the tube posteriorly and deep into the submandibular tunnel, which can easily occur when the circuit is disconnected for suctioning prior to extubation [21, 22].

If the patient is missing teeth, or if their third molars have yet to emerge, a retromolar approach can also be used. With this technique a flexible endotracheal tube, such as an armored tube, can be placed orally and positioned behind a posterior molar or through a gap due to missing teeth, before exiting the mouth at the oral commissure. Children in particular are well suited for the retromolar method. Arora et al. reported 79 of 80 (99%) pediatric patients were able to accommodate a retromolar endotracheal tube while maintaining centric occlusion [23].

When using a standard oral RAE tube or one of the intubation methods described above, endotracheal tube fixation must be performed in a way that minimally distorts facial soft tissue anatomy, especially if facial incisions will be utilized to approach additional fracture sites. Midline endotracheal tube fixation to the lower lip is the most commonly utilized method for securing the airway (Fig. 12.5); if nasal, midline oral, retromolar, submental, or submandibular intubation is not suitable, the patient should undergo temporary tracheotomy.

Maintenance

The vast majority of these patients are good candidates for standard maintenance strategies. Combinations of inhalational agents, opiates, and neuromuscular blocking agents should provide satisfactory surgical conditions while maintaining hemodynamic stability. Normotensive blood pressures should be maintained throughout the anesthetic, with a goal decrease in mean arterial pressure no greater than 20% of baseline.

Concerns over end-organ perfusion, especially long-term neurocognitive deficits, have rendered deliberate hypotension, a less attractive strategy. Peripheral nerve monitoring may be utilized, necessitating the avoidance maintaining neuromuscular blockade. The use of a paralytic-free intubation can be employed, as well as using a short-acting paralytic agent (succinylcholine) or a single, lower end of the intubating dose range of an intermediate-acting agent (rocuronium). The use of dexamethasone at a dose of 0.5 mg/kg IV, up to 10 mg, can help decrease the incidence of postoperative nausea and vomiting, provide adjuvant analgesia, and decrease airway edema. Since the risk of significant airway edema in this trauma pattern is minimal, a reduced dexamethasone dosing regimen of 0.1 mg/kg, up to 4 mg, may also be appropriate [24, 25]. In cases employing nerve monitoring, remifentanil infusions can maintain akinesia while also decreasing the risk of coughing during extubation [26]. Acetaminophen, dexmedetomidine, and ketorolac can provide additional analgesia and help to minimize the total dose of opiates [27]. Following the procedure, a nasogastric tube should be used to clear the stomach of blood, which is highly irritating and may worsen postoperative emesis. A 5-HT3 receptor antagonist, such as ondansetron 0.1 mg/kg, up to 4 mg, should be used at the end of the case as well.

Emergence

Patients with midface trauma are typically good candidates for extubation in the operating room. The risk of maxillary prolapse noted at induction is removed following surgical stabilization of the maxilla. Unfortunately, air movement through the nasal passage may still be compromised due to mucosal edema and the presence of blood clots. An emergence strategy that minimizes the risk of coughing or the need for bag-mask ventilation is ideal. The increase in intracranial pressure associated with coughing should not cause concern in isolated midface injury; however even transient increases in intravascular pressure related to coughing can interrupt hemostasis. Similarly, pressure from bag-mask ventilation can increase the risk of postoperative hemorrhage. The administration of proper sedation and analgesia during maintenance can help mitigate such occurrences. Emerging on a remifentanil or propofol infusion may decrease the likelihood of coughing on extubation. Using pressure support ventilation or spontaneous ventilation toward the end of the case provides additional information that will aid in extubation. Patients that are hyperventilating may be able to tolerate additional longer-acting analgesics and sedatives. The patient should be extubated after satisfying all standard extubation criteria. Patients with a submental or submandibular endotracheal tube should be transitioned to an oral ETT at the end of the maxillary or mandibular repair, unless mandibulomaxillary occlusion is to be maintained postoperatively. Any submental or submandibular endotracheal tubes may be removed, with subsequent closure of the orocutaneous tract.

Bullet Points

- A floating palate can obstruct airflow through the nasopharynx.
- Inhalational induction is ideal for otherwise appropriate candidates.
- A larger face mask may help improve a poor seal noted during mask induction.
- Oral airway for upper airway obstruction.
- Avoid the use of nasal airways when possible.
- Epistaxis may precipitate laryngospasm and complicate induction or emergence.
- Oral intubation with a straight or preformed RAE tube.
- Standard maintenance.
- Pressure on the orbit during surgery may precipitate a robust oculocardiac reflex.
- Possible nerve monitoring.
- Standard emergence.

Lower Face Trauma

Mandibular Fractures

Fracture

Mandibular fractures in children do not always require surgical intervention. Stable or "favorable" fractures may be managed nonoperatively

with adherence to a soft diet. Fractures are classified as favorable or unfavorable, depending on the stability of the fracture. Stable fractures are those in which the bone edges are held stable by the natural vectors of pull of the muscles of mastication. Mobile fractures that require stabilization and reduction such as those with persistent malocclusion cannot be repaired or effectively stabilized without maxillomandibular fixation (MMF) or jaw wiring [28]. A patient undergoing surgical repair of a mandibular fracture will require this fixation intraoperatively, and often MMF is maintained for 2–3 weeks postoperatively. In select patients, MMF is removed prior to emergence, so long as the reduction is maintained with some form of internal fixation, using either a resorbable or titanium plating system. In children who are still growing, titanium plates used for fracture stabilization will need to be removed at a later date in order to avoid possible growth restriction and subsequent deformity.

Mandibular fractures in children differ somewhat from those seen in adults. The pediatric mandible is structurally different in several ways; most notably the symphasis, body, and inferior ramus typically contain dental follicles or unerupted dentition, depending on the child's stage of dental maturity (Fig. 12.6a). These tooth buds amount to large areas of structural weakness within the mandible and extend from the lingual to buccal cortices. These follicles are often involved in mandibular fractures involving the parasymphasis and angle areas in particular (Fig. 12.6b). A sudden load-bearing force to the mandibular symphasis, from a fall onto the chin or blunt trauma to the inferior third of the face, is associated with a common fracture pattern seen in children. Following blunt force to the more flexible symphasis and mandibular body, the thin and more fragile neck of the mandibular condyle below the temporomandibular joint will fracture. Some subcondylar fractures may be treated nonoperatively, with a 2–3 week period of strict adherence to a soft diet, but those fractures associated with malocclusion and anterior open bite deformity require operative MMF to properly align fracture fragments and restore mandibular height.

In adult or adolescent patients with mandibular fractures, proper alignment of the bite or occlusion may be maintained postoperatively through MMF, with the jaws wired together using the permanent teeth as anchors. In children with primary or mixed dentition, the roots of deciduous teeth are not strong enough to withstand the forces necessary to maintain fracture stability through MMF. In very young patients, circummandibular wiring may be required. In most cases involving school-age children, dental splints may be utilized for stabilization (Fig. 12.6a, c). Fabrication of such splints and the subsequent placement of these require endotracheal tube placement outside of the occlusal plane; typically a nasal intubation is utilized in such cases. However, in cases requiring MMF in which there is trauma to the midface limiting the option of nasotracheal intubation, alternative methods of intubation such as retromolar, submental, or submandibular tube placement can be considered.

In complex cases with neurologic injury, trauma to the extremities, or abdominal injuries, in which multiple procedures are anticipated, placement of a tracheotomy may be advisable.

Unique Considerations

In acute trauma requiring stabilization of the airway, tooth fragments or loose dentition may interfere with intubation or subsequent extubation. Frequently dental fragments within the pharynx and airway will be identified on computed tomography imaging; however, prior to induction or at the time of intubation or subsequent extubation, the surgeon and the anesthetist should confirm that any and all debris has been removed from the aerodigestive tract to prevent accidental aspiration in the recovery period.

Induction

The induction for patients with mandibular fractures can be approached in much the same way as with midface fractures. The anesthesia and surgical team should perform an assessment for tooth fragments prior to induction, ideally prior to moderate or deep sedation. These patients are candidates for age-appropriate inductions. NPO

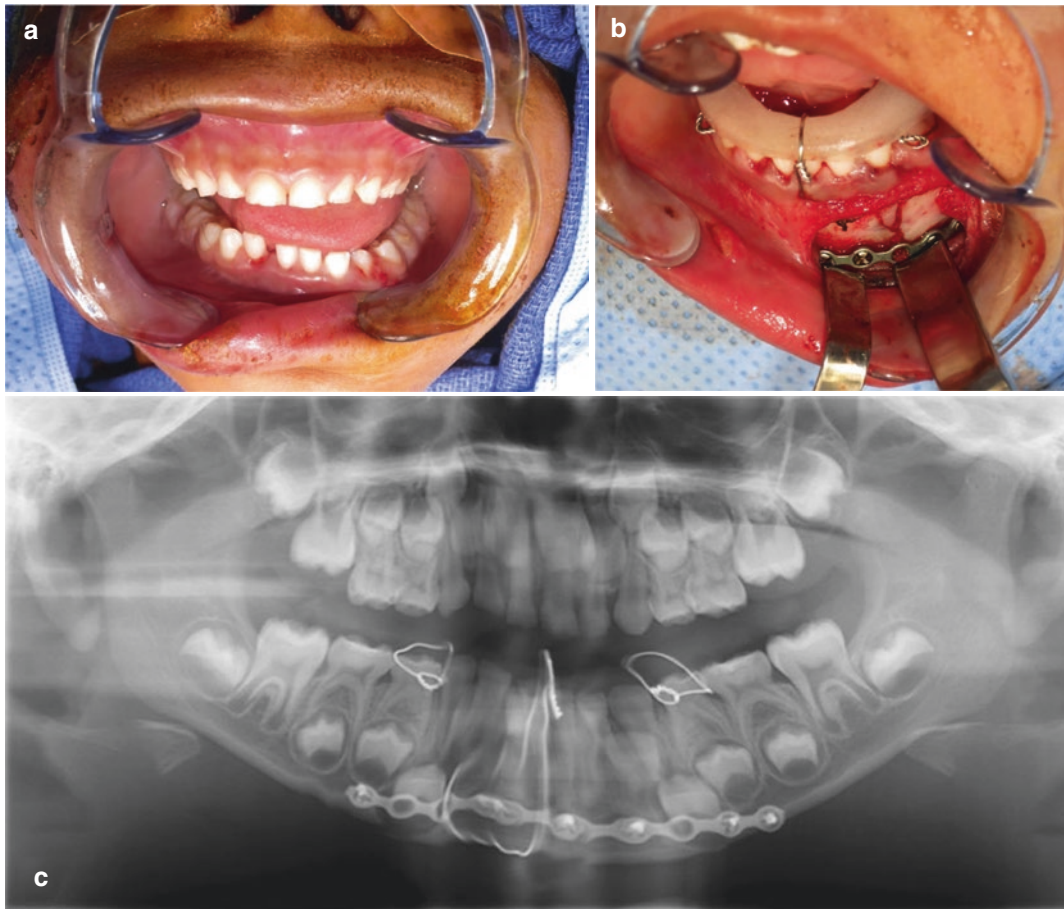

Fig. 12.6 (**a**) Bilateral parasymphyseal mandibular fractures in a 6-year-old child, note the irregularity of the teeth with gap formation at the fracture sites. (**b**) Internal fixation with a titanium mini-plate and a dental splint. Circummandibular wires in place for splint stabilization. (**c**) Panorex plain film of the mandible following fixation with titanium plate. Note the dental follicles present in the mandibular arch; each of the two parasymphyseal fracture lines pass through one of these follicles

guidelines should be observed, but consider full stomach precautions in the setting of recent oral bleeding or poor pain management.

Airway Management

The airway management for patients with mandibular fractures can be approached in much the same way as with midface fractures with a few notable considerations. Some traditional external airway manipulation techniques will be inadequate. In the setting of bilateral fractures, a jaw thrust will not reliably elevate the base of the tongue. Nasopharyngeal airways should be used early if proper positioning and mouth opening is unable to relieve an upper airway obstruction. Nasal intubations are the primary route for securing the airway. Anterior traction on the mandibular symphasis or direct anterior retraction of the oral tongue can also improve obstructions. Nasal intubations are the primary ETT route of choice for these patients. If a nasal intubation is contraindicated, the team can consider retromolar, submental, or submandibular ETT placement.

Maintenance

Standard maintenance strategies, as outlined in the midfacial trauma section, can be employed for these patients.

Emergence

Similar to patients with midface trauma, these patients are typically good candidates for extubation in the operating room. Close communication with the surgical team should include discussion of preserved MMF. These patients should be extubated after fully meeting extubation criteria. The surgical team should be immediately available to remove the MMF in cases of failed extubation. If the patient fails extubation, the patient should be reintubated. Oral intubations in this setting are encouraged to quickly reestablish oxygenation and ventilation.

Tongue/Floor of Mouth/Oropharynx

Unique Considerations

Soft tissue injuries involving the oral cavity and oropharynx are common in children, with penetrating trauma dominating as the most common source of injury. Most children with oropharyngeal and oral cavity trauma do not require anesthesia or intubation to secure the airway, but there are some notable exceptions.

Injuries to the oral tongue and floor of mouth rarely require operative repair, but they may present in a delayed fashion in the context of infection. In such cases, the child will show signs and symptoms of oral cavity edema similar to the symptoms of Ludwig's angina, with drooling, tongue protrusion, floor of mouth elevation, and obligate nasal breathing [29]. In such cases, the use of a nasopharyngeal airway allows for effective bypass of the tongue base and more anterior structures. Laryngeal mask airway (LMA) placement and/or transoral intubation is usually contraindicated; nasal fiber optic intubation is the method of choice for securing the airway in this scenario. In more simple cases of anterior tongue laceration or partial avulsion, nasal intubation is also favored. Following repair or surgical intervention for oral tongue and anterior floor of mouth trauma, emergence and extubation may be complicated by the presence of residual soft tissue edema. In some infectious cases, and depending on surgeon preference, the use of corticosteroids may be contraindicated. In this scenario it is advisable to replace the nasal endotracheal tube with a nasopharyngeal airway to prevent obstruction during emergence. Once the child is awake enough to protect his or her airway, the nasopharyngeal airway can be removed (either by the child or the recovery room staff, whichever comes first!)

Rarely, penetrating trauma to the oropharynx will necessitate neuroimaging to assess for injuries to the great vessels, such as carotid dissection or pseudoaneurysm. These cases usually involve toddlers or young children who were running with a sharp object in the mouth and sustained a mechanical fall. Because of the younger age of these children and the need for IV contrast and limited motion during imaging, these patients will often require sedation. With penetrating injuries to the pharynx there may exist some degree of crepitus in the neck; deeper injuries involving the hypopharynx may be associated with pneumomediastinum. Limited use of positive-pressure ventilation is advisable during induction and emergence in such cases.

Induction

Induction of these patients can proceed similarly to standard pediatric patients. The preoperative assessment should include airway patency in the supine position, with general reassurance if ventilation remains intact. If the patient is struggling to ventilate, the team should have a heightened suspicion for complete upper airway collapse post induction. A nasopharyngeal airway is likely to bypass the obstruction. Additional rescue options would include rapid nasal intubation or careful oral interventions.

Airway Management

Nasal intubation is preferred when working in the oropharynx. If the patient isn't a candidate for a nasal ETT, a conversation with the surgical team should include the feasibility of working around an oral ETT or a retromolar ETT fixation, with elective tracheostomy being the final option.

Maintenance

The maintenance of anesthesia for these patients is similar to standard anesthetics. Nerve monitor-

ing is rarely utilized, allowing for neuromuscular blockade. If the pathology includes infection, consider avoiding dexamethasone.

Emergence

A standard emergence should be well tolerated with these patients. Special consideration should include evaluation of the oropharynx to help predict post extubation obstruction. Airway patency can be reestablished with a nasopharyngeal airway.

Soft Tissue

Avulsion and penetrating soft tissue trauma in the lower third of the face may also involve cranial nerves, necessitating direct repair or grafting procedures when indicated. Agents used for neuromuscular blockade may need to be adjusted when intraoperative nerve monitoring is required.

Complicated perioral soft tissue trauma, which is often the case following dog bites, may require complex repair necessitating general anesthesia. In such cases the use of nasal intubation with a nasal RAE tube secured by tape to the glabellar area or lower eyelid area will usually allow for enough soft tissue mobility to facilitate soft tissue repairs of the inferior perioral tissues (Fig. 12.7).

Unique Considerations

Induction

The induction of general anesthesia with these patients can be complicated if the injury interferes with creating a tight seal with the face mask. These patients may benefit from preinduction analgesics to increase face mask tolerance.

Airway Management

The location of the injury and repair approach will influence the ETT route. An oral ETT secured away from the surgical cite may suffice. A nasal ETT should be placed if an oral ETT will lead to unacceptable tissue distortion.

Maintenance

These patients should tolerate a standard maintenance plain. One potential modifier would include the use of nerve monitoring.

Emergence

There are no special emergence considerations for these patients.

Neck Trauma

Because of the anatomical differences outlined above, the larynx and soft tissues of the neck in a young child are relatively protected from blunt

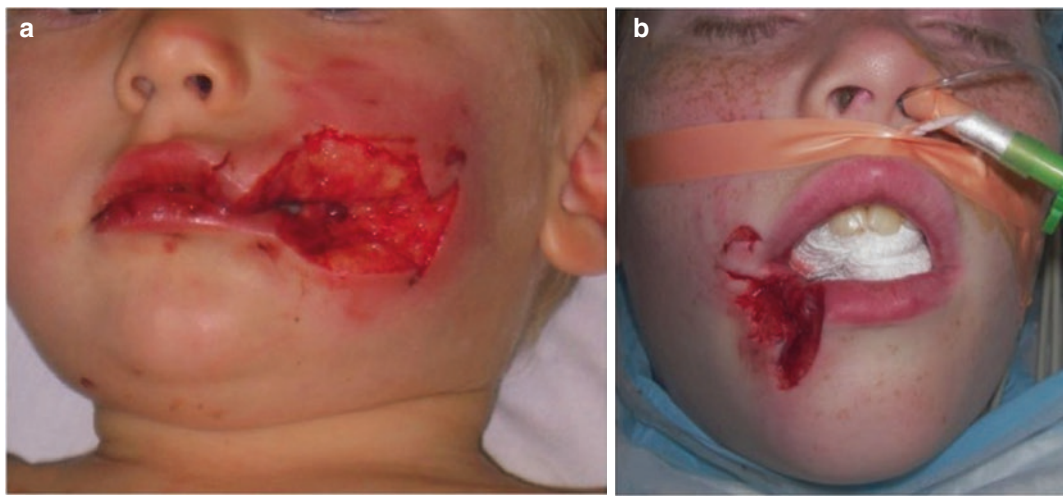

Fig. 12.7 Injuries involving the oral commissure (**a** and **b**) require referencing both the upper and lower lips for repair. (Photo A courtesy of Robert J Tibesar, MD)

traumatic injury, as vital neck structures are shielded from exposure by the projection of the mandible. However, when laryngotracheal injury does occur in children, it is most commonly related to some sort of blunt force trauma to the neck [29]. Bicycle injuries and falls are the most common mechanisms observed in small children [30]. Soft tissue injuries such as hematoma and edema are more common than in adults, given a relatively looser connection between the mucosa and the underlying perichondrium observed in children. Additionally, the greater elasticity and compliance of laryngotracheal cartilages in children is somewhat protective against fracture of the laryngotracheal framework and narrower/shorter cricothyroid and cricotracheal membranes appear to protect somewhat against laryngotracheal separation injuries [31].

Management of penetrating neck wounds remains an area of debate within the field of pediatric trauma. The nuances of which injuries require prompt operative exploration versus radiographic assessment remain controversial and discussion of these issues is beyond the scope of this chapter.

Laryngotracheal Separation/ Penetration

There is a high association between cervical spine injuries in children and laryngotracheal injury [31]. In adults, an awake tracheotomy under local anesthesia is favored as the safest way to secure the airway in such cases. However, management is more controversial in the pediatric population, as most young children are not cooperative enough to allow for safe and rapid establishment of a surgical airway under local anesthesia. In such cases, a rapid sequence intubation followed by intubation over a bronchoscope or rigid telescope prior to tracheotomy is recommended [32].

Positive-pressure ventilation through a face mask or laryngeal mask airway should be limited if not avoided given the potential for exacerbating pneumomediastinum or pneumothorax (Fig. 12.8). Laryngotracheal injuries carry with them a high incidence of concurrent damage to the recurrent laryngeal nerves [33, 34]. For this reason direct repair or grafting procedures may

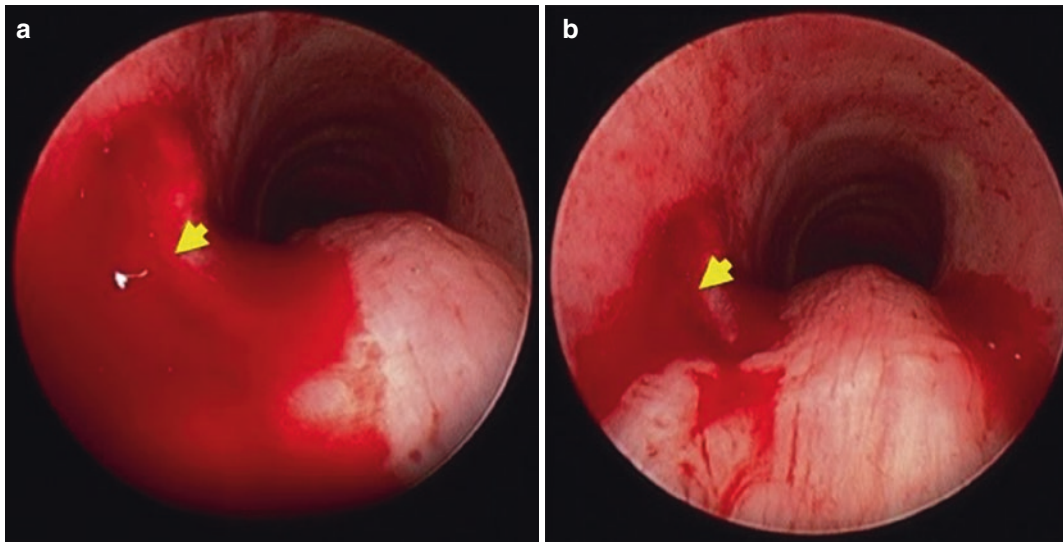

Fig. 12.8 A teenage boy s/p stab wound to the left anterior neck, crepitus noted in the field when transorally intubated by emergency services. Subsequent neck exploration for bleeding revealed the inferior thyroid gland as a source. More thorough exploration of the wound demonstrated a left paratracheal laceration extending to the esophagus. Bronchoscopy at the time of neck exploration confirmed the location of the tracheal laceration (**a** and **b**). Note how a deep intubation or blind passage of a tracheal suction catheter may be capable of exacerbating such an injury and how prolonged positive-pressure ventilation might precipitate tension pneumomediastinum. Remarkably there was no injury to the recurrent laryngeal nerve in this case, and the patient made an uneventful recovery

be indicated at the time of neck exploration. Agents used for neuromuscular blockade may need to be adjusted when intraoperative nerve monitoring is required.

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13 Anesthetic Management of Morbidly Obese Patients Undergoing Airway Surgery

Songyos Valairucha and Raafat S. Hannallah

Introduction

Obesity has become one of the most important public health problems in the United States and many other countries around the world [1]. In the United States, prevalence of childhood obesity has increased up to threefold over the last three decades [2, 3]. It now affects one in six children and adolescents with the highest prevalence in Black and Mexican-American youth [4]. According to Center for Disease Control and Prevention (CDC) 2011–2014 report, the prevalence of obesity was 17.5% of among 6–11-year-olds and 20.5% of 12–19-year-olds [5]. More than 30% of pediatric patients presenting for surgery in one large pediatric setting were found to be overweight or obese [6].

Along with the increase in weight come a number of potential health issues such as obstructive sleep apnea, metabolic syndrome, and cardiac disease, and it has been shown that comorbidities are more common among obese children. They are at increased risk of adverse events associated with anesthesia and surgical procedures [7]. Obesity is identified as one of the major risk factors of death or permanent neurological injury after tonsillectomy [8].

Morbidly obese children are a special group of patients requiring special attention in the perioperative period especially during airway related surgery. Understanding the anatomical, physiological, metabolic, and pharmacological changes are crucial for the anesthesiologist to tailor the anesthetic technique for the best possible outcomes.

Defining Obesity in Children

The norms for BMI in children vary with age and sex because of growth and differences in the distribution of fat, muscles, and bone density occurring at puberty. Therefore, specific growth curves showing the percentiles for age- and sex-specific BMI are used to define obesity in children and teenagers from 2 to 18 years of age. In 2000, the National Center for Health Care Statistics and the Centers for Disease Control (CDC) published BMI reference standards for children between the ages of 2 and 20 years (Fig. 13.1a, b). BMI percentiles can also be determined using a simpler alternative "BMI Percentile Calculator for Child and Teen" (aged 2 through 19 years old) available on the CDC website: https://nccd.cdc.

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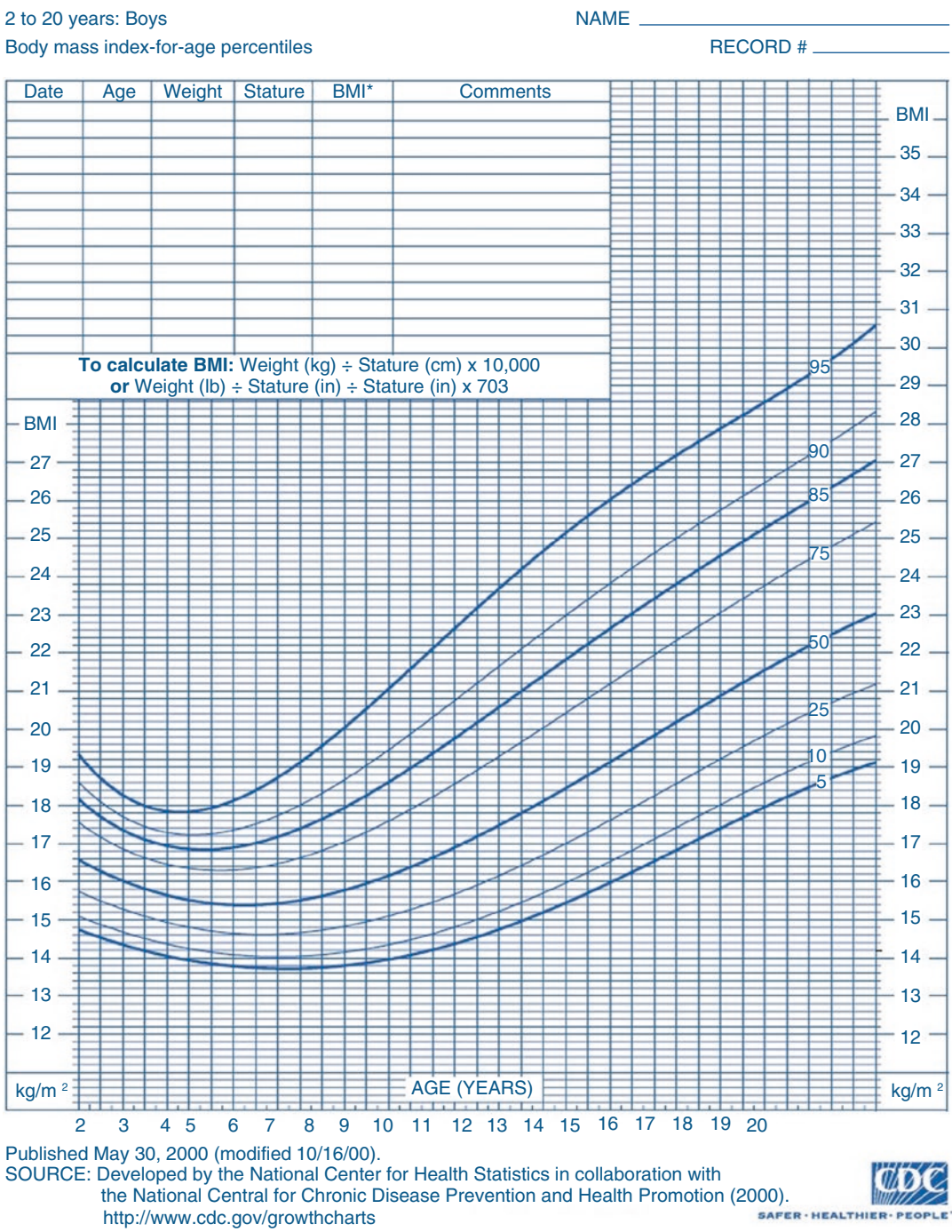

Fig. 13.1 (**a**) Body mass index-for-age percentiles, boys, 2–20 years, CDC growth charts: United States. (**b**) Body mass index-for-age percentiles, girls, 2–20 years, CDC growth charts: United States

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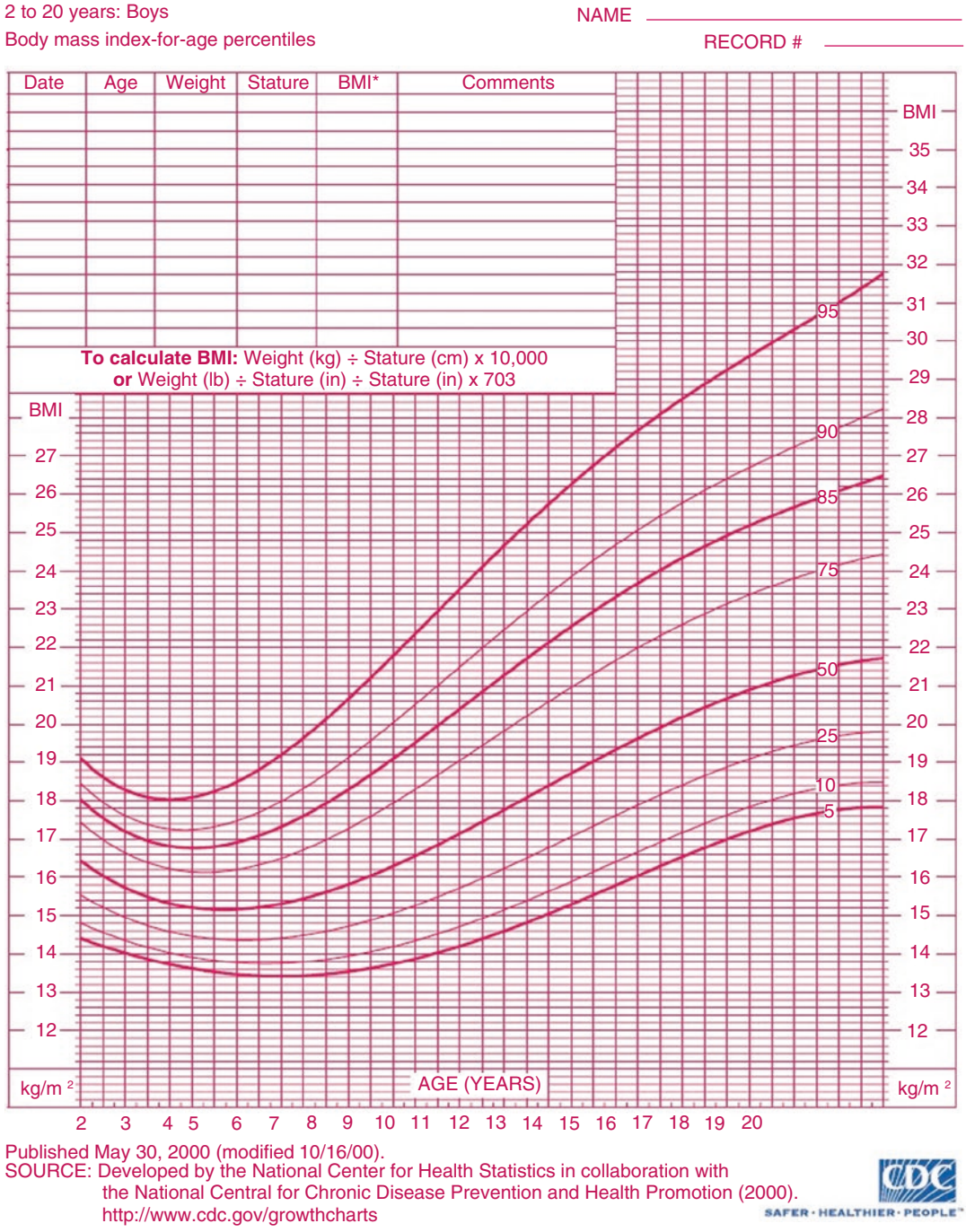

Fig. 13.1 (continued)

Table 13.1 Definition of obesity in children and teenagers

Weight status category	Percentile range
Normal	5th to <85th percentile
Overweight	85th to <95th percentile
Obese	95th to <97th percentile
Morbidly obese	>97th percentile

gov/dnpabmi/Calculator.aspx. This calculator provides BMI and the corresponding BMI-for-age percentile on a CDC BMI-for-age growth chart. The definitions used to categorize weight status for children are shown on Table 13.1. Nafiu et al. proposed a more simplified definition as follows: any preschool age child (aged 2–5 years) with BMI ≥ 20 kgm^2 is classifiable as obese, any school age child (aged 6–12 years) with BMI ≥ 25 kgm^2 is classifiable as obese, and any young adolescent (aged 13–18 years) with BMI ≥ 25 kgm^2 is classifiable as overweight or obese [9]. This group of patients has a significantly greater risk for having perioperative complications [7, 10] and requires special considerations during perioperative period.

Special Risk Considerations for Morbidly Obese Children

Obstructive Sleep Apnea

Obstructive sleep apnea (OSA) is a public health problem and is often associated with obesity [11]. The prevalence of OSA in the general pediatric population is estimated to be 1–6%. However, in obese children and adolescents, the evidences suggest that the prevalence and severity of OSA are increased and are reported to be 19–61% [12]. In recent study by Mathew et al., 24% of morbidly obese (>150% IBW) children and young adults (3–20 years old) had OSA using an AHI >5/h. Moreover, SaO_2 was <90% for >3% of the total sleep time in 20% of these children [13].

There are four common clinical phenotypes that associate with OSAS in children: (1) obesity, (2) lymphoid hypertrophy, (3) craniofacial, and (4) neuromuscular. The prevalence of OSAS in obese children seems to exceed that of any other phenotype. A population-based study involving children between 2 and 18 years of age found that obesity was the most significant risk factor for OSAS [14]. However, it is not uncommon that more than one cause may have contributed to their OSAS. It has been shown that about 45% of obese children with OSAS have evidence of adenotonsillar hypertrophy [11].

Both anatomic and functional factors contribute to pathophysiology of OSAS in obese children. Anatomical obstruction is caused by adenotonsillar hypertrophy and parapharyngeal fat pads. The latter have been shown to be significantly larger in obese subjects with OSA, when compared to BMI-matched subjects without OSA [13]. Functional mechanisms can be explained by alterations in neuromotor tone and tissue properties that lead to increased airway collapsibility and increased resistance. Obese children with OSAS having large tonsils and adenoids do not obstruct while awake because of high motor tone, and adenotonsillectomy in these children does not cure OSAS in a large number of patients [11].

The presence of a diagnosis of OSA in morbidly obese children carries implications for the anesthetic technique and disposition planning. In 2014, the American Society of Anesthesiologists Task Force on Perioperative Management of patients with OSA published an updated report of Practice Guidelines for the Perioperative Management of Patients with OSA which includes the clinical criteria to identify and assess OSA in children (Table 13.2) [15]. The recommendation is that if any characteristics noted during the preoperative evaluation suggest that the patient has OSA, the anesthesiologist and surgeon should jointly decide whether to (1) manage the patient perioperatively based on clinical criteria alone or (2) obtain sleep studies, conduct a more extensive airway examination, and initiate indicated OSA treatment in advance of surgery. If the decision is to proceed without a sleep study, such patients should be treated as though they have moderate sleep apnea unless one or more of the signs or symptoms above is severely abnormal (e.g., markedly increased BMI, respiratory pauses

Table 13.2 Identification and assessment of OSA in children (modified from practice guidelines for the perioperative management of patients with obstructive sleep apnea: an updated report by the American Society of Anesthesiologists Task Force on Perioperative Management of patients with obstructive sleep apnea) [15]

A. Clinical Signs and Symptoms Suggesting the Possibility of OSA

1. Predisposing physical characteristics
   - BMI: 95th percentile for age and sex
   - Craniofacial abnormalities affecting the airway
   - Anatomical nasal obstruction
   - Tonsils nearly touching or touching in the midline
2. History of apparent airway obstruction during sleep: two or more of the following are present
   - Intermittent vocalization during sleep
   - Parental report of restless sleep, difficulty breathing, or struggling respiratory efforts during sleep
   - Night terrors
   - Child sleeps in unusual positions
   - New onset enuresis
3. Somnolence (one or more of the following is present)
   - Parent or teacher comments that child appears sleepy during the day, is easily distracted, is overly aggressive, is irritable, or has difficulty concentrating
   - Child often difficult to arouse at usual awakening time

If a patient has signs or symptoms in two or more of the above categories, there is a significant probability that he or she has OSA. The severity of OSA may be determined by sleep study (see below). If a sleep study is not available, such patients should be treated as though they have moderate sleep apnea unless one or more of the signs or symptoms above is severely abnormal (e.g., markedly increased BMI, respiratory pauses which are frightening to the observer, patient regularly falls asleep within minutes after being left unstimulated without another explanation) in which case they should be treated as though they have severe sleep apnea.

B. Sleep Study

If a sleep study has been done, the results should be used to determine the perioperative anesthetic management of a patient. However, because sleep laboratories differ in their criteria for detecting episodes of apnea and hypopnea, the sleep laboratory's assessment (none, mild, moderate, or severe) should take precedence over the actual AHI. If the overall severity is not indicated, it may be determined by using the table below:

Severity of OSA	**Pediatric AHI**
None	0
Mild OSA	1–5
Moderate OSA	6–10
Severe OSA	>10

AHI apnea–hypopnea index: the number of episodes of sleep-disordered breathing per hour

which are frightening to the observer, patient regularly falls asleep within minutes after being left unstimulated without another explanation) in which case they should be treated as though they have severe sleep apnea [15]. However, the Childhood Adenotonsillectomy (CHAT) Study Randomized Clinical Trial demonstrated that OSA severity could not be accurately predicted by traditional clinical parameters alone [16]. The American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) advocates for preoperative PSG in children with obesity prior to undergoing tonsillectomy to help plan perioperative management, provides a baseline for postoperative polysomnography (PSG), and defines severity of sleep disturbance [17].

Difficult Airway and Ventilation

In obese children, the risk for desaturation during induction of anesthesia, emergence, and in the postoperative care unit is greater compared with normal-weight children because of the following physiologic and anatomical changes associated with obesity (Fig. 13.2) [18].

1. *Higher incidence of upper airway obstruction and difficult airway*
   Mask ventilation and intubation can be more difficult in obese children. Jaw thrust, two-hand mask ventilation, or the use of oropharyngeal or nasopharyngeal airways is more often necessary to achieve sufficient mask ventilation. The causes of obesity-related difficult airway can be explained by the following:
   - MRI in obese adults shows that there is increased deposition of adipose tissue into the uvula, tonsils, tonsillar pillars, tongue, aryepiglottic folds, and lateral pharyngeal walls resulting in decreased pharyngeal space volumes. Obese children with OSA have higher tonsil volume than normal-weight children which may result in the higher incidence of upper airway obstruction after induction of anesthesia, as all commonly used anesthetic drugs have been demonstrated to cause pharyngeal collapse.

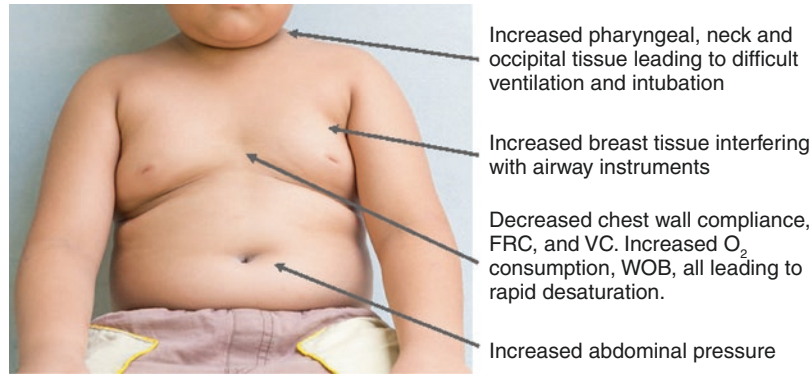

Fig. 13.2 Physiologic and anatomical changes associated with obesity resulting in difficult airway and ventilation

- The pharynx is collapsible because its anterior and lateral walls lack bony support. Its patency is dynamic and determined by the transmural pressure across its walls and the compliance of the walls. In obese adults, extraluminal pressure is increased by superficially located fat that may compress the upper airway externally.
- The short, thick neck may limit neck extension during laryngoscopy, and the larger tongue may make intubation difficult.

2. *Reduced Tolerance to Hypoventilation/Apnea*
   During apnea, morbidly obese children have a shorter time to desaturation which greatly increases the risk of hypoxic injury if airway difficulties are encountered. Rapid desaturation can be explained by the following:
   - They have altered respiratory physiology: decreased respiratory compliance, vital capacity, and functional residual capacity. V/Q mismatching increases more after induction of anesthesia due to atelectasis in supine position leading to hypoxia. Positive end-expiratory pressure (PEEP) should be applied during induction and maintenance of anesthesia to increase the functional residual capacity (FRC) and prevents atelectasis.
   - Increased work of breathing and oxygen consumption from increase fat and muscle tissues.

Comorbidities

Childhood obesity is associated with multisystem pathophysiologic changes leading to numerous comorbidities (Table 13.3) [18, 19]. Interestingly, both obesity and untreated OSAS are independently associated with similar cardiovascular, pulmonary, and metabolic morbidities. However, the magnitude of derangement when obesity and OSA coexist is unclear but likely to be at least additive. Most of the abnormalities are mediated via the sympathetic nervous system, oxidative stress, and inflammation. The consequences are mainly on the cardiovascular system such as systemic hypertension, ventricular hypertrophy, or even pulmonary hypertension leading to right heart failure. In most of comorbidities, incidences increase with increasing BMI and duration of obesity [18].

Medication Dosing

Drug dosing in a morbidly obese patient continues to be problematic because of a relative lack of evidence and understanding regarding how to safely and effectively dose medications for them. Pharmacokinetic studies of anesthesia-related drugs in obese adults are limited, and there are even less data about children and adolescents; thus extrapolations have to be made from studies of obese adults. It was found that obese children had a greater odd of being dosed with medications outside their recommended ranges. These findings suggest that they are potentially at greater risk of medication ineffectiveness (underdosing) or adverse events (overdosing) [20]. For certain medications, the target effect can be measured, and their dosing can be based on that endpoint such as peripheral nerve stimulation for

Table 13.3 Comorbidities and pathophysiologic changes in obese children [18, 19]

System	Comorbidities	Pathophysiologic changes
Respiratory	OSAS Chronic Hypoxia Asthma Bronchial hyperactivity Atelectasis	Decrease in: • Lung volume: FRC, VC, inspiratory capacity • Diffusion capacity • FEV_1 • Chest wall and lung compliance Increase in: • Work of breathing • Lower airway obstruction • Closing Capacity • Exercise-induced asthma in 30% of overweight and obese children • OSA in about 17% of the obese children >150 percentile with chronic nocturnal hypoxemia leads to progressively pulmonary hypertension
Cardiovascular	Hypertension Left ventricular hypertrophy Cor pulmonale	Increase in: • Vascularization of the adipose tissue: increase in cardiac output and blood volume stiffness and wall thickness of the carotid artery as early signs of arteriosclerotic process in school children • Early development of arterial hypertension, approximately a threefold higher risk than nonobese children • Activity of sympathetic nervous system: higher resting heart rate and blood pressure • Left-ventricular mass and hypertrophy • Left-ventricular dysfunction
Endocrine	Diabetes Glucose intolerance Dyslipidemia	Metabolic syndrome and resistance to insulin in 50% of severely obese adolescents
Gastrointestinal	Gastroesophageal reflux? Fatty liver disease	Ambiguous data about reflux: higher incidence of reflux in obese children, and no difference between normal-weight and obese children No difference in residual gastric volume after 6 h fasting and 2 h without liquid between obese and normal-weight children Fatty liver disease: progress from hepatic fatty degeneration to fibrosis (histologically)
Neurological/ psychological	Pseudotumor cerebri Low self-esteem Poor school performance	Hypersomnolence, but more often they display hyperactivity or aggressiveness, poor attention, and poorer performance in school

muscle relaxant, BIS for sedatives. However, there is no specific and reliable monitoring for analgesics especially opioids; therefore careful titrating of small incremental dose to respiratory rate and CO2 is advised.

Calculation of the optimal drug doses for induction and maintenance of anesthesia are based on total body weight (TBW), ideal body weight (IBW), or lean body weight (LBW) [19] (Table 13.4).

$$\text{IBW} = \left(\text{BMI at the 50th percentile for the child's age}\right) \times \left(\text{height}\left(\text{m}\right)\right)^2$$

BMI at the 50th percentile can be identified by using CDC age- and gender-specific curves of reference BMI.

$$\text{LBW} = \text{IBW} + 0.3 \times \left(\text{TBW} - \text{IBW}\right)$$

LBW is increased in obese children because 20–40% of the excessive weight is due to an increase in muscles, bones, and other lean body tissues [21]. Most of the metabolic processes involved in pharmacokinetics and pharmacodynamics take place in the lean body mass. Lean body mass changes with sex, height, and TBW. Important pharmacokinetic variables such

Table 13.4 Dosage of common intravenous anesthetics in obese children [19, 22]

Drug	Initial dose	Maintenance dose
Sedatives		
Propofol	LBW	TBW
Thiopental	LBW	
Midazolam	?	
Dexmedetomidine	LBW	LBW
Opioids		
Morphine	IBW	IBW
Fentanyl and sufentanil	TBW	LBW
Remifentanil	LBW	LBW
Muscle relaxants and reversal agents		
Succinylcholine	TBW	
Non-depolarizing muscle relaxant	IBW	IBW
Sugammadex	TBW	
Neostigmine	TBW	

as volumes of distribution and clearance can be related to LBM. Cardiac output, an important factor in early distribution of drugs, correlates with BMI but in a nonlinear fashion [22].

Most of the sedatives and anesthetics are lipophilic molecules. Volume of distribution of these drugs is higher as the fat mass increases in obese patients. Loading dose requirement is theoretically affected directly by volume of distribution. Therefore, for most lipophilic drugs, loading dose should be calculated based on TBW. Maintenance dose of drug is generally based on its clearance. However, this pharmacokinetic data is usually not available for obese children. Moreover, alteration in pharmacodynamics, increased sensitivity, of sedatives and anesthetics in obese patient is unpredictable and needs to be considered. Thus, the maintenance dose based solely on total body weight and clearance alone would likely result in overdose. It is recommended that lipophilic drugs should be re-dosed based upon clinical studies based evidence. However, if no data is available, LBW-based maintenance dose can be used but with caution [23].

For hydrophilic drugs, the volume of distribution does not increase proportionately to the increased BMI. Thus loading doses of these drugs should be estimated based upon the lean body mass rather than actual weight. Estimates for maintenance doses of these drugs are more complicated. Most antibiotics and neuromuscular blocking agents are classified as hydrophilic drugs. Penetration of antibiotics into tissue in obese may be lower resulting in lower minimum inhibitory concentrations (MICs). Therefore, higher doses for antibiotics may be needed. On the contrary, obese are more predisposed to residual effects of neuromuscular blockers and thus may require lower target site concentrations [23].

A recent study by Olutoye et al. has shown that the ED_{95} of propofol for loss of consciousness is significantly lower in obese children than in their normal-weight peers and recommended a propofol induction dose of 2.0 mg/kg based on the actual body weight in obese children with BMI > 95th percentile, 3.2 mg/kg for children with BMI < 85th percentile, and 2.5–3.2 mg/kg for the rest [24]. It has been shown that the induction dose of propofol should be calculated based on LBW [25]. However, in morbidly obese children and adolescents has shown that TBW was the main determining factor of propofol clearance. As a result, its maintenance dose should be based on TBW [26].

Non-depolarizing muscle relaxants should be based on LBW. It is recommended that succinylcholine and neostigmine be dosed to TBW. The safest reversal dose of sugammadex for rocuronium and vecuronium is calculated on TBW as well. Dosage of remifentanil and fentanyl should be calculated on LBM. Pharmacokinetic models for sufentanil incorporate TBW. With an unchanged systemic clearance but a marked increased distribution volume, lower midazolam concentrations and sedative effects may be expected in obese compared to normal-weight adolescents. The findings imply that a higher initial dose of midazolam may be needed for this population group [22, 27].

Opioid Sensitivity

In animal model, chronic hypoxia due to repeated episodes of desaturation from severe OSAS results in upregulated increase in the density of mu opioid receptors in the respiratory-related

areas of the brainstem. Therefore, both respiratory depressant effect and analgesic effect occur at lower blood concentrations of opioids than in patients or animal models who have not experienced repeated episodes of desaturation. In children with severe OSA, the severity of the nocturnal oxygen desaturation (nSAT) correlates with the sensitivity to exogenously administered opioids. The morphine dose required to achieve a uniform analgesic endpoint in children with OSA who exhibited a low preoperative nSAT <85% was less than in those whose preoperative nSAT >85% (Fig. 13.3) [28–30]. Children with OSAS who underwent tonsillectomy required lower doses of opioids (1/3 to ½ of standard dose) to achieve the same level of analgesia compared with children undergoing the same procedure but for the indication of recurrent tonsillitis [30, 31]. An unforeseen risk of perioperative opioid use in children with severe OSA is that age-appropriate doses of opioids may produce exaggerated respiratory depression. If apnea is seen after small dosages of opioids, the child should be treated as having severe OSA, and further opioid dosages should be completely avoided or minimal and followed by close monitoring of respiration. Children with severe OSAS who exhibit nocturnal hypoxemia require OSA-appropriate opioid regimens.

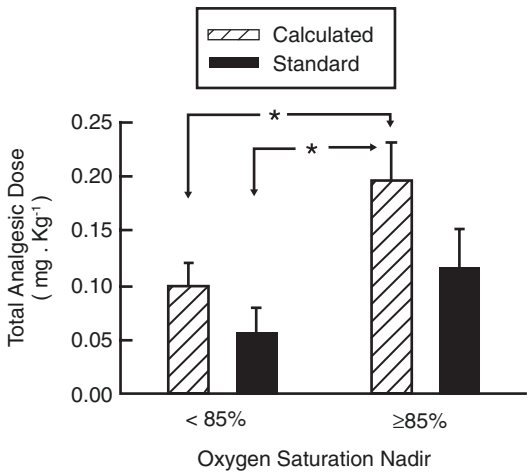

Fig. 13.3 Mean total analgesic morphine dose in children with obstructive sleep apnea after adenotonsillectomy. Children who received the calculated regimen (50% of [0.0007 · age (months)] + [0.0021 · saturation nadir (%)] – 0.1138 mg/kg/dose.) for analgesia are designated by the hatched bar, and those who received the standard pediatric morphine regimen (0.05 mg/kg/dose) are designated by the filled bar

The key strategy in providing safe and effective postoperative pain relief in morbidly obese children is avoiding potent opioids where possible by using multimodal analgesia. These following aspects should be considered [22].

1. Initiate these methods to reduce the need for opioid use intraoperatively, which then will facilitate the reduction of postoperative opioid use.
2. Using core analgesics in line with the steps in the WHO pain ladder.
   - Step 1: Non-opioids – acetaminophen + NSAIDS
   - Step 2: Weak opioids – tramadol
   - Step 3: Strong opioids – narcotics, titrated to effect while monitoring respiratory rate and end-tidal CO_2 levels
3. Incorporation of opioid-sparing adjuvant agents: such as dexamethasone, dexmedetomidine, ketamine, and lidocaine.
4. Use of local or regional anesthesia whenever feasible.

Opioid-free anesthesia and postoperative analgesia for airway surgery can be easily achieved by combining above non-opioid drugs and adjuvants as each of these drugs has been shown to reduce the opioid requirement peri- and postoperatively. Dexmedetomidine has not only analgesic effects but also sedative and autonomic blocking effects. Its autonomic blocking effects are especially beneficial during opioid-free anesthesia. Unlike most of anesthetic agents that reduce pharyngeal tone, diminish the ventilatory response to carbon dioxide, and impair patients' ability to rescue themselves from obstructive apnea during sleep, dexmedetomidine does not produce significant respiratory depression and maintains airway tone with an easily arousable sedation state. These effects may be particularly useful in children with severe OSAS [14, 32]. Perioperative dexmedetomidine administration as an adjuvant leads to significant opioid sparing

in morbidly obese adolescent and adult patients undergoing bariatric surgery with overall better pain control and without any reported major adverse events [33, 34].

Risk of Aspiration

Cook-Sather et al. studied gastric fluid characteristics in pediatric patients undergoing day surgery and found that obese children had similar gastric fluid volume (per IBW) and pH when compared to nonobese children [35]. However, they may be at slightly increased risk of pulmonary aspiration due to increased intra-abdominal pressure from a greatly thickened abdominal wall. The indication for rapid sequence induction should always be questioned in the fasting obese child because the risk of hypoxia during rapid sequence induction is higher than the potential risk of pulmonary aspiration. It cannot be generally recommended to apply a rapid sequence induction in elective cases in obese children.

Ambulatory Surgery

For morbidly obese children, the indication for surgery and the presence of other comorbidities are used to determine if surgery can proceed at the ambulatory surgical center. Children with no significant comorbidities presenting for peripheral surgery may be accepted on a case-by-case basis. Morbidly obese children undergoing airway surgery are not acceptable candidates for ambulatory surgery because almost all of them have severe OSAS and other comorbidities. Despite removal of the hypertrophied tonsils and adenoids, children with severe OSAS continue to demonstrate obstructive apnea and desaturation during sleep on the first night after adenotonsillectomy. This underscores the need to admit these children to a hospital for continuous overnight monitoring postoperatively. Because the onset of respiratory complications in children with severe OSAS may be delayed, practice guidelines from the AAO-NHS, the AAP, and the ASA all recommend that discharge criteria from a monitored setting should include observation with saturation monitoring during sleep [15, 36].

One major problem in using this guideline is that percentile does not directly measure body fat. Some very athletic adolescents can have a high BMI-for-age due to extra muscle mass, but not necessarily excess body fat [36].

IV Access

Securing of peripheral venous lines before induction is recommended in morbidly obese children. Dealing with difficult airway while trying to place intravenous lines in this group of patients may be unsafe. This can be achieved by combination of topical anesthetic cream (EMLA – Lidocaine/Prilocaine) or commercial local anesthetic patch (Synera – Lidocaine/Tetracaine) and 50% Nitrous oxide with minimal patient's movement, even in small children (Author's experience). After a contact time of 35 min, the Synera patch led to superior analgesia during venous puncture in children than the EMLA patch. With regard to visibility of the veins and success rate of the punctures, differences between the two patches were not observed [37].

Frequently, peripheral intravenous line placements can be very difficult or impossible, causing severe stress and time-consuming in morbidly obese children. They were more likely to have failed first attempt than the lean controls, and the most likely site for success after failed attempt on the back of the hand is the volar surface of the wrist [38]. Therefore local anesthetic cream application to reduce pain during venous puncture should be applied to both at the back of the hand and on the volar surface of the wrist. The anesthesiologist and the surgeon must balance the value of persisting vs. proceeding with securing the airway first. In children presenting with history of difficult venous access, ultrasound-guided peripheral venous access leads to faster peripheral IV access, lower median number of punctures, and higher success rate at first cannulation [39]. Central venous line is rarely indicated during airway surgery.

Common Airway Surgery in Morbidly Obese Children

Adenotonsillectomy

Tonsillectomy with or without adenoidectomy represents about 15% of all surgical procedures performed on children annually in the United States, and approximately one-third of those children are overweight or obese [40]. Even though studies have shown that obese children with OSA benefit less from adenotonsillectomy compared to normal-weight children [11] suggesting that obesity itself plays an important role in the pathogenesis of OSA in obese children, adenotonsillectomy is still considered to be the first-line treatment of OSA for obese children with adenotonsillar hypertrophy [12]. In a study at the Mayo clinic in Rochester, morbidly obesity (BMI > 98th percentile) in children undergoing tonsillectomy has been shown to independently increase the risk of perioperative respiratory complications even after adjusting for the presence of severe systemic disorders or syndromes and preoperative respiratory disorders. It was also associated with an increased rate of unplanned hospital admission [41]. A more recent study confirmed that obesity is associated with a 67% increase in major and minor respiratory complications when compared to nonobese children [42].

The anesthetic goals for adenotonsillectomy in morbidly obese children are (1) to provide a smooth, atraumatic induction without airway obstruction or desaturation, (2) to achieve a secured airway throughout the procedure, (3) to establish IV access for volume expansion and medications as indicated, (4) to provide the surgeon with optimal operating conditions, (5) to provide rapid emergence so that the child is awake and able to protect the recently instrumented airway, and (6) to provide adequate perioperative analgesia without airway obstruction and respiratory depression [28].

Pre-anesthetic Evaluation and Preparation

The preoperative assessment should focus on airway issues (OSAS, history of airway difficulty with previous anesthetics), cardiopulmonary issues (especially pulmonary hypertension), and other common comorbidities. All morbidly obese children presenting for adenotonsillectomy should be presumed to have OSAS.

The family interview should include focused questions related to snoring, apneic episodes, frequent arousals during sleep, and daytime somnolence. ASA has published practice guidelines for the perioperative management of patients with obstructive sleep apnea which includes clinical signs and symptoms as well as sleep study criteria to identify and assess OSA in children (Table 13.2) [15].

In North America, the indication for adenotonsillectomy in 77% of children is obstructive breathing [109, 112, 113]. The reality is that less than 10% are evaluated with a sleep test prior to surgery. The challenge is to evaluate the severity of SDB based on clinical criteria alone.

The ASA has created a risk assessment scoring system for patients with sleep apnea (Table 13.5) [15]. There are three areas scored: the severity of sleep apnea, the invasiveness of surgery, and the requirement for postop opioids. Each area is scored on a scale of 0–3. Total point score is combination of severity of OSA points and the greater of the score for either type of surgery and anesthesia points or opioid requirement points (6 is at the highest possible score). Patients with score of 4 may be at increased perioperative risk from OSA, and patients with a score of 5 or 6 may be at significantly increased perioperative risk from OSA. Per this scoring system, morbidly obese children with severe OSAS undergoing adenotonsillectomy would be scored with the highest risk of 6 points.

Preoperative polysomnography (PSG) remains the gold standard to diagnose and estimate the severity of OSA. The AAO-HNS advocates for PSG before tonsillectomy in high-risk children with sleep-disordered breathing if they exhibit certain complex medical conditions including obesity, Down syndrome, craniofacial abnormalities, and neuromuscular disorders [17]. Review of sleep studies is crucial for making a safe anesthetic plan. AHI $\geq$15 and O_2 saturation nadir <80% on PSG have been shown to be inde-

Table 13.5 Scoring system for perioperative risk from OSA [15]

A. Severity of sleep apnea based on sleep study (or clinical indicators if sleep study is not available)	
Severity of OSA points	Points
None	0
Mild	1
Moderate	2
Severe	3
B. Invasiveness of surgery and anesthesia	
Type of surgery and anesthesia points	
Superficial surgery under local or peripheral nerve block anesthesia without sedation	0
Superficial surgery with moderate sedation or general anesthesia	1
Peripheral surgery with spinal or epidural anesthesia (with no more than moderate sedation)	1
Peripheral surgery with general anesthesia	2
Airway surgery with moderate sedation	2
Major surgery, general anesthesia	3
Airway surgery, general anesthesia	3
C. Requirement for postoperative opioids	
Opioid requirement points	
None	0
Low-dose oral opioids	1
High-dose oral opioids, parenteral, or neuraxial opioids	3
D. Estimation of perioperative risk	
Total point score = the score for A + the greater of the score for either B or C	0–6

pendent predictors of postoperative O_2 saturation <90% and length of stay >24 h following adenotonsillectomy in children with severe OSA [43]. A recent study found that AHI ≥ 40 is a strong predictor of postoperative respiratory complications in children undergoing tonsillectomy for OSA [44]. Role of PSG in assessing high-risk populations before tonsillectomy for SDB is summarized in Table 13.6 [17].

Nocturnal oximetry may be the preferred first test to help identify severe OSA in younger children as they may not be cooperative with a PSG study. However, some of these children exhibit a high central apnea index and a low obstructive AHI without desaturation events so that a negative test with nocturnal oximetry does not exclude severe OSA.

Table 13.6 Role of PSG in assessing obese children before tonsillectomy for SDB

Role of PSG	Rationale
Avoid unnecessary or ineffective surgery in children with primarily nonobstructive events	Identify primarily nonobstructive events or central apnea that may not have been suspected prior to the study and may not benefit from surgery
Confirm the presence of obstructive events that would benefit from surgery	The increased morbidity of surgery in obese children requires diagnostic certainty before proceeding
Define the severity of SDB to assist in preoperative planning	Obese children with severely abnormal SDB require preoperative cardiac assessment, pulmonary consultation, anesthesia evaluation, or postoperative inpatient monitoring in an intensive care setting
Provide a baseline PSG for comparison after surgery	Persistent SDB or OSA despite surgery is more common in obese patients than in otherwise healthy children
Document the baseline severity of SDB	High-risk patients are more prone to complications of surgery or anesthesia

Children with cardiac involvement from OSA and obesity are at increased risk of perioperative cardiopulmonary complications. Echocardiography is recommended for cardiac evaluation for any child with signs of right ventricular dysfunction, systemic hypertension, or multiple episodes of desaturation below 70% on PSG. Electrocardiogram and chest radiograph are not sensitive evaluation tools. Routine blood gas analysis is not necessary, but a basic metabolic panel can identify a patient with compensatory metabolic alkalosis in response to chronic hypercarbia, and a hemoglobin level may identify the patient with severe chronic hypoxemia [45]. Table 13.7 summaries recommended preoperative laboratory investigation for morbidly obese children undergoing adenotonsillectomy.

Using of a continuous positive airway pressure (CPAP) device prior to surgery has been shown to be beneficial in adult patients with severe OSA [46]. Effective CPAP/BiPAP therapy may improve pulmonary hypertension [45], and according to ASA guideline, its initiation should be considered to reduce perioperative risk from

Table 13.7 Preoperative laboratory investigation for morbidly obese children undergoing adenotonsillectomy

Laboratory Investigation	Rationale
Blood testing	Hemoglobin levels: baseline level before surgery and polycythemia in the patient with severe chronic hypoxemia Basic metabolic panel: metabolic alkalosis in response to chronic hypercarbia Fasting glucose levels: higher incidence of diabetes
ECG	An ECG should be obtained in morbidly obese children with severe OSAS to look for evidence of pulmonary hypertension and right heart failure
Echocardiography	There are no publications showing a positive predictive value of routinely performed preoperative echocardiography in morbidly obese children. However, for patients with positive evidence of pulmonary hypertension and/or right heart failure on ECG or with history of a poor functional capacity, echocardiogram should be performed
Polysomnography	Sleep study is the gold standard to diagnose and estimate the severity of OSA
Spirometry	There is no evidence for routinely performed spirometry in obese children The use of spirometry in patients with OSA or other respiratory findings seems to be supported by current evidence

OSA, particularly if OSA is severe [15]. One point may be subtracted from total OSA risk score if a patient has been on CPAP before surgery and will be using his or her appliance consistently during the postoperative period. However, there are no reports on its impact to support this measure in children [47].

Premedication

The goal is to calm the child while avoiding the sedative and respiratory depressant effects of anxiolytics whenever possible. Preoperative anxiolysis and sedation can increase the risk of excessive postoperative sedation as its residual effects may persist, especially after relatively short surgical procedure like tonsillectomy, and may potentially exacerbate postoperative respiratory complications as well as prolong recovery room stay. Distraction techniques and parental presence during induction are preferable than premedication with anxiolytics in children with significant OSA. Transient oxygen desaturation has been reported in 1.5% of children with OSA who received 0.5 mg/kg oral midazolam [48]; thus after administration of premedication, all children with severe OSA with symptoms of sleep-disordered breathing should be closely monitored with continuous pulse oximetry [49, 50], and premedication with short-acting drugs and/or those that can be antagonized such as midazolam is advised. However, midazolam PO is seldom given to obese children since the maximum dose of 20 mg would be ineffective in a very large child.

Monitoring

Standard monitoring is usually adequate for adenotonsillectomy surgery in obese children. Larger blood pressure cuffs are needed for accurate measurement. In patients of significant associated cardiac morbidities, an arterial line for invasive blood pressure monitoring and blood gas analysis should be considered. Monitoring of anesthetic depth using bispectral index (BIS) devices may be helpful to guide the correct dosage of hypnotic drugs [18].

Induction/Airway Management

Morbidly obese children with severe OSA can quickly obstruct and become desaturated during induction. Anesthesia clinicians should be prepared for management of the potentially difficult mask ventilation or endotracheal intubation in these patients, with difficult airway equipment and assistance readily available. They should be

pre-oxygenated in reverse Trendelenburg position prior to induction of anesthesia. Proper positioning can significantly improve respiratory mechanics and oxygenation by decreasing the high intra-abdominal pressure and may improve the success in airway manipulation. "Ramping" is a well-described position for adult obese patients being readied for airway manipulation. It is essentially positioning to obtain a horizontal plane between the external auditory meatus and sternal notch. The goal is to provide upper torso and head/neck elevation coupled with neck extension, so the patient's face is parallel to the ceiling. This "Ramped" position improves access to the airway in a variety of ways and offers several advantages including (1) improved line of sight and laryngoscopy view, (2) augmented respiratory effort and improved pulmonary mechanics, (3) downward gravitational displacement of torso/breasts, (4)"open" submental space between mandible/chin and sternum, (5) ease mouth opening (more space for mandibular hinging), (6) ease cricoid-laryngeal cartilage manipulation, (7) provide improved access for invasive/surgical options, (8) more room to manipulate conventional/advanced laryngoscopic devices, and (9) improved mask ventilation [51].

Application of continuous positive airway pressure of 5 cm H_2O by using tight-fitting mask during preoxygenation has been shown to prevent desaturation episodes in a rapid sequence induction in adult obese patients [52]. Preoxygenation with pressure support of 10 cm H_2O and PEEP of 10 cm H_2O for 5 min can add up to a 140 mm Hg to the PaO_2, improving the apnea time by another minute [53]. However this maneuver can be uncomfortable and may be impractical in younger children.

During induction of anesthesia, early pharyngeal airway obstruction may require a jaw thrust maneuver, insertion of an oral or nasopharyngeal airway, and the application of continuous positive airway pressure (CPAP). When an inhalational induction is performed, care must be used to avoid placing an airway, while patients still react to stimulation, or laryngospasm may occur. Persistent respiratory efforts against an obstructed airway from laryngospasm or pharyngeal airway obstruction can result in negative pressure pulmonary edema [14]. The studies indicate that children with high BMI and sleep-disordered breathing undergoing both ENT and non-ENT surgery are at increased risk for perioperative laryngospasm. Mechanisms underlying these increased risks are unclear. One clinical explanation could be light anesthesia since difficult mask ventilation is more commonly reported in children with high BMI and SDB. Other explanations include increased airway sensitivity and possible subclinical airway inflammation [10]. In morbidly obese children with severe OSA, it is prudent to consider securing IV access before induction of anesthesia to expedite administration of muscle relaxants, or IV agents should pharyngeal obstruction, or laryngospasm occur during induction to facilitate rapid instrumentation of the airway. Propofol-associated loss in airway caliber can be reversed with the application of CPAP. CPAP acts as a pneumatic splint to increase the caliber of the pharyngeal airway. Of equal importance, CPAP increases longitudinal tension on the pharyngeal airway, thereby decreasing the collapsibility of the upper airway, and increases lung volumes. Small increments in CPAP between 5 and 10 cm H_2O increase the dimension of the pharyngeal airway dramatically [28].

The use of the laryngeal mask airway (LMA) for adenotonsillectomy was described in 1990, but it was not until the widespread availability of a model with a flexible spiral, metallic reinforced shaft made it practical for use in adenotonsillectomy [28]. It is used in some centers for tonsillectomy because it is less stimulating to the airway and usually results in a smoother extubation with less coughing and straining. Other advantages cited for the LMA over the ETT included a decrease in the incidence of postoperative stridor and laryngospasm [54], although recent evidence disputes these advantages [55]. Indeed a recent review suggests that use of LMAs has not been widely accepted at least in North America. The French Association for Ambulatory Surgery (AFCA) and the French Society for Anesthesia, Intensive Care (SFAR) have published clinical practice guidelines, which recommend a cuffed endotracheal tube for tonsillectomy

[56]. We recommend the use of a cuffed endotracheal tube (ETT) for obese children during adenotonsillectomy, and a supraglottic airway device should be reserved for rescuing airway obstruction in these patients especially during a "can't intubate, can't ventilate" situation [57] or as an adjunct to the management of a difficult airway [14]. Specific advantages of cuffed ETT in this population include its ability to:

- Provide open access to the surgical site, potentially resulting in a more effective resection [58]. On the other hand, LMA takes up more room of oropharyngeal space which may already be narrow from excessive upper airway tissue, a relatively large tongue, and more fat tissue in obese patients.
- Provides definitive airway control that only rarely needs to be replaced. Several studies have reported rates of LMA failure during adenotonsillectomy with the need to convert to ETT, ranging from approximately 4% to 17% [54, 55, 59]. The conversion rate is lower (<1%) in nonobese children with normal airway anatomy and without OSA [59, 60]. Moreover, LMA may be difficult or impossible to place or seat in patients with very large tonsils.
- Adequately ventilate patients with positive pressure during both intraoperative and postoperative periods. Because of decreased lung compliance in obese children, a higher peak inspiratory pressure is warranted when positive pressure ventilation is needed, and this may not be possible with LMA. Obese children also require postoperative ventilation in ICU more often. LMA is not a secured airway device in this setting as it is placed in supraglottic area.
- Prevent the air leak and the consequent bubbling of gas in secretions and blood that can interfere with surgery as well as minimizes pollution by anesthetic gases and decreases the risk of an airway fire when electrocautery is used [28].

While an awake fiberoptic intubation is considered the gold standard approach in a patient with suspected difficult airway, this may not always be feasible in the pediatric patient. Compared to adults, pediatric patients are less likely to cooperate with awake airway instrumentation, so it is usually reserved for mature adolescents. Consequently, the majority of difficult pediatric airways are managed after induction of general anesthesia or deep sedation. Instillation of lidocaine jelly (2%) in the pharynx prior to inhalation induction will allow for early insertion of a supraglottic airway device (e.g., oral airway or an LMA) without inducing untoward airway responses or possibly laryngospasm. Video laryngoscopy has been studied in adult obese patients and may provide improved intubating conditions compared to a conventional laryngoscope [61]. Recent meta-analysis demonstrates that video laryngoscopy improved glottis visualization in pediatric patients with normal airways or with potentially difficult intubations but with the expense of longer time to intubation [62]. There are no specific studies in obese children. Further studies are needed to clarify the efficacy and safety of video laryngoscopy in this group of patient.

Baraka et al. described apneic oxygenation technique by nasopharyngeal oxygen supplementation in morbidly obese adult patients during elective intubation (general anesthesia with muscle relaxation). The time to oxygen saturation (SpO_2) less than 95% was significantly longer in the apneic oxygenation group treated with nasopharyngeal oxygenation (240 vs 145 s) [63]. Ramachandran et al. found similar results; the lowest SpO_2 level in the apneic oxygenation group was higher than the control group, and the onset of desaturation was delayed [64]. Another study demonstrated the novel use of apneic oxygenation via RAE tube placing in buccal area to adult obese patients during induction of anesthesia that clinically prolonged safe apnea times (750 vs 296 s) [65]. In a newly described technique, transnasal humidified rapid-insufflation ventilatory exchange (THRIVE), nasal high-flow oxygen insufflation has been shown to prolong the safe apnea time in healthy children but has no effect to improve CO_2 clearance [66]. Currently, there are no clear data to confirm, support, or

refute its use in the pediatric population. However, it is simple to initiate, easy to administer, inexpensive (via high-flow nasal cannulas), readily available, and appears to have no reported complications; therefore it should be considered as a potentially useful technique.

Maintenance of Anesthesia

The main goal of anesthetic management for morbidly obese children is early and full recovery of consciousness and protective reflexes. To achieve this goal, multimodal analgesia and multimodal anesthesia are the keys and should be initiated from the moment of induction. Utilization of short acting anesthetic agents helps facilitate this process [22].

Of the currently available inhalational agents, both sevoflurane and desflurane have low blood–gas partition coefficients and low oil–gas solubilities resulting in a rapid onset and offset combined with a high degree of control over the anesthetic level obtained, as measured by the end-tidal concentrations. Sevoflurane provides a smooth induction of anesthesia as children who are scheduled for adenotonsillectomy have a high incidence of airway reactivity and laryngospasm. Desflurane used for maintenance in intubated patients provides a rapid emergence and recovery [67, 68] as shown in a recent meta-analysis exploring the differences in emergence between sevoflurane and desflurane which reported decreased time to extubation in favor of desflurane. N_2O is the inhalational agent with the lowest blood–gas solubility and a lipid solubility, less than Desflurane, and is being increasingly used in morbidly obese patients as a volatile-sparing adjunct. Its second gas effect during induction and emergence can accelerate wash in and wash out of volatiles [22]. However, it should not be used during airway surgery due to its combustibility.

Remifentanil allows the maintenance of a profound level of opioid effect without the prolonged apnea seen with longer-acting opioids, which is especially important for children with severe sleep apnea. Remifentanil may increase postoperative pain because of its central sensitization effect leading to increased opioid requirement and possibility of increased risk for postoperative respiratory depression [32].

Determining the optimal analgesic regimen for tonsillectomy in obese children can be even more complicated because children with high BMI appear to have increased early post-tonsillectomy pain, a phenomenon that currently lacks any solid explanation [69].

If muscle relaxant is used, full reversal of neuromuscular blockade is mandatory. Sugammadex has been shown to provide a safer and faster recovery (less time to reach a train-of-four ratio ≥ 0.9) from profound rocuronium-induced neuromuscular blockade than neostigmine did in adult patients with morbid obesity. Upon PACU arrival, level of SpO_2, ability to swallow ($p = 0.0027$), and ability to get into bed independently were better in patients who received sugammadex after bariatric surgery [70].

Perioperative Analgesia

Over the last decade, there has been a shift from opioids as the mainstay of perioperative analgesia to non-opioid regimens including dexmedetomidine, acetaminophen, NSAIDs, dexamethasone, and ketamine. Multimodal approach is the key to staying away from opioid-induced respiratory depression.

Acetaminophen It is commonly used as a component of multimodal analgesic approach in these children [71]. An intravenous formulation of acetaminophen is available in many countries, offering the theoretical advantage of greater predictability than the oral and rectal routes.

NSAIDS Despite concerns that the routine use of NSAIDs for adenotonsillectomy might increase the risk for post-adenotonsillectomy hemorrhage [72, 73], the AAO-HNS now recommends their use for postoperative analgesia. An audit of more than 4800 pediatric tonsillectomies in which the NSAIDs diclofenac and ibuprofen were routinely used reported a primary hemor-

rhage rate of 0.9% [74]. Because the effects of ketorolac on platelet function are reversible, the effect is dependent on the presence of ketorolac within the body [75]. Thus, unlike the effect of aspirin, this effect is short-lived. However, we recommend avoiding NSAIDs, especially ketorolac, *during* surgery. When used for postoperative analgesia, they should be administered after hemostasis is achieved [76] and should only be administered in consultation with the surgeon. NSAIDs and acetaminophen have been shown to be effective analgesics for post-tonsillectomy pain management [77], especially when they are used in alternating doses [78].

Steroids A single intraoperative dose of dexamethasone reduces post-adenotonsillectomy pain and edema when electrocautery has been used. The minimum morphine-sparing dose for dexamethasone is reported to be 0.5 mg/kg [79]. The use of dexamethasone is used to be controversial because of a possible linkage to post-tonsillectomy hemorrhage. In 2008 Czarnetzki et al. reported an increase in bleeding in children who had received dexamethasone up to 0.5 mg/kg (maximum 20 mg) [80]. However, these findings have been refuted by others [81–85]. The consensus opinion summarized in an editorial by Yee et al. in 2013 is that single intraoperative dose of dexamethasone does not cause clinically important hemorrhage following tonsillectomy. Single doses of dexamethasone have not been associated with aseptic necrosis of the hip or infections but have been responsible for precipitating the acute tumor lysis syndrome [86–88]. However blood glucose levels can increase after one dose of dexamethasone; thus it should be used cautiously in patients with history of diabetes or glucose intolerance.

Local Infiltration of Local Anesthetic Infiltration of local anesthetics into the tonsillar fossa during tonsillectomy is reported to decrease postoperative pain, but the pain relief is transient [89]. In addition, life-threatening complications have been reported after local anesthetic infiltration in the tonsillar fossa, including intracranial hemorrhage, bulbar paralysis, deep cervical abscess, cervical osteomyelitis, medullopontine infarct, and cardiac arrest. The risks associated with injection of local anesthesia in the tonsillar fossa may outweigh its potential benefits, particularly in inexperienced hands [90, 91]. Blockade of neural input to the upper airway dilator musculature in children with OSA is also problematic. Serious life-threatening complications, including severe upper airway obstruction (UAO) and pulmonary edema, have been reported after local anesthetics have been infiltrated in the tonsillar fossa to prevent pain after adenotonsillectomy. The pharynx in children with OSA is not only smaller in size, but also more collapsible, even during wakefulness, compared with those children who do not have OSA. Topical anesthesia applied to the mucosa of the pharynx of children with OSA reduces the caliber of the pharynx and may thereby compromise airway patency.

Dexmedetomidine An infusion of dexmedetomidine 1–2 mcg/kg iv over 5–10 min combined with an inhalation agent can provide satisfactory intraoperative conditions for adenotonsillectomy without adverse hemodynamic effects. In children with OSAS, postoperative opioid requirements are significantly reduced, and the incidence and severity of severe emergence agitation are reduced, with few children desaturating [92]. After larger doses of dexmedetomidine (2 and 4 mcg/kg), the opioid-free interval increases, and the postoperative opioid requirements decrease. However, duration of stay in the PACU is prolonged [93]. A meta-analysis of randomized controlled trials showed that intraoperative use of dexmedetomidine was as effective as opioids (fentanyl or morphine) in preventing postoperative pain and emergence agitation in children who had undergone tonsillectomy and adenoidectomy [94].

Ketamine Recent studies have found great success in adding ketamine to oral midazolam syrup for premedication to help reduce agitation and postoperative pain in the first 30 min following surgery [95]. Combination of single dose of ketamine (0.25 mg/kg iv) and acetaminophen (15 mg/kg iv) provided significantly better postoperative

analgesia in children at 0.5 and 6 h after adenotonsillectomy than acetaminophen alone [96].

Codeine Once considered a "low-risk" oral opioid and commonly used for post-tonsillectomy pain, codeine now is not recommended because of its safety and efficacy profile. Respiratory arrest after codeine has been reported in both adults and children who demonstrate ultra-rapid metabolism of codeine. Whereas the ultra-rapid metabolizing genotype is present in 3% of Caucasians, it is present in 10–30% of Arabian and Northeast African populations. In contrast, almost 10% of children lack of metabolizing "CYP2D6" enzymes, rendering codeine an ineffective analgesic. The FDA recently required that the manufacturers of all codeine-containing products add a boxed warning to the labeling of their product that describes the risk posed by codeine after a child has undergone tonsillectomy or adenoidectomy and codeine use is contraindicated in such patients [28, 97].

Choice of Spontaneous vs Controlled Ventilation

Children with OSA have a diminished ventilatory response to CO2 and are more sensitive to opioids compared to others without OSA. Spontaneous respiration during maintenance of anesthesia enables an assessment of the response to small challenges of opioid analgesics and is usually recommended during adenotonsillectomy [29]. In this manner, the anesthesiologist can assess the sensitivity of the child with OSAS to opioids. Controlling respiration precludes such an evaluation. However, in morbidly obese children, there are several pathophysiologic changes of respiratory system including decreased chest wall compliance, decreased FRC from increased intra-abdominal pressure, and increased oxygen consumption. These changes contribute to higher rates of perioperative hypoxia from reduced oxygen reserves, more rapid desaturation, and increased work of breathing. Maintaining spontaneous breathing following induction of anesthesia in the supine position for this group of patients can be challenging. Pressure support ventilation mode preserves patient's initiating effort to breathe while allowing positive pressure ventilatory support. PEEP of 5–10 cm H_2O, intermittent recruitment maneuver, and head-up position are recommended to prevent basal atelectasis [52].

Dexmedetomidine has the benefit of providing analgesia and sedation with minimal respiratory depression. Its use along with other non-opioid analgesics makes the objective of maintaining spontaneous respiratory effort for these obese children more plausible [34].

Emergence and Postoperative Case

Non-depolarizing muscle relaxant is rarely administered during routine adenotonsillectomy. However, in morbidly obese children, it may be given as a part of "balanced" anesthesia to prevent coughing, gaging, or movement. Full antagonism of neuromuscular blockade is mandatory as residual neuromuscular blockade in the recovery room will selectively depress the function of the upper airway dilators relative to the diaphragm, promoting collapse of the pharyngeal airway. In comparison with neostigmine, sugammadex can more rapidly reverse rocuronium-induced neuromuscular block regardless of the depth of the block [98]. It has been shown to provide a safer and faster recovery (less time to reach a train-of-four ratio ≥ 0.9) from profound rocuronium-induced neuromuscular blockade than neostigmine did in adult patients with morbid obesity. Upon PACU arrival, level of SpO_2, ability to swallow ($p = 0.0027$), and ability to get into bed independently were better in patients who received sugammadex after bariatric surgery [70, 99].

Extubation of the trachea should be performed when the child is fully awake with complete return of protective airway reflexes. Placement of a nasopharyngeal or oropharyngeal airway prior to extubation is sometimes useful. Intact airway and pharyngeal reflexes are of utmost importance in preventing aspiration, laryngospasm, and air-

way obstruction. After extubation, the child should remain in the tonsil position postoperatively while being carefully observed and monitored during transport to the recovery room. Lateral positioning has been shown to increase upper airway cross-sectional area and total upper airway volume when compared with the supine position [100]. Once patients can maintain adequate airway patency, they should be placed in the upright position to increase functional residual capacity (FRC) and reduce the risk of basal atelectasis.

Despite removal of the hypertrophied tonsils and adenoids, children with OSAS continue to demonstrate obstructive apnea and desaturation during sleep on the first night after adenotonsillectomy, with the frequency of the obstructive events and the severity of desaturation usually greater in those children with severe OSAS. This underscores the need to admit these children to a hospital for continuous overnight monitoring postoperatively. The majority of desaturation events on the first postoperative night are obstructive apnea. Statements from the American Academy of Pediatrics and the American Academy of Otolarygology–Head and Neck surgery now recommend admission to hospital following adenotonsillectomy for, respectively, an AHI >24 and an AHI >10 events per hour. Current pediatric tertiary care admission practices following adenotonsillectomy were recently published and show that 73% of respondents reported using some measure of obesity as a criterion for postoperative admission [101]. Fung et al. found that obese children were nearly 9 times more likely to have postoperative respiratory events, such as oxygen desaturation, airway obstruction, respiratory depression, cough, and bronchospasm, compared with their normal-weight counterparts. In obese children, of those experiencing desaturation events in the immediate postoperative period, 75% of them continued to experience respiratory events through the first postoperative night [102]. Therefore, it is prudent to observe the obese child overnight, especially if a preoperative PSG was not performed, owing to the uncertainty of the severity of the obstruction and degree of hypoxemia.

Morbidly obese children with severe OSA and complex medical diseases, who are critically dependent on the function of upper airway musculature, may benefit from delayed extubation. Acute relief of chronic UAO favors the exudation of intravascular fluid into the pulmonary interstitium and noncardiogenic pulmonary edema, which may present preoperatively, intraoperatively, and postoperatively. Supportive measures include the administration of oxygen, endotracheal intubation, mechanical ventilation with positive end-expiratory pressure, and administration of furosemide. Individuals with obstructive sleep apnea who use continuous positive airway pressure (CPAP) devices may benefit from the use of CPAP upon emergence by splinting open airways. In the past, it was generally felt that CPAP or BiPAP was contraindicated after surgery on the airway, following case reports in the ENT literature describing subcutaneous emphysema and pneumomediastinum/pneumothorax after T&A. Although there was no relationship to positive pressure airway support, the hypothetical risk was assumed. However, a retrospective study suggested that BiPAP is a safe and effective method of respiratory assistance for children after T&A [103]. In a study of 1735 consecutive pediatric patients undergoing tonsillectomy with or without adenoidectomy, Tweedie and colleagues reported that the odds ratio for obese patients requiring an unexpected PICU admission was 10.6 compared to nonobese patients [104].

Diagnostic Laryngoscopy and Bronchoscopy

Although diagnostic laryngoscopy and bronchoscopy procedures (DLB) are usually brief, the anesthetic management can be challenging in morbidly obese children with OSA because of a potential difficult airway and rapid desaturation. The anesthetic plan and goals should be discussed with endoscopists prior to induction, emphasizing obesity related comorbidities especially pulmonary and cardiac function as well as potential for a difficult airway. Anesthetic goals may include the following: (1) maintain sponta-

neous ventilation initially when surgeons may be attempting to evaluate vocal cord movement for dysfunction; (2) maintain a patent airway with an ability to provide controlled ventilation and, if needed, to ensure effective oxygenation and ventilation; (3) provide an adequately deep level of anesthesia; (4) prevent a laryngospasm; and (5) provide a rapid recovery of airway reflexes and ventilation.

Anesthesia for DLB in morbidly obese children can be done with total intravenous anesthesia (TIVA) technique or inhalational agents. It usually starts with an inhalational induction and then switches to TIVA during procedure when ventilation is intermittently interrupted, and it becomes difficult to maintain an appropriate depth of anesthesia with inhalational technique. A TIVA technique has the advantage that it can be given continuously during the procedure, resulting in a more stable level of anesthesia. A combination of local anesthetics deposited on the vocal cords with TIVA using propofol and dexmedetomidine is a common anesthetic regimen. Remifentanil and/or Ketamine titrated to effect are frequently used as supplements. Dexmedetomidine maintains spontaneous ventilation, airway patency, and tone, making it an ideal choice for dynamic upper airway evaluation even at higher doses (3 mcg/kg/h) in children with OSA [105, 106]. Recent study showed that, in adult patients with OSA, sedation with dexmedetomidine for sleep endoscopy comparing to with propofol resulted in slightly lower degree of upper airway narrowing, significant higher minimal oxygen saturation, and less number of patients with oxygen saturation <80% [107]. Small doses of ketamine (0.5–1 mg/kg) can be used to enhance analgesia and increase depth of anesthesia without further compromising the airway by muscle relaxation or suppressing respiratory drive [108]. A study showed that ketamine was accompanied by lower levels of upper airway dilator muscle dysfunction compared to the equi-anesthetic concentration of propofol, with preservation of ventilation with a wide dose range of ketamine [109]. A combination of ketamine and dexmedetomidine bolus followed by a dexmedetomidine infusion has been shown to provide sedation without exacerbating respiratory problems in children with Down syndrome and OSA [109]. The combination of dexmedetomidine and ketamine provided fewer oxygen desaturations to <85% compared with either propofol alone or sevoflurane plus propofol for drug-induced sleep endoscopy in children with persistent OSA despite surgical interventions (including previous tonsillectomy and adenoidectomy) [110]. Remifentanil infusion titrated of the patients' respiratory rates provide a good level of immobility while still permitting relatively rapid emergence. However, it frequently induces apnea and should be started at a very low dose due to sensitivity to opioids in morbidly obese children.

Due to their physiologic changes, rapid desaturation is expected in this patient population during DLB; therefore strategies to maintain oxygenation and ventilation are needed. There are various techniques that can be employed.

1. Spontaneously breathing with oxygen insufflation: Supplemental oxygen can be connected to the oxygen port on the surgical laryngoscope to provide oxygen to the oropharynx that is drawn into the lungs during spontaneous ventilation. Alternatively, an ETT connected to the anesthesia machine circuit can be placed in the surgeon's hand that is holding the laryngoscope with the distal opening of the tube in the posterior oropharynx. This technique should delay the onset of desaturation.
2. Apneic technique with intermittent mask ventilation and/or intubation: This technique will provide both oxygenation and ventilation, but surgical procedure is interrupted intermittently. It may be needed in patients with severe OSA who most likely would stop breathing or have significant hypoventilation during a deep plane of anesthesia. For patients who require prolonged surgical interventions, intermittent intubation may be more appropriate than mask ventilation.
3. Ventilation through the rigid bronchoscope: This technique can be done by attaching the anesthesia circuit with a flexible extension to the side port of the rigid bronchoscope. High

resistance may be encountered during positive pressure ventilation because of the length and the small diameter of the rigid bronchoscope. Moreover, the ventilation is more difficult and unlikely to be adequate due to leakage around the bronchoscope and low lung compliance in morbidly obese child.

4. Jet ventilation technique: This technique provides an unimpaired vision of laryngotracheal structures and access for surgical instruments. However, there are several potential problems related with it in morbidly obese children. Because of high inflation pressure requirement, barotrauma such as pneumothorax and pneumomediastinum and severe CO_2 retention can occur especially if there is an obstruction to expiratory flow [110]. There is also the possibility of hypoxemia, because the high-pressure oxygen entrains room air, diluting the inspired oxygen consumption. Therefore, jet ventilation has been considered a poor alternative for obese children. However, recent evidence has challenged this notion and reported the feasibility safety of jet ventilation in obese adult patients [110, 111].

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14 Extracorporeal Membrane Oxygenation (ECMO) Considerations in Fulminant Airway Obstruction

Andrew J. Matisoff and Mark M. Nuszkowski

Introduction

Extracorporeal membrane oxygenation (ECMO) is the most common form of mechanical cardiopulmonary support used in children. Since its introduction in 1970 by Baffles for use in children with congenital heart disease, over 57,000 children have been placed on ECMO support for life-threatening conditions [1]. In pediatric patients with life-threatening obstruction of the central airways, the use of ECMO has emerged as a technique for stabilization until the obstruction can be relieved and ventilation can be established. With the development of rapid deployment ECMO teams, many patients who fail to respond to standard measures of resuscitation can be placed onto ECMO as a means of stabilization. In patients where fulminant airway obstruction is anticipated, the use of ECMO backup which includes an ECMO cannulation team and a primed ECMO circuit can be ready to assist if needed. While ECMO plays a vital role in supporting children with life-threatening conditions, a large number of severe complications continue to occur as a result of ECMO. Clinicians must weigh the significant risks of ECMO when considering its use in patients with airway obstruction.

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The ECMO Circuit

ECMO is essentially a prolonged use of the extracorporeal cardiopulmonary bypass (CPB) circuitry for acute, reversible, cardiac, or respiratory failure. In venovenous (VV) ECMO, the blood is drained from the venous circulation (right internal jugular or femoral vein) and returned to the venous circulation via the internal jugular or right atrium. It is primarily used for respiratory disorders when the cardiac function is adequate. Venoarterial (VA) ECMO involves drainage of blood through the venous circulation and returning it to the arterial system via the femoral artery, carotid artery, or aorta. It is used for patients with cardiac dysfunction or in cases of ECPR [2, 3].

A standard ECMO circuit consists of a mechanical pump, a membrane oxygenator, and a heat exchanger, connected by tubing between the venous access and arterial access of the patient (Fig. 14.1). The mechanical pump, either roller or centrifugal, provides the cardiac support, while the oxygenator provides the respiratory function. There are routinely two types of pumps used in ECMO, the roller pump and the centrifugal pump. The roller pump works by compressing a

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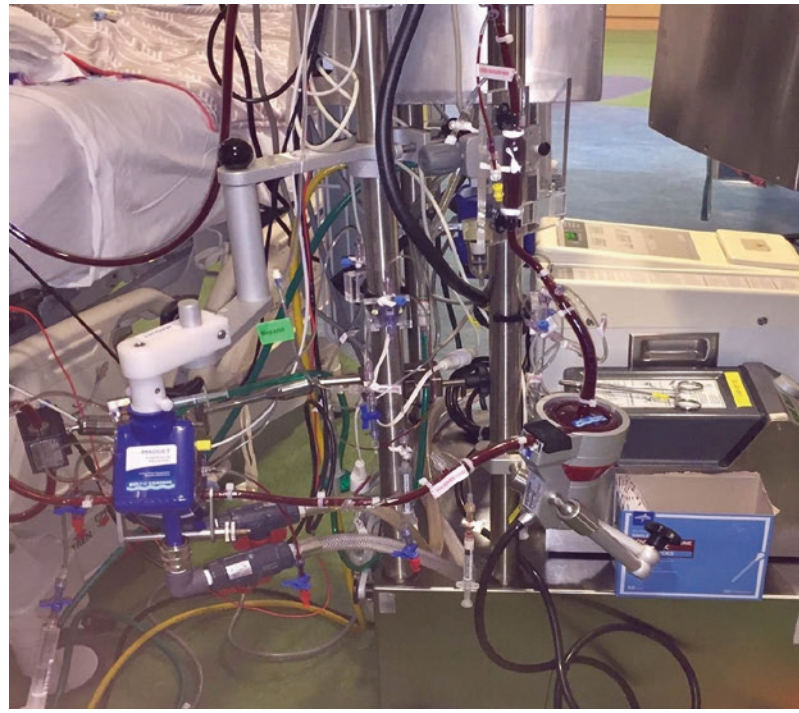

Fig. 14.1 A typical pediatric ECMO circuit

segment of tubing, which pushes blood forward, thereby producing continuous blood flow. The centrifugal pump consists of an impeller which couples magnetically with an electric motor either directly or through a tether. The spinning of this magnet in conjunction with another magnet in the driving unit produces a pressure differential causing forward blood flow [4]. While more costly than roller pumps, centrifugal pumps are gentler on blood-forming elements, with less red cell damage over the course of a long ECMO run. In addition, centrifugal pumps cannot become over pressurized, which can occur with roller pumps if the circuit were to be clamped or kinked while the pump is running. Conversely, if a centrifugal pump is stopped without clamping, retrograde flow can develop, while the occlusive nature of the roller pump prevents it. Excessive negative pressure on the pumps can be controlled with the use of an in-line reservoir, a compliance chamber which is added to the venous system of the ECMO circuit.

All ECMO circuits have a gas exchange device called an oxygenator, which adds oxygen and removes carbon dioxide from the blood. Composed of compressed polymethylpentene (PMP), these new fibers are extremely efficient at gas exchange, with minimal plasma leakage, and relatively low resistance to blood flow, making them easy to prime [4]. Many of the newer oxygenators also have the heat exchanger, comprised of a metal coil, mainly stainless steel, built into the oxygenator bundle [5, 6]. Water passing through the coil alters the blood temperature, which in turn alters the core temperature of the patient accordingly. Incorporating the heat exchanger into the oxygenator allows for the patient temperature to be controlled during ECMO while maintaining a lower prime volume [3]. After a cardiac arrest, for example, a patient may be actively cooled and slowly rewarmed over the course of several hours or days providing for optimal recovery.

ECMO Cannulation

Like other components of the ECMO circuit, vascular cannulas have been redesigned by use of computer animation and simulation, which have

improved efficiency of blood flow and overall performance. Cannulas are commercially available in a variety of models and sizes ranging from 6 Fr (2 mm diameter) to 51 Fr (17 mm diameter), with distinct features of each type targeted to a specific cannulation strategy, customizing them to the unique requirements of the individual patient. Proper positioning of the tip of the cannula near the inferior cavoatrial junction is necessary for optimal cannula performance. This is important, as incorrect placement will result in recirculation of the blood within the ECMO circuit, which reduces overall efficiency of gas exchange. Ultimately, cannula selection is based on the estimated flow rate, level of support to be provided, cannulation site, and type and size of the vessels to be accessed for either VA or VV ECMO [1].

Rapid Response Teams

A rapid response ECMO team consists of a surgeon to perform the ECMO cannulation, an ECMO specialist (perfusionist or respiratory therapist), surgical nurses and scrub technologists, and an intensive care physician. In the operating room, the anesthesiologist can perform the role of the intensive care physician during ECMO deployment.

The decision to place a patient on ECMO is usually made by the intensive care physician, often in consultation with the surgeons performing the cannulation. When a rapid response ECMO is activated, the team is contacted and expected to arrive at the patient's side to perform the cannulation in a designated amount of time. Some institutions perform all ECMO cannulations in the cardiac intensive care unit and operating rooms, so if ECMO is required, the patient must be transferred to these locations prior to cannulation. Surgical supply carts with all supplies necessary for intrathoracic, cervical, or femoral cannulation are immediately available at all times and are brought to the cannulation along with the ECMO circuit. The ECMO circuit consists of an oxygenator, a venous reservoir, and a centrifugal pump [2]. The carbon dioxide vacuumed circuits are primed in a sterile fashion with a crystalloid prime, and blood products are sent for and used to prime the circuit when necessary [2, 7]. During extracorporeal cardiopulmonary resuscitation (ECPR), CPR and other resuscitative measures are continued in a sterile fashion, while the cannulation is being performed until adequate ECMO flows are achieved [2]. While the use of rapid response teams has improved the process and flow of ECMO cannulation, evidence of improved survival is lacking. Turek et al. analyzed demonstrated reduced neurologic complications but no improvement in survival over an 8-year period after implementation of a pediatric rapid response ECMO program [8].

Indications for ECMO

The ELSO registry documents the use of ECMO for respiratory support, cardiac support, and ECPR. Through July 2017, 87,376 patients have required ECMO with neonates composing the largest population of patients.

VV ECMO is used to support the respiratory system when life-threatening hypoxia is inevitable despite maximal ventilatory support. Common causes include ARDS, congenital diaphragmatic hernia, and as a bridge to lung transplantation [9]. In neonatal and pediatric patients who require ECMO for pulmonary support, 72% and 58% of patients survive to discharge, respectively [1].

VA ECMO is used to support the heart due to low cardiac output despite adequate intravascular volume, inotropic support, and an intra-aortic balloon pump (IABP). In pediatric patients, the most common uses of VA ECMO are sepsis, inability to wean cardiopulmonary bypass, and chronic cardiomyopathy [1, 2, 9]. The survival to discharge after ECMO for cardiac support remains low at 51% in pediatric patients [1].

The number of patients who require either VV or VA ECMO for ECPR remains low at 9223 through July 2017, with a much lower survival to discharge under 40% [1].

Indications for ECMO in Fulminant Airway Obstruction

In pediatric patients, central airway obstruction most commonly occurs due to aspiration of a foreign body [10]. Clinicians are able to preserve adequate ventilation and oxygenation in the majority of these patients via endotracheal intubation, rigid bronchoscopy, and jet ventilation. In cases of severe tracheal obstruction when ventilation cannot be maintained, imminent death and disability can occur due to hypoxia. The use of venovenous (VV) ECMO can ensure adequate oxygenation and carbon dioxide removal until the airway obstruction is relieved.

When fulminant airway obstruction is suspected or anticipated, a multidisciplinary approach to plan for ECMO if standard airway measures are unsuccessful could be lifesaving. Airway management should be performed in a location where ECMO cannulation is most suitable, preferably the operating room. Prior to any airway management, a plan for the type of ECMO needed (VV versus VA), cannula size, need for blood products, site of ECMO (neck versus chest), and patient positioning for ECMO should occur between team members [11, 12]. An ECMO circuit should be primed, and a team of surgeons and nurses trained to perform ECMO cannulation should be immediately available. In the nonurgent setting, the patient may be placed on ECMO prior to managing the airway to avoid periods of prolonged hypoxia [11, 13].

Several cases documenting the utility of VV ECMO for airway obstruction have been described, with the majority in the adult literature. Kim et al. retrospectively analyzed 15 patients treated with ECMO for airway obstruction ranging in age from 9 to 50 [12]. Seven patients were electively placed on ECMO in anticipation of life-threatening airway obstruction occurring during induction of anesthesia or surgery. All of these patients were successfully weaned off ECMO. Two of three patients died who were placed on ECMO emergently due to loss of the airway during induction of anesthesia. Five of seven patients survived who required emergent ECMO for massive hemoptysis. The authors concluded that ECMO was a useful adjunct for airway obstruction, but was better when used electively in anticipation of airway obstruction [14]. Hong et al. described 19 cases of VV ECMO use in adult patients with airway obstruction due to malignant tumors [15] and benign lesions in a single center study [15]. Ninety-four percent of these patients were successfully weaned off ECMO after treatment of the underlying cause of airway obstruction with minimal complications. The authors suggested expanding the use of VV ECMO to include airway obstruction and that its use could allow proper management of patients who were previously deemed too high risk for surgical relief of the airway obstruction. Park described the successful use of ECMO in three children with complicated foreign bodies. The indications for ECMO were inability to perform rigid bronchoscopy due to hypoxia or the potential loss of airway support. No complications resulted from ECMO which was weaned rapidly after foreign body removal [13].

Some neonates born with critical tracheal stenosis cannot survive beyond birth without immediate intervention for airway obstruction. ECMO is useful to stabilize these infants prior to airway reconstructive surgery. Kunisaki performed a retrospective review of three children at Boston Children's Hospital who required ECMO within 24 h after birth for critical tracheal stenosis due to complete tracheal rings [2] and bronchogenic cyst [1, 16]. All children underwent subsequent successful airway reconstructive surgery with excellent neurologic outcomes. Then authors stated that "ECMO is the preferred extracorporeal technique in relatively unstable infants with isolated tracheal anomalies" [16].

Another indication where ECMO may be the treatment of choice is the rare occurrence of pediatric sand aspiration due to accidental burial. In severe cases these patients present with severe hypoxia and acute respiratory distress syndrome (ARDS) and require multiple bronchoscopic lavages. Issac et al. and Baquis et al. described

two cases where ECMO was required to maintain oxygenation, while the surgeons were able to remove the sand particles from the airways [17–19]. Both patients survived with good neurologic outcome.

Contraindications to ECMO

All patients who are placed onto ECMO must have a reasonable chance of survival after the problem that led to ECMO cannulation has been reversed. In patients with end-organ failure, the patient should be a candidate for organ transplantation or destination ventricular assist device placement prior to placement onto ECMO. In patients with severe airway obstruction, only patients who are expected to recover with good neurologic function after the obstruction is relieved should be considered for ECMO [2]. Because the decision to place a patient onto ECMO is often made rapidly during an emergency situation, there is a potential for variability among institutions and practitioners on which patients are candidates for ECMO. Makdisi and Wang summarized the absolute and relative contraindications for placing a patient onto ECMO (Table 14.1).

Table 14.1 Contraindications to ECMO [2, 9]

1. Unrecoverable heart and not a candidate for transplant or destination therapy of VAD support
2. Disseminated malignancy
3. Known severe brain injury
4. Unwitnessed cardiac arrest
5. Prolonged CPR without adequate tissue perfusion
6. Unrepaired aortic dissection
7. Severe aortic regurgitation
8. Severe chronic organ dysfunction (emphysema, cirrhosis, renal failure)
9. Compliance (financial, cognitive, psychiatric, or social limitations in patient without social support)
10. Peripheral vascular disease is contraindicated in peripheral VA ECMO
11. VV ECMO is contraindicated in cardiogenic failure and in severe chronic pulmonary hypertension (mean pulmonary artery pressure >50 mmHg)
12. Relative: contraindication for anticoagulation, advanced age, and obesity

Complications of ECMO

Despite the obvious clinical benefits of ECMO, complications from ECMO are numerous and frequent. The severity and types of complications often depend on the type of ECMO used (VV versus VA) and the manner in which it was instituted (elective versus emergent) [2, 7, 9]. Patients who require VA ECMO for ECPR likely have the highest number of complications due to the emergent and limited time allowed for placement onto ECMO [9]. Given the frequency and severity of complications on ECMO, clinician should weigh the risks of such complications against its possible benefits prior to its institution.

Bleeding at the site of cannula insertion or at other sites such as pulmonary, intra-abdominal, and intracerebral occurs due to anticoagulation, and platelet dysfunction is often severe and frequently requires surgical intervention. It has been reported in 17 and 34% of ECMO patients [20]. Treatment involves decreasing the anticoagulation and infusion of blood products as necessary. Thrombosis due to clot formation in the ECMO circuit can lead to strokes, pulmonary embolism, and limb ischemia. Limb complications due to hypoperfusion or thrombosis which result in auto-amputations can be devastating. Infection is common on ECMO due to immunosuppression from blood products and exposure to a large foreign surface. Neurologic complications, including seizures, hemorrhage, and infarction, can occur, with neonates at especially high risk. Other common complications include renal insufficiency, metabolic derangements, hypertension, and arrhythmias.

Weaning from ECMO for Airway Obstruction

Weaning from ECMO involves incrementally decreasing ECMO flows while monitoring for signs of cardiopulmonary dysfunction and providing medical management as necessary to support the patient's blood pressure and ventilation [2, 7, 21]. The decision to wean a patient from ECMO depends on several factors, with the

most important one being the resolution of the underlying problem which resulted in ECMO. In patients who require ECMO for airway obstruction, ECMO can be rapidly weaned when the source of airway obstruction is removed. If the source is a foreign body such as a tumor or inhaled foreign body, the patient should tolerate removal from ECMO as soon as the foreign body is removed [12, 15, 22, 23] provided they have adequate fluid, electrolyte, and nutritional status [2]. Documented cases describing ECMO use for airway obstruction have been associated with rapid weaning from ECMO, provided the underlying problem was corrected [12, 15, 23]. If the cause of airway obstruction is severe tracheal stenosis which required surgical intervention such as a tracheoplasty, some surgeons may maintain the patient on ECMO to allow for adequate healing of the tracheal suture line [24]. Patients who have required ECMO for longer periods may have other factors which impede weaning from ECMO, such as cardiac dysfunction, pulmonary edema or hemorrhage, or renal insufficiency.

Anesthetic Management of Patients on ECMO

Anesthesiologists who manage patients on ECMO should have a thorough understanding of the physiologic and pharmacokinetic effects of ECMO to preserve end-organ function and maintain adequate sedation and analgesia. Patients on ECMO require constant monitoring of volume status, coagulation, cardiac function, and organ perfusion. In VA ECMO, flows are initiated at 100–150 ml/kg/min for pediatric patients. Anticoagulation is initiated with a heparin bolus followed by an infusion of 10–30 units/kg/h [7]. Vasopressor infusions are added to maintain the mean arterial pressure greater than 45 mmHg in neonates and greater than 60 mmHg in children and adults [2, 7]. Invasive blood pressure and central venous pressure monitoring is essential for accurate measurement of blood pressure, central venous pressure, and blood gas analysis [25]. NIRS monitoring is commonly used as noninvasive measure of cerebral hypoxia. Cerebral desaturation on one side of the brain as demonstrated by a NIRS monitor may be an early indicator of cannula misplacement or inadequate cerebral venous drainage [7]. Communication between the surgeon, ECMO technologist, and anesthesiologist is essential to monitor ECMO flow rates, lactate, and coagulation status in addition to standard measures of volume status such as mean arterial pressure, urine output, central venous pressures, and weight.

VA ECMO leads to non-pulsatile blood flow and a decrease in aortic pulse pressure. Hypertension is common due to increases in afterload. Hypotension most often occurs due to inadequate ECMO flows. This is caused by either inadequate venous drainage or poor ECMO arterial flow. Inadequate cannula size, cannula malposition, hypovolemia, and systemic vasodilation are common causes of inadequate ECMO flow [2, 9, 25]. Management of hypotension and inadequate oxygen delivery on ECMO may require increasing ECMO flow rates, addition of volume or blood products, and the use of inotropic drugs and vasoconstrictors [7, 9, 25]. Cardiac function should be routinely assessed by echocardiography [21].

Effect of ECMO on Anesthetic Drugs

Patients on ECMO may have increased requirements for anesthetic drugs owing to several factors. Initiation of ECMO results in increased volume of distribution (Vd), drug sequestration in the ECMO circuit, decreased protein binding, and alterations in renal, hepatic, and cerebral blood flow [26]. Hydrophilic drugs such as gentamicin, fentanyl, and midazolam are affected the most by this and could have significantly reduced plasma concentrations, especially upon initiation of therapy. However, once the binding sites on the circuit are saturated, one can expect stable pharmacokinetics. An initial bolus dose of fentanyl followed by an infusion with constant monitoring for signs of inadequate analgesia is essential to ensure adequate analgesia [27]. In contrast, highly protein bound drugs may have their effective concentration increased due to

reduced plasma proteins available for binding. Clinical trials documenting the effects of ECMO on anesthetic drugs are lacking. Dagan showed a decreased clearance of morphine of patients on ECMO possibly due to decreased hepatic perfusion [28]. Less morphine is sequestered in the ECMO circuit than fentanyl due to its low lipophilicity [27]. In a retrospective cohort study that enrolled consecutive adult patients with severe respiratory failure with (n = 34) or without (n = 60) venovenous ECMO support requiring at least one sedative to maintain a level of wakefulness appropriate to maintain patient comfort and safety while optimizing oxygenation and ventilator support [27]. The authors found that the maximum median 6-h sedative exposure was nearly twice as high in the ECMO group and was reached nearly 3 days later when compared to the group not receiving ECMO. However, there was no significant difference in 6-h sedative [29].

Several clinical trials are ongoing to study the effect of ECMO on the pharmacokinetics and pharmacodynamics of various anesthetic drugs. Until more literature is available, clinical monitoring of the effects of various anesthetic drugs necessary for their administration.

The use of ECMO for critical airway obstruction has allowed many patients who were previously untreatable to be managed safely. We anticipate an expanded use of ECMO in the future in patients with fulminant airway obstruction. Because elective use of ECMO in anticipation of airway obstruction results in improved outcomes and reduced complications, adequate disaster planning and team communication are essential to its success.

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Prevention Airway Complications During Aerodigestive Surgery

15

Nina Rawtani and Yewande Johnson

Introduction

Aerodigestive surgery includes patients with complex respiratory and gastrointestinal diagnoses. These disorders can include dysphagia, feeding disorders, gastroesophageal reflux, sleep apnea, asthma, congenital anomalies of the airway or esophagus, esophagitis, and airway malacia [1]. Routine procedures for disorders include tonsillectomy, adenoidectomy, laryngoscopy and bronchoscopy, and gastrointestinal endoscopy. The most common airway complications during aerodigestive surgery include apnea, aspiration, laryngospasm, bronchospasm, stridor, obstruction secondary to edema, and hypoxia. Less frequently but potentially more devastating bleeding and airway fires may occur. The understanding of the risks and mitigating factors is important in reducing morbidity and mortality.

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Anesthetic Complications During Routine Surgery

Tonsillectomy and adenoidectomy are two of the most common procedures performed in pediatrics. Bleeding, burns, and airway fires are known intraoperative complications, and postoperative hemorrhage is a well-known complication of this procedure.

Intraoperative bleeding can occur due to retained adenoid tissue or failure to achieve adequate hemostasis [2]. Given the risk of bleeding following a tonsillectomy, a presurgical hematocrit should always be obtained. This will allow for evaluation of the degree of hemorrhage if the patient experiences a post-tonsillar bleed. Since hypovolemia may occur due to decreased postoperative oral intake along with acute blood loss, the hematocrit may underestimate the degree of blood loss. Other signs of hypovolemia and anemia should be assessed and adequate resuscitation should occur. Should blood loss continue, the patient should be taken back to the operating room for surgical hemostasis. The patient is considered a full stomach since the patient may have a significant amount of blood that has been swallowed. This will necessitate a rapid sequence intubation. Additionally there may be difficulty visualizing vocal cords due to bleeding.

Respiratory complications in tonsillectomy and adenoidectomy surgery are seen in part due to the patient's diagnosis and other comorbidities.

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These patients may be having the surgery because of frequent upper respiratory infections or tonsillitis that may be associated with a highly reactive airway including bronchospasm or laryngospasm during surgery [3]. Obstructive sleep apnea is also an indication for the procedure and can lead to perioperative complications due to the severity of the disease. Patients with transient episodes of hypoxia and hypercarbia during sleep may continue to have these symptoms during the perioperative period. Limiting opioid use during the operation can prevent an exaggerated respiratory depression and thus decrease risk of respiratory complications [4]. In addition, patients may develop pulmonary hypertension and cor pulmonale due to chronic airway obstruction. Intraoperatively dexmedetomidine and IV acetaminophen may be used as part of an opioid-sparing anesthetic. In the postoperative period, multimodal analgesia includes acetaminophen and if not contraindicated ibuprofen to limit the use of opioids which may cause hypoxia, hypopnea, and other untoward effects.

Codeine must be avoided in all patients post tonsillectomy or adenoidectomy as respiratory depression leading to death has been reported. This may occur since codeine is a prodrug that is converted to morphine in vivo. For patients that are rapid metabolizers or ultrarapid metabolizers through the CYP450 enzymatic pathway, there may be an unexpected accumulation of morphine. In the patient population that is already sensitive to opioids because of acute and chronic airway obstruction, this may have a significant deleterious effect. As such this medication now contains an FDA black box warning for use after tonsillectomy.

Peritonsillar abscess procedures can result in anesthetic complications such as laryngospasm, bronchospasm, rupture of peritonsillar abscess, trismus, and hypotension due to dehydration and fever. Induction and intubation may be challenging because the location of the abscess and edema may result in difficulty identifying anatomy. Careful manipulation must be done to avoid rupturing the abscess [5].

Diagnostic laryngoscopy and bronchoscopy are common procedures conducted usually to evaluate the airway or lungs. Anesthetic management of these patients can be complex because of symptoms requiring the procedure and the procedure in itself. Many of these patients may already have a concerning airway due to stridor, laryngotracheomalacia, subglottic stenosis, foreign body, and pneumonia. Many of these procedures are conducted with an unprotected airway and can lead to apnea, hypoxia, aspiration, bronchospasm, and laryngospasm if the patient is not at an appropriate anesthetic level [3]. If jet ventilation is utilized to facilitate oxygenation during the examination, complications may include barotrauma from the oscillating high pressure, CO_2 retention, and gastric rupture [6]. If a bronchoscopy is conducted due to an aspirated foreign body, caution should be taken with use of positive-pressure ventilation. These patients may have a full stomach and may have increased risk of bronchospasm and laryngospasm due to irritated airways. Bronchospasm may be treated with an inhaled beta-2 agonist such as albuterol. For patients with history of reactive airway disease, inhaled bronchodilators should be given prophylactically during the preoperative period.

Gastrointestinal endoscopy in the pediatric population includes diagnostic endoscopy, esophageal dilation, ERCP, and foreign body removal [7]. Maintaining the airway while inducing deep sedation requires an anesthetic appropriate for the patient's condition. Patients who are not intubated are at risk of aspiration or reflux, laryngospasm if not deeply anesthetized, apnea, hypoventilation, and compression of trachea from endoscope [8]. Infants usually require intubation for this procedure due to potential of tracheal compression and inadequate ventilation from abdominal distention with air during the scope.

Patients undergoing aerodigestive surgery are also at increased risk for stridor. This occurs due to subglottic swelling leading to turbulent air flow. Intravenous steroids may be given intraoperatively to reduce the risk of developing stridor. However, should it occur, racemic epinephrine nebulized may be needed postoperatively if significant stridor is present.

Avoidance and Treatment of Laryngospasm

Laryngospasm is the involuntary laryngeal closure usually conducted as a reflex to prevent foreign material from entering into the trachea and ultimately the lungs. It may occur during anesthesia due to stimulation or abnormal excitation. Inspiratory effort still occurs while the intrinsic laryngeal muscles contract [9]. This phenomenon during anesthesia mainly occurs in children with the overall incidence of 0.87% [10]. The incidence is higher in infants between 1 and 3 months compared to children until 9 years of age. Laryngospasm may result in cardiac arrest, post-obstructive negative-pressure pulmonary edema, aspiration, bradycardia, and oxygen desaturation [11].

Avoidance is correlated to recognizing which patients are at increased risk and ensuring all receive an appropriate depth of anesthesia prior to stimulation. Patients at increased risk for laryngospasm include those with history of nonspecific reactive airway disease, asthma, or recent upper respiratory infection.

Laryngospasm typically occurs during induction, emergence, or if the depth of anesthesia is not sufficient during the procedure and an endotracheal tube is not in place. Preventative measures during anesthesia include inhalational induction with a volatile anesthetic that is less irritating to the airway, such as sevoflurane (Fig. 15.1). Laryngoscopy should be conducted only after the patient is deeply sedated.

If laryngospasm occurs and the patient is hemodynamically stable, an attempt may be made at performing a jaw-thrust maneuver or inserting an oral or nasal airway while ventilating with positive pressure and 100% oxygen. Inhalational anesthetic and propofol may also be used to resolve laryngospasm. Succinylcholine must be used for patients refractory to the above treatment or if the patient is experiencing significant desaturation or bradycardia. In the absence of an IV, succinylcholine may be given intramuscularly. In patients less than 6 years old, atropine should also be given since succinylcholine may cause bradycardia through stimulation of sinus node muscarinic receptors. Help should be sought during a laryngospasm event in order to help facilitate treatment (Fig. 15.2).

To prevent laryngospasm during emergence, patients should not be extubated during Stage II of anesthesia. The patient should be extubated either while they have absent airway reflexes or after the return of purposeful movement after coughing and/or breath holding have resolved (Fig. 15.3).

Avoidance and Treatment of Airway Fires

Operating room fires are a rare but potentially devastating when they occur. The majority of intraoperative fires that occur during general anesthesia involve surgery on the airway with the

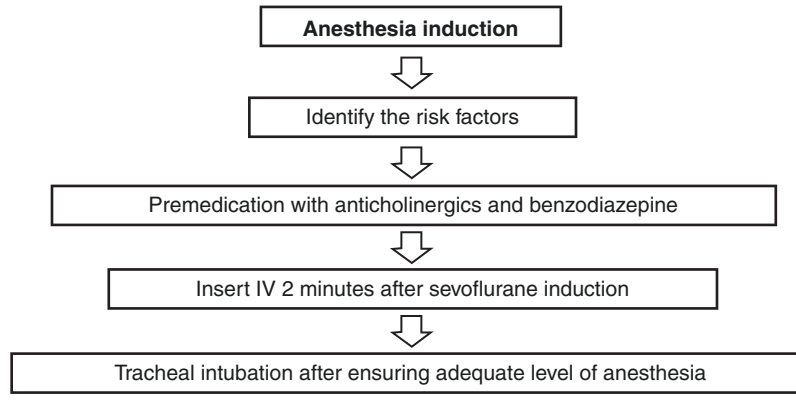


Fig. 15.1 Measures to prevent laryngospasm during anesthesia induction

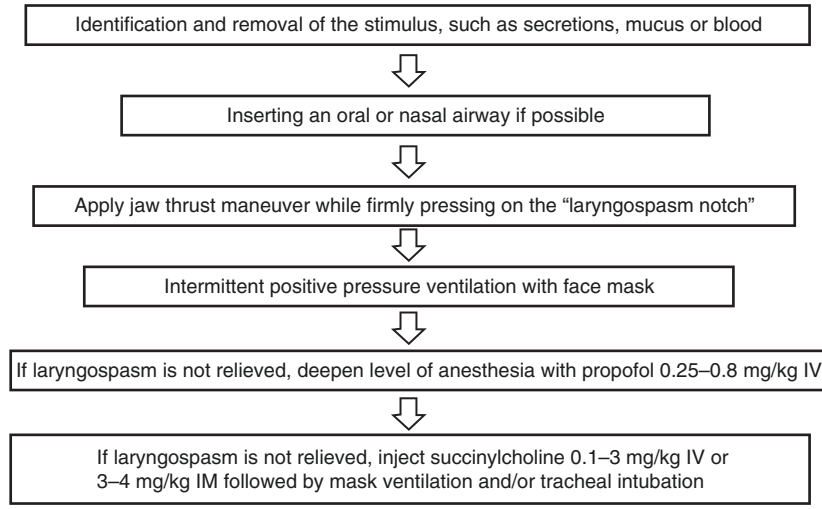


Fig. 15.2 Steps to resolve laryngospasm event

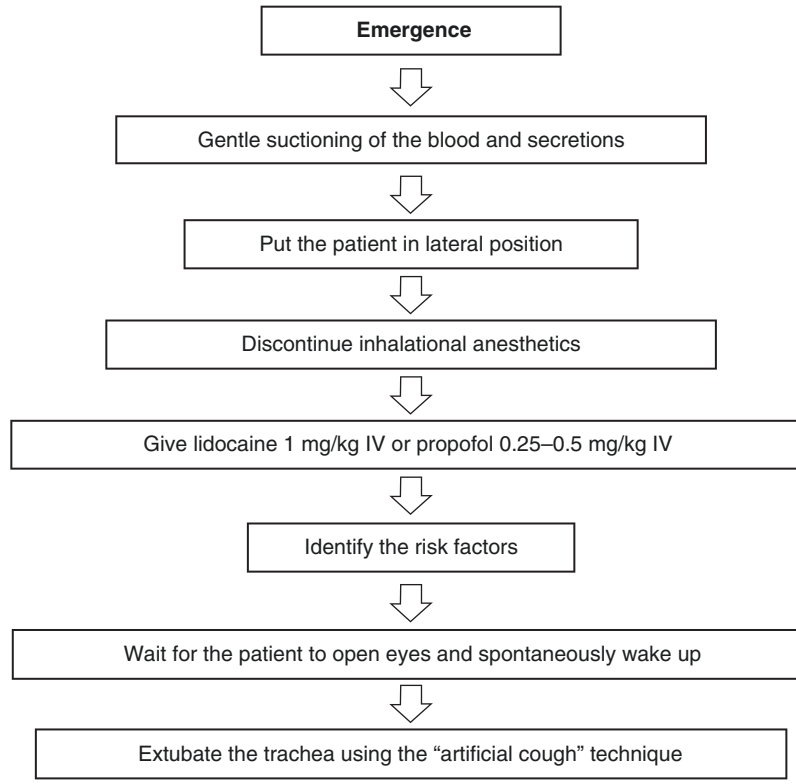


Fig. 15.3 Steps to prevent laryngospasm during emergence

majority of this subset coming from tracheostomy and tonsillectomy procedures [12].

The surgical time-out process should include stating the risk of an operating room fire. If an electrocautery, laser, or other sources of ignition will be used in an oxidizer-rich environment, then the procedure is categorized as high risk and appropriate precautions should be taken.

The three required components of a fire are an oxidizer, fuel, and an ignition source (Table 15.1). While conducting airway surgery, communica-

tion among the operating room personnel is critical especially given supplemental oxygen is present in the surgical field. To avoid airway fires, minimization of the risk of each of the three components of it is recommended. This includes keeping oxidizer-rich gases (oxygen and nitrous oxide) to a minimum. If the patient will tolerate, room air is preferable. Additionally the use of a cuffed endotracheal or tracheostomy tube without a leak is preferable as retrograde flow of oxygen is possible thus providing an oxidizer source.

In the operating room environment, the fuel sources are numerous. These include surgical gown and drapes, sponges, lap pads, dressings, tapes, and alcohol and other skin preparation solutions. Surgeons must be careful not to allow the ignition source to come into contact with the fuel source. Adequate time should be allowed for preparation solutions to dry before draping the patient. Towels, sponges, and other materials that are in close proximity to fuel sources should be moistened.

Table 15.1 Sources of fire risk during aerodigestive surgery

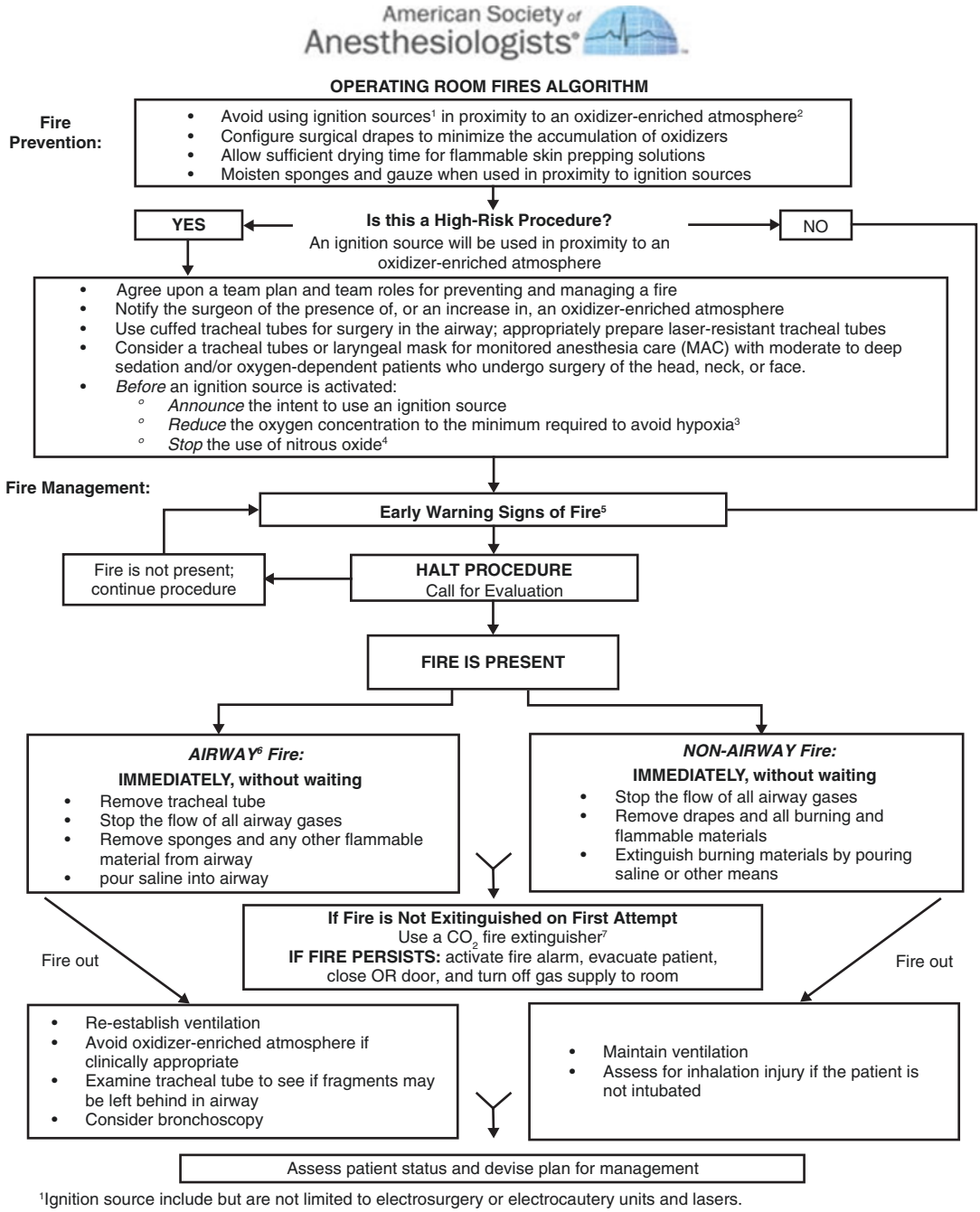
Oxidizers	Ignition	Fuel
Oxygen (above FiO_2 0.21) Nitrous oxide (any concentration)	Electrocautery Laser Fiber-optic light source/cable	Endotracheal tube Tracheostomy Surgical sponge Alcohol-based skin preparations

Over 90% of operating room fires have electrocautery as the ignition source [12]. Other ignition sources that are commonly present during aerodigestive surgery include fiber-optic light sources/cables and carbon dioxide lasers.

Laser procedures of the airway, such as used for the treatment of laryngeal papillomas, require additional steps to mitigate the risk of airway fire. Standard endotracheal tubes are composed of PVC material which is easily damaged by laser contact. Should the patient require an endotracheal tube during the laser procedure, laser-resistant tubes are recommended. These resistant tubes may be red rubber, silicone based, or stainless steel spiral reinforced and are all appropriate options when a CO_2 laser is being used. Even with specialty tubes, the surgeon must be careful to avoid the endotracheal tube as the laser may cause damage leading to cuff puncture or transection of the tube. Should tube damage occur, the oxidized environment may cause an airway fire. Ideally the cuff of the laser-resistant tube should be filled with saline, preferably tinted with methylene blue so that if cuff rupture occurs, it is easily identified by the surgeon. The double-cuff design on the stainless steel reinforced tube adds an added layer of protection should one of the cuffs be inadvertently damaged by the laser (Fig. 15.4).

For high-risk patients, the ASA operating room fire algorithm (Fig. 15.5) indicates that each member of the team has knowledge of his or

Fig. 15.4 Double-cuff design on stainless steel reinforced tube adds an added layer of protection should one of the cuffs be inadvertently damaged by laser



[1]Ignition source 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 complaint.

[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. 15.5 American Society of Anesthesiologists operating room fires algorithm

her role for preventing or managing a fire should one occur. As previously stated, this includes the anesthesiologist placing a cuffed or laser-resistant endotracheal tube and the surgeon announcing before using the ignition source so that the oxygen concentration may be reduced and nitrous oxide discontinued.

Additionally, members of the surgical airway team should conduct an operating room fire drill at least annually so that each member is cognizant of her/his role and has rehearsed the operating room fire algorithm and evacuation plan. This includes all members of the team being aware of the immediate initial steps should an airway fire occur: (1) remove endotracheal tube (if present), (2) stop the flow of all airway gases, (3) remove flammable material from the airway, and (4) pour saline into the airway. If the fire is not successfully extinguished with these steps, then a carbon dioxide fire extinguisher is warranted. If the fire persists, the operating room fire alarm must be activated and the patient and personnel should be evacuated from the operating room. Upon evacuation the OR doors should be closed to lessen the risk of fire spreading.

Role of the Anesthesiologist in Mitigating Risk

A thorough history and physical examination will guide the anesthesiologist in determining which patients are most at risk for airway-related complications. The history should include history of sleep apnea, and if sleep study is present, the apnea-hypopnea index should be reviewed. It is imperative that history of recent upper or lower respiratory infections be noted as this patient population is at increased risk of stridor, bronchospasm, and other respiratory complications. Careful consideration must be given to evaluate whether a child that was recently ill should undergo elective surgery. Airway hyperresponsiveness may persist after an upper respiratory illness for weeks to months. Historically the recommendation has been that patients that have experienced an upper respiratory infection (URI) in the past 4 weeks should not undergo elective surgery secondary to increased risk of intraoperative respiratory dysfunction [13]. However, given the average number of URIs approximating 8 per year in the 1-year-old age group, waiting for a 4-week URI interval-free period may not be realistic. The signs and severity of URI symptoms should be evaluated. Symptoms can include acute rhinorrhea (patients with adenoid hypertrophy may have chronic rhinorrhea), productive cough, fever, decreased appetite, and decreased activity along with other patient comorbidities that may be present in deciding whether to proceed with surgery.

A thoughtfully tailored anesthetic plan will help mitigate risk. This plan should include ensuring an adequate depth of anesthetic along with techniques as outlined in this chapter to reduce incidence of complications during aerodigestive surgery.

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16 Management of Immediate Postoperative Airway Events in Children

Domiciano Jerry Santos and Evonne Greenidge

Introduction

Otorhinolaryngologic procedures account for a large percentage of pediatric anesthesia cases yearly. The most common procedures in children less than 15 years old were myringotomy and tonsillectomy with 699,000 and 289,000 cases, respectively, in 2010 [1]. Less common procedures include cochlear implant, mastoidectomy, tympanoplasty, laryngoscopy and bronchoscopy, turbinate reduction, peritonsillar abscess drainage, and airway foreign body retrieval. The discussion of perioperative management of these cases usually emphasizes the preoperative management, surgical technique, and intraoperative anesthetic management. However, many of the complications usually occur after the surgery is complete. The transport to and management in the postanesthesia care unit (PACU) may represent the most critical period for pediatric patients particularly in these cases. In most instances respiratory complications including laryngospasm [2] represent the greatest risk for morbidity and mortality. Overall life-threatening complications in pediatric cases are rare [3].

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PACU Basics

Location

The distance from the operating rooms to the PACU should be as short as possible and clear of obstructions from equipment, stretchers, and personnel. As the anesthesia provider is watching and observing the patient, having to navigate small hallways and multiple turns can lead to more potential hazards. Well-lit and wide hallways can allow for quick assessments of any change in the patient's condition by the anesthesia and surgical staff.

Transport from OR

The transportation from the operating room to the PACU has many potential dangers but is often done with minimal monitoring. Even a short transfer can produce dangerous hypercarbia and hypoventilation leading to desaturation. Vigilance must be maintained for signs of airway obstruction and desaturation. If the patient is still anesthetized or has no protective airway reflexes, monitoring with pulse oximetry should be maintained throughout transport. In addition portable pulse oximetry may be

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necessary for those patients who have increased risk of hypoventilation or desaturation like a child with severe obstructive sleep apnea (OSA). Some institutions require the use of portable pulse oximetry to detect hypoventilation or hypoxia during transport because it is such a critical time period. Trained anesthesia personnel should conduct the transfer of patients to the PACU. Patients should preferably be transported in the lateral position to drain blood/secretions from the oropharynx during transport to PACU. This position prevents upper airway obstruction, allowing the tongue to fall to the dependent side. In addition blood/secretions will be away from the glottis by falling out of the mouth from the dependent side. This will avoid the potential to trigger a cough or a laryngospasm. Many institutions advocate rescue airway equipment to be available during transport, including self-inflating bag valve mask, oral and nasal airways, and medications to facilitate intubation and sedation (succinylcholine, atropine, sedatives, analgesics, etc.) [4]. In intubated patients, appropriate equipment including laryngoscope, endotracheal tubes, medications to facilitate intubation, and resuscitation medications should be immediately available. A self-inflating bag valve mask or other circuit to provide positive pressure is also required.

Oxygen for Transport

The role of supplemental oxygen has been debated. The actual percent of oxygen delivered is quite variable depending on the delivery system. Even a small increase in supplemental oxygen can artificially increase the oxygen saturation making early detection of hypoventilation more difficult. A high fraction of inspired oxygen (FiO_2) does help promote atelectasis in recovering patients. Typically in the pediatric population, supplemental oxygen is usually delivered via face mask or blow-by rather than via a nasal cannula because a nasal cannula is less reliable and less tolerated by younger patients. Some institutions advocate the use of a Jackson-Rees circuit as it provides some feedback about respiratory effort. The use of supplemental oxygen is more helpful during this transition time as long as vigilance is maintained for signs of airway obstruction and hypoventilation.

PACU Handoff

Handoffs and transfers are part of everyday life in the hospital. Improper handoff and communication errors can lead to medical error, harm to patients, and death. According to a survey by Choromanski et al. in 2014 [5], only 49% of all anesthesia programs have a set handover protocol, and only 12% of the institution reported a sufficient exchange of information. In an article by Vidyarthi [6], it is estimated that in teaching institutions there are over 4000 handoffs taking place in a normal day. In the perioperative setting, the most important handoff occurs between the anesthesia team and the PACU team. There are many vital bits of information transmitted during this period while the patient is also emerging from anesthesia. The information provided during handoff should include those listed in Table 16.1.

The structure for handoff can vary by institution. There are several communication MNEMONICS that may aid in the process during transfer. For example, I-PASS [7], ISBAR [8], and I PUT PATIENTS FIRST [9] are commonly used (see Tables 16.2, 16.3, and 16.4). Ultimately, resources, time, and care need to be taken during transfer to provide a safe transition to the next phase in patient care.

PACU Assessment

The PACU nurse should be readily available to receive the patient in the PACU bay prior to arrival. Each bay should have monitors, suction readily available, and the ability to pro-

Table 16.1 PACU handoff

Age
Weight
Procedure
Medical history
Social history
Family history
IVs, drains, invasive catheters
Inputs and outputs
Any pertinent labs pre-op or intra-op
Disposition: orders, pain plan, discharge
Communication in case of emergency (direct contact)

Table 16.2 I-PASS

Illness severity
Patient summary
Action list
Situation awareness and contingency plans

Table 16.3 ISBAR

Identification
Situation
Background
Assessment
Recommendation

Table 16.4 I PUT PATIENTS FIRST

Identify yourself and role and obtain nurse's name
Patient's past medical history (medical, surgical, social)
Underlying diagnosis and procedure
Technique (general anesthesia, neuroaxial, regional)
Peripheral IVs, arterial lines, central lines, drains
Allergies
Therapeutic interventions (pain medications, antibiotics)
Intubation (very difficult, moderately difficult, easy)
Extubation likelihood (already extubated, very likely, unlikely, definitely no extubation planned)
Need for drips (epinephrine, vasopressin, norepinephrine, insulin, propofol, etc.)
Treatment plan for postoperative care (blood pressure goals, ventilator settings)
Signs (vital signs during case and most recent)
Fluids (ins and outs, blood product(s), administered)
Intraoperative events (if any)
Recent labs (hemoglobin, glucose, etc.)
Suggestions for immediate post-op care (e.g., special positioning, pain control, need for pumps, etc.)
Timing/expected time of arrival to ICU

vide supplemental oxygen. As monitors are being placed, the patient's airway patency and adequacy of ventilation should be assessed simultaneously. Any issues or concerns should be reported immediately to the anesthesia provider. The first set of vital signs usually includes oxygen saturation, blood pressure, respiratory rate, heart rate, and temperature. The rest of the initial assessment can be done after handoff is complete. This includes examination of the dressing of the wounds, intravenous catheters, surgical drains, indwelling catheters, level of consciousness, muscular strength, and pain assessment [10].

Pulse Oximetry

Pulse oximetry is recommended throughout the recovery process until the patient is fully awake. In some instances monitoring may continue until discharge from the PACU. This will be the first warning of hypoxia or hypoventilation. The use of pulse oximetry has led to lower frequency of rescue events and transfers to the intensive care unit (ICU) [11]. Pulse oximetry may be misleading if the patient has oxygen supplementation. Direct observation and assessment of adequate ventilation is the best monitor when oxygen supplementation is used. The duration of pulse oximetry use is debatable with some advocating continued use even if children are discharged to the ward or floor. Some institutions only discontinue use after the child is discharged from the institution. The duration should be based on the individual patient with consideration of the site of surgery, anesthetic management, and postoperative course including the use of analgesics or sedatives, which may influence respiratory drive.

Respiratory Rate

The PACU nurse should check respiratory rate over 1 min while assessing the respiratory pattern. Some institutions use the thoracic impedance to determine the respiratory rate and pattern. However, there are limitations to using thoracic impedance. One such limitation is the change in amplitude does not accurately mimic tidal volume [10]. This monitor may give the pattern of respiration, but it does not give the adequacy of the ventilation.

CO_2 Monitoring

Some institutions use carbon dioxide (CO_2) sampling from nasal cannula to determine respiratory

pattern and determine ventilation efficacy. Like thoracic impedance, this has some limitations, a major one being sampling error that occurs from a patient who predominantly mouth breathes or does not tolerate the device. Sampling error also occurs with entrapment of air when the patient has low tidal volumes [10]. Like thoracic impedance, CO_2 sampling can be a useful adjunct for the pediatric population in helping to assess a respiratory pattern.

Blood Pressure Monitoring

Blood pressure is frequently checked every 15 min if the patient is hemodynamically stable. If the blood pressure is unstable, more frequent checks are necessary until the values are within a normal range.

ECG

Electrocardiogram (ECG) is usually used for monitoring in the PACU. However, arrhythmias are rare in pediatric population unless there is preexisting cardiac conduction abnormality. Arrhythmias can also be secondary to electrolyte abnormalities like hypokalemia or hypercarbia or hypoxia can also be the cause of an arrhythmia. The presence of sudden heart rate changes, achycardia and bradycardia can provide valuable clinical information in the postoperative arena. Bradycardia is most common observed secondary to hypoxia or vagal stimulation. For small children and infants whose cardiac output depends on their heart rate, bradycardia can be an ominous sign. In addition to displaying the heart rate and rhythm, the appropriate placement of 3EKG leads can give the rhe provider a respiratory rate and pattern which is invaluable when narcotics are prescribed in the post-operative period. Tachycardia is often caused by pain, hypovolemia, high core temperature, or hypercarbia from hypoventilation.

Temperature

Temperature is usually checked less frequently if normal. Hyperthermia can lead to increased metabolic demand, tachypnea, and increased work of breathing. If the labored breathing is prolonged, it can produce respiratory fatigue and eventual respiratory failure. Hypothermia can have same deleterious effect by causing the body to shiver, which increases metabolic demand and oxygen consumption. Hypothermia can also slow drug metabolism, leaving children at risk of slow wake up due to prolonged anesthetic effects. Slow awakening and decreased consciousness can lead to airway obstruction and hypoventilation.

PACU Phase I

Phase I in the PACU is the most critical time. It is the time when patients regain consciousness and protective airway reflexes. Vital signs usually return to within 20–40% of baseline. Direct lines of communication should be readily available to the charge nurse, anesthesia team, and surgical team. In the pediatric population, the most common complications relate to the respiratory system. Specifically with otorhinolaryngologic procedures, obstructions of the airway are even more common, during this phase of recovery. The PACU nurse plays a very important role in prevention of airway obstruction and assessment of adequate respiration. They are often the first to provide immediate intervention to establish a patent airway for a sedated patient. Since most issues occur within the first 2 h after completion of surgery according to Theilhaber et al. [12], this crucial period necessitates ease with accessing any available assistance. All airway or ventilation issues should be reported to the anesthesia provider; however, prompt treatment like performing a jaw thrust, repositioning of the head, neck and mask over the face with supplemental oxygen should not be delayed. Additional personnel to help during emergencies are the recovery nurse, charge nurse, and surgical staff. In the initial Phase I of recovery, the nursing ratio should be 1:1 until the patient can protect their airway and vital signs are stable. The maintenance of the "lateral recovery position" for the patient recovering from a deep extubation and obese children who may or may not have obstructive sleep apnea is of paramount importance during this period.

For patients who are unstable or are in need of airway or respiratory support, a second PACU

nurse may be necessary. Additional resources like nursing aides are helpful to provide comfort to children until parents arrive in the bay.

PACU Phase II

Phase II in the PACU is after return of normal vital signs and level of consciousness. The emphasis of this phase is getting the patient "street ready." In this phase there is more coordinated movement from the patient as all protective reflexes have returned. There is more emphasis on getting pain- and nausea-free during Phase II. Some cases like bilateral myringotomy can be fast-tracked to Phase II to facilitate early discharge if appropriate. This minimizes resources in PACU and minimizes changes in RN staff. Additionally, parental satisfaction is increased with a shortened duration of stay.

Role of Anesthesiologist in PACU

Ideally the role of the anesthesia provider does not cease after proper handoff is given to the PACU team. It continues through both Phase I and II of recovery. If possible an anesthesia provider who is assigned to manage the clinical care of the children after surgery in the PACU presence for immediate response to emergencies and allows for respiratory support in patients who continue to obstruct post-surgery; assessment and treatment of nausea, vomiting, and pain; and assessment of "street readiness" prior to discharge. Some institutions have a dedicated anesthesia provider in PACU who manages all PACU care. Having a dedicated anesthesia provider is an institutional decision that is not always practical. Therefore, having a direct line of communication to the anesthesia provider who completed the case is essential. A clinical situation like obstruction of the airway and/or hypoventilation resulting in desaturation should trigger an escalation to any anesthesia or surgical provider within the perioperative area. In some institutions there is internal call alert system within the perioperative suite for any available anesthesia provider called an "Anesthesia Stat." This initiates a response when additional help is needed.

The decision to intubate in the PACU should be made by the anesthesia team in consultation with the ENT team. The brief summary of the current situation including previous anesthetic management and possible solutions should be discussed as the team prepares to instrument the airway. Airway edema, blood or secretions in the airway, and prior surgical procedure should all be considered when deciding to intervene. A rapid sequence intubation should be considered for a potential full stomach with oral intake or blood in the stomach. These are all potential pitfalls during an emergency intubation in the PACU.

For emergency airway management, the use of an airway cart or difficult airway cart may be beneficial if already located in the recovery unit. Ideally this would have various sizes of endotracheal tubes, laryngoscope blades, laryngeal mask airways, oral and nasal airways, and other intubation adjuncts readily available for use in these emergencies.

Preoperative Considerations

The preoperative assessment can be crucial in predicting and preventing complications in the PACU. Desaturation can occur in the healthiest patients with uncomplicated intraoperative anesthetics and surgical procedures. There are patients however with a higher likelihood of postoperative respiratory complications despite expert surgical and anesthetic care. Children less than 3 years old, weight in the third percentile relative to age, congenital cardiac disease, severe obstructive sleep apnea, morbid obesity, history of prematurity with concomitant respiratory disease, and hypotonia are all potential risk factors for respiratory issues in the postoperative period [12–14]. The PACU team should maintain high vigilance during Phase I of recovery for these patients.

The risk for respiratory complications after adenotonsillectomy is increased for children with craniofacial anomalies. They can be difficult to mask ventilate and intubate should any airway events occur in the recovery area. Other risk factors for desaturation after adenotonsillectomy include large turbinates, deviated septum, Mallampati score 3–4, cor pulmonale, hypertension, neuromuscular disorder, genetic

abnormalities, chromosomal anomalies, and growth impairment caused by disordered breathing [14].

URI

Patients with upper respiratory tract infections (URI) within the last 4 weeks have an increased risk of laryngospasm or bronchospasm in the perioperative period [10]. This is due to irritability of the airways. Children who have history of upper respiratory tract infections should be carefully monitored in the PACU until the return of airway reflexes.

OSA

Special consideration should be given to patients with obstructive sleep apnea (OSA) undergoing otorhinolaryngologic procedures. According to Baugh et al. [15], the prevalence of OSA is rising, now affecting approximately 1–4% of the pediatric population. However, more than 10% of all children have sleep-disordered breathing which includes the spectrum from mild mouth breathing and snoring to severe obstructive sleep apnea, according to Pomerantz [16]. The American Society of Anesthesiologists classifies severe OSA in pediatric population as an Apnea-Hypopnea Index (AHI) of greater than 10 (number of episodes of sleep-disordered breathing per hour). Sleep-disordered breathing has been linked to excessive daytime sleepiness, inattention, poor concentrations, hyperactivity, and hypertension [16]. Often adenotonsillectomy is used to help alleviate the obstructive component of the disease.

Intra-op Considerations

The choice of airway management affects postoperative recovery and length of stay in PACU. For children with URI, instrumentation of the airway with laryngeal mask airway (LMA) or endotracheal tube (ETT) may increase the chance of postoperative respiratory complications.

The occurrence of intraoperative events determines duration and location of postoperative care. Surgical events like trauma to teeth, larynx, or neighboring structures are a consideration when determining adequate postoperative monitoring. Special consideration for airway events including laryngospasm, difficult intubation, aspiration, airway obstruction, airway edema, and cardiac arrest must be made. For ENT procedure, airway fires are a complication that can also influence recovery and the disposition of the patient.

ENT Procedure Considerations

The indications for adenotonsillectomy include sleep-disordered breathing, recurrent infections, and obstructive sleep apnea. Although the procedure is safe in terms of risk of perioperative events, there is still a concern in the immediate postoperative period. Complications are more common in patients less than 3 years old with OSA, Down syndrome, and other comorbid conditions [15] (see Table 16.5). These complications include pain, nausea, vomiting, and respiratory compromise [15] (see Table 16.6). Mortality rate after T&A is estimated at 1 in 16,000 to 1 in 35,000, with one third of deaths attributed to bleeding [15]. Aspiration, cardiopulmonary failure, electrolyte imbalance, or anesthesia complications accounted for the

Table 16.5 Risk factors for T&A postoperative complications

Age less than 3
Heart disease – congenital or acquired
Down syndrome
OSA
Bleeding disorder
Craniofacial disorders

Table 16.6 Postoperative T&A complications

Pain
Nausea
Vomiting
Dehydration

remainder of deaths. Malpractice claims after tonsillectomies were related to airway compromise as the major cause of death or injury [15].

PACU Considerations

Airway

Particularly with ENT procedures, the patency of the airway is the most important assessment. The airway can be obstructed above the larynx, at the level of the larynx, or below the larynx. A quick assessment and treatment may be instrumental in preventing morbidity or mortality. The most common cause of airway obstruction above the larynx is the tongue. This can be readily treated by lateral position of the patient. Depending on the level of consciousness, a nasal or oral airway may be used to alleviate this obstruction. Other causes can be the soft tissue in the upper airway such as enlarged turbinates or residual tonsil tissue, edema following adenotonsillectomy, secretions, or blood. Supplemental oxygen may be helpful, but close observation must be maintained as obstruction can worsen, requiring positive pressure support with mask or possibly reintubation.

Laryngospasm

At the level of the larynx, obstruction often can be laryngospasm, partial spasm, paralysis of the vocal cord, or secretions with/without blood. Laryngospasm can be caused by blood or secretions irritating the vocal folds resulting in spasmodic closure. It is a complete obstruction and must be treated emergently by positive pressure ventilation, muscle paralysis (short-acting succinylcholine is preferable), or some sedative, like propofol, to break the spasm of the vocal folds and allow flow of air for ventilation.

Post-Extubation Croup

Below the larynx the obstruction may be more ominous. Some causes include hematoma, tumor, or subglottic stenosis presenting as stridor. Post-extubation croup is often caused by multiple intubation attempts or irritation of the airway below the vocal cords causing local inflammatory reaction. For patients who had multiple, traumatic, or prolonged intubations, subglottic stenosis can be the cause of the stridor. Prompt treatment with inhaled vasoconstrictive agents can reduce the edema. Racemic epinephrine is first line treatment. Nebulized racemic epinephrine 2.25% solution 0.05–0.1 cc/kg diluted with 2–3 cc of normal saline will benefit acute symptoms in 10–30 minutes. Careful observation must be continued, as the edema may still be present requiring a second dose in 2–3 h. Humidified supplemental oxygen is often beneficial. The role of steroids, like dexamethasone, may not be helpful in the short term but may help reduce airway edema from an inflammatory response. These patients should be observed for at least 4 h for possible rebound symptoms. Some institutions advocate overnight admission. If the symptoms persist, the anesthesiologist and otolaryngologist need to decide the risk or benefit of reintubation as this can make the stenosis worse in the long term. With prolonged symptoms, transfer to the intensive care unit may be necessary.

Obstructive Sleep Apnea (OSA)

Postoperative respiratory complications in children with OSA include desaturation requiring oxygen supplementation, airway obstruction, and respiratory insufficiency requiring airway intervention. When compared to children without OSA, the incidence of these complications is higher [17]. For those with preoperative polysomnography before tonsillectomy, the results may predict an adverse respiratory event in the postoperative period. Jaryszak et al. [18] found respiratory events occurred in children with a higher AHI, hypopnea index, and body mass index and low nadir of oxygen saturation. The primary concern was desaturation requiring oxygen supplementation.

According to Pomerantz [16], sleep-disordered breathing has a higher incidence of

resolution after adenotonsillectomy for patients who are not obese. Besides obesity other risk factors for persistent or recurrent OSA post-surgery are children with craniofacial anomalies, neuromuscular disorders, family history of OSA, and African-American ethnicity [14, 15]. Some of these patients have preoperative use of CPAP to help with obstruction. They are encouraged to bring their device for postoperative use. Use of their home CPAP has been shown to have a higher compliance rate.

Patients with OSA also have a higher sensitivity to opioids. Careful titration of opioids, with approximately half the usual per kilogram dose, may be necessary. Even small doses of opioids can cause hypoventilation in the children with OSA. Use of opioids with commonly used sedatives, like benzodiazepines or dexmedetomidine, should be done with extreme caution. This may lead to profound sedation, hypoventilation, and airway obstruction.

Bleeding

Postoperative hemorrhage is a big concern after any surgery; however, in ENT procedures, hemorrhage can lead to high morbidity and mortality. One of the most common surgeries performed is adenotonsillectomy. The rate of primary hemorrhage (first 24 h) is 0.2–2.22% commonly caused by surgical technique and inadequate hemostasis of bleeding vessels. The secondary hemorrhage rate of 0.1–3% usually occurs 5–10 days post-surgery. Sloughing of the primary eschar as the tonsil bed heals causes secondary hemorrhage. Other documented risk factors for bleeding are children greater than 12 years old, males, history of acute tonsillitis, previous history of peritonsillar abscesses, and bleeding diathesis [15].

Postoperative hemorrhage is also a concern with surgeries in the neck as major vessels that do not have adequate hemostasis can expand rapidly in the neck and can cause occlusion of the airway. Endoscopic sinus surgery or other procedures, which utilize intraoperative vasoconstrictors to assist in hemostasis, can have bleeding after the vasoconstrictors duration action has completed [17]. In all these cases, quick assessment by both the anesthesia and surgical team is necessary. There may be an emergent need to return to the operating room for hemostasis. Correction of intravascular fluid volume is important either with crystalloid or blood products if necessary. In the interim, reintubation may be necessary to secure a definitive airway. This reintubation may be done in the PACU or maybe more easily secured in the operating room if readily available.

PONV

Other postoperative complications common in otorhinolaryngologic procedures to consider are nausea and vomiting. Nausea and vomiting have high incidence in middle ear procedures. Therefore, preemptive treatment plans should be utilized. These include adequate hydration, use of nonnarcotic analgesics like acetaminophen and local anesthetic at the incision site if possible, steroids [19], and 5-HT3 antagonists, like ondansetron. Vomiting can be problematic with adenotonsillectomy as the vomiting or retching can disrupt the hemostasis obtained during surgery. Other common complications for otorhinolaryngologic procedures include referred otalgia, velopharyngeal insufficiency, nasal pharyngeal insufficiency, and more commonly pain and dehydration [15].

Emergence Delirium

Delirium in the postoperative period is a concern in ENT procedures. Sikich and Lerman estimated delirium occurred in 28% of the procedures [20]. The management of postoperative delirium places a strain on personnel and parents as well as the potential for injury to the patient or staff members. The Pediatric Anesthesia Emergence Delirium (PAED) scale is a scoring system that can help in determining the degree of the delirium. There are five elements: (1) The child makes eye contact with the caregiver, (2) the child's actions are purposeful, (3) the child is aware of

his/her surroundings, (4) the child is restless, and (5) the child is inconsolable. The degree of delirium increased directly with the total score [20].

Post-op Disposition

The decision for postoperative discharge is based on the patient's history, surgical procedure, and perioperative course including significant intraoperative events. Several factors must be considered in the decision to prolong the period of monitoring or admit for observation. Early discharge from the postoperative recovery area is possible if the postoperative course is without any complications. Any unexpected events should trigger a discussion with the ENT team regarding an unplanned hospital admission.

Medical comorbidities should be considered in the decision regarding discharge from the hospital. Some conditions should dictate the need for close monitoring in the hospital setting. For children undergoing tonsillectomy, certain risk factors may predict a prolonged hospital stay. These include age less than 4, history of sickle cell disease, and reactive airway disease [13, 21]. Also important is history of sleep-disordered breathing which may serve as a risk factor for respiratory complications postoperatively especially in the case of obesity [15, 22]. The severity of sleep-disordered breathing should be considered in the decision for postoperative admission or overnight hospitalization after adenotonsillectomy. Baugh et al. [15] suggest a history of complicated medical histories including cardiac complications of OSA, neuromuscular disorders, prematurity, obesity, failure to thrive, craniofacial anomalies, or recent respiratory infection be treated in a hospital setting.

Postoperative complications may delay discharge or necessitate hospital admission. According to Baugh et al. [15], an estimated 1.3% of patients after tonsillectomy experience a delay in discharge, while up to 3.9% have secondary complications requiring readmission for pain, vomiting, fever, or bleeding. Other reasons include vascular injury, subcutaneous emphysema, atlantoaxial subluxation, taste disorders, and persistent neck pain [15]. Other reasons for delayed discharge include nausea and vomiting, commonly following tympanomastoidectomy [17].

Same-Day Discharge

The most common method of assessment to follow a child's progress through the postoperative period is the Aldrete score. This tool is used to assess five primary functions: the respiratory system, circulatory system, mental capacity, activity, and oxygen saturation of the patient at various times throughout the recovery period. The modified version of this assessment tool uses saturation instead of child's color. Each function has three categories. The respiratory system categories are the ability to deeply breathe and cough, difficulty breathing or limited breathing, and apnea. Circulation utilizes the blood pressure and the deviation from baseline. Blood pressure within 20% of baseline gets the highest score and blood pressure greater than 50% of baseline the lowest score of zero. Activity is scored based on movement (either voluntary or on command) of all or two extremities. The lowest scores are given if there is no movement. Mental capacity categories are awake, arousal to stimulation, and unresponsive. The last assessment is based on oxygen saturation. Having saturation higher than 92% on room air achieves the highest score, and having saturation less than 90% with supplemental oxygen receives the lowest score [10].

Period of Observation

Each postoperative unit maintains discharge criteria that must be satisfied prior to being sent home. In addition there may be a requirement for assessment by either surgery or anesthesia provider prior to leaving the unit. The period of observation varies based on procedure and expected postoperative course. Most institutions have a 4 h PACU observation stay for healthy children >4 years old undergoing a tonsillectomy. This observation period increase when

children have severe upper airway obstruction or other comorbidities.

The indications for overnight admission vary by institution, but some general considerations include age, history of OSA, postoperative issues, and obesity [23]. For children less than 3 years old with sleep-disordered breathing undergoing tonsillectomy, there is a higher risk of postoperative respiratory complications [15]. In these cases, overnight hospitalization is recommended either in the PACU or hospital setting. A history of other medical comorbidities makes the intensive care unit an appropriate setting for overnight admission [10–12, 14, 15].

PICU

There are some cases that require direct admission to the pediatric intensive care unit (PICU) for protracted inpatient care (Table 16.7). The absolute indications are patients who are hemodynamically unstable and patients who need intubation with mechanical ventilator support for an extended period of time. Other indications for direct admission are patients who need neurologic assessment, high risk of bleeding because of bleeding diathesis, and severe craniofacial abnormalities. Strong considerations for PICU admission should be given to patients who have severe obstructive sleep apnea with comorbid conditions like obesity, sickle cell disease, coagulopathies, congenital heart disease, and arrhythmias [10–12, 14, 15].

Table 16.7 Direct to PICU admission

Hemodynamically unstable
Prolonged mechanical ventilation
Craniofacial abnormalities
Congenital heart disease
OSA – severe
Sickle cell disease
Coagulopathies
Airway trauma
Foreign body removal
Preoperative pulmonary support – CPAP, BIPAP, ventilator
Surgical procedure – tracheostomy, LTR, etc.

Intraoperative events may also necessitate admission to the intensive care unit. Some examples are laryngotracheobronchitis, epiglotitis, airway trauma, and angioedema. Removal of airway foreign bodies like peanuts, battery erosion, or other sharp penetrating traumas to the airway will benefit from close monitoring in case of any respiratory events. Surgical procedures like laryngotracheal reconstruction, tracheostomies, and choanal atresia repair are best observed in the PICU setting where immediate interventions can be remedied. Children with poor preoperative pulmonary function may benefit from early respiratory support first with CPAP/BIPAP or nasal intermittent positive pressure ventilation (NIPPV) and intense chest physiotherapy. This care is more easily provided in an intensive care unit.

The last subset of patients to consider for ICU admission is the pediatric patient who had adverse event in the PACU or floor after an otorhinolaryngologic procedure. Theilhaber et al. [12] found that patients who had a mild adverse event in the first couple of hours post procedure were the highest risk for severe adverse event. Severe adverse event was defined by desaturations requiring positive pressure ventilation, child requiring CPAP, NIPPV, oral airway, or reintubation.

Ambulatory Surgery

Pediatric ENT procedures are commonly performed in ambulatory surgery centers. The selection of the patient with no comorbid conditions that may warrant prolonged of overnight monitoring is important. Any significant complications may warrant transfer to a hospital for admission and inpatient care.

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17 Opioid Metabolism, Variability, and Overdose Management in Pediatric Airway Patients

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Introduction

The number of elective pediatric otorhinolaryngologic procedures continues to rise [1]. More than 500,000 inpatient and outpatient tonsillectomies are performed each year in children below 15 years of age. Indications for adenotonsillectomy can be broken down into three broad categories: infection, obstruction, and mass lesion. Of those, chronic or recurrent tonsillitis and obstructive adenotonsillar hyperplasia are the major indications for surgical removal [2]. In the latter population, the enlarged lymphoid tissue may lead to a state of chronic airway obstruction. The resultant intermittent obstruction may then lead to a predictable cascade of events if left untreated: sleep apnea, chronic carbon dioxide (CO_2) retention, and cor pulmonale [3, 4]. Unlike their adult counterparts, the presentation of OSA (obstructive sleep apnea) is strikingly different in the pediatric population. Daytime somnolence and obesity, common with adult OSA, are rare features in young children, who may present with failure to thrive, behavioral problems, and poor school performance. Of paramount concern is the pediatric patient with either a formal diagnosis of OSA or a less severe form of sleep-disordered breathing, such as obstructive hypopnea, where chronic CO_2 retention is a hallmark feature [1, 2]. It is within this patient population where intraoperative and postoperative course may be tenuous and need treatment of opiate over dosage.

The use of opioids for perioperative pain management in children with pediatric airway and tonsillectomy procedures results in clinical challenges because of reported postoperative deaths and life-threatening respiratory depression. This is especially a major concern in children with significant obstructive sleep apnea. This chapter reviews opioid metabolism, genetic factors that affect opioid metabolism, adverse postoperative outcomes, and management of opioid overdose in children undergoing airway procedures.

Metabolic Pathways for Opioids

Metabolism of narcotic drugs predominantly takes place in the liver. Metabolic pathways are distinctively significant at two levels of narcotic biotransformation. Some opioids like codeine, oxycodone, and hydrocodone are prodrugs with little analgesic efficacy of their own. They are metabolized to their active counterparts by hepatic oxidative pathways. The sec-

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ond crucial level is the inactivation and elimination of opioids. In large part, narcotics are conjugated to form polar, water-soluble metabolites that are eliminated via the kidneys. Pharmacokinetics of opioids is of exceeding importance, given the wide spectrum of genetic variability in the enzyme systems responsible for biotransformation and the resultant variability in response.

Hepatic Cytochrome P450 System

Cytochrome P450 (CYP450) family of enzymes constitute the phase I metabolic pathway and play a role in metabolism of over 80% of all therapeutic drugs [5]. CYP450 enzyme system mediates hepatic oxidative metabolism of majority of phenylpiperidine opioids like fentanyl, alfentanil, sufentanil, and meperidine. The isoenzyme CYP3A4 is principally responsible for dealkylation of these synthetic opiates.

Fentanyl undergoes N-demethylation to form the major metabolite norfentanyl and other minor metabolites [6]. Norfentanyl is excreted by the kidneys. A minor proportion of the fentanyl administered is excreted unchanged in the urine. The fentanyl metabolites are believed to have minimal pharmacologic activity.

Sufentanil undergoes N-dealkylation to form inactive metabolites. The only metabolite that possesses minimal narcotic activity is desmethyl sufentanil [7]. Less than 1% of sufentanil is excreted unchanged by the kidneys. Alfentanil similarly is dealkylated by the CYP3A4 system to form noralfentanil and other minor metabolites [7].

Meperidine is extensively demethylated in the liver to produce normeperidine [8]. Normeperidine is pharmacologically active, with about 50% of the analgesic efficacy of the parent drug. Normeperidine also has CNS stimulant properties. It is known to provoke seizures after prolonged meperidine administration especially in patients with renal failure. Methadone is an orally administered opioid used mainly in chronic pain setting. It is metabolized by the CYP3A4 and CYP2B6 enzyme systems [9].

Codeine, hydrocodone, and oxycodone are considered weak opioids and are placed in the second step of the World Health Organization (WHO) analgesic ladder. These are prodrugs, converted to their respective active forms by the CYP2D6 isoenzyme, which is subject to diverse genetic polymorphisms, extensively described in literature.

Codeine is a 200-fold weaker opioid compared to morphine and is a widely used oral opioid in postoperative setting. A major proportion of codeine is inactivated by conjugation to codeine-6-glucuronide and N-demethylation by CYP3A4 to norcodeine [10]. About 5–10% of codeine undergoes CYP2D6-mediated O-demethylation to its active metabolite morphine, which is responsible for its analgesic efficacy.

Similarly, hydrocodone is transformed to hydromorphone, which has 10- to 33-fold greater affinity to μ-opioid receptor compared to hydrocodone [11]. Oxycodone is O-demethylated by CYP2D6 to oxymorphone, which is several times more potent compared to the parent drug. Nonetheless, majority of oxycodone undergoes N-demethylation by CYP3A4 to noroxycodone, which is an inactive metabolite [11]. Tramadol is a weak opioid transformed to *O*-desmethyltramadol by the CYP2D6 system. *O*-desmethyltramadol has greater analgesic activity compared to tramadol. Tramadol also exerts analgesic effect via serotonin and norepinephrine reuptake inhibition [12].

Uridine Diphosphate Glucuronosyltransferase (UGT) System

UGT enzymes mediate the phase II conjugation reactions, wherein the nonpolar molecules are converted to hydrophilic polar molecules that can be excreted by the kidneys [13]. The major opioid that is the substrate of this enzyme system is morphine. Both hepatic and extra-hepatic conjugation has been described for morphine [14]. This explains the near normal systemic clearance of morphine in cirrhosis or during anhepatic phase

of liver transplantation, secondary to glucuronide conjugation that occurs in the kidneys. About 75–85% of morphine is conjugated by UGT2B7 to inactive metabolite morphine-3-glucuronide (M3G). 5–10% of the morphine administered is conjugated to morphine-6-glucuronide (M6G). M6G has a greater analgesic potency compared to morphine and is a major contributor to the analgesic efficacy of morphine. It is longer acting compared to morphine, and so, it also contributes to adverse effects such as respiratory depression especially in the setting of renal failure [15]. About 5% of morphine administered is demethylated to normorphine [11].

Active metabolites of codeine, hydrocodone, and oxycodone ultimately undergo UGT-mediated glucuronide conjugation and are eliminated in urine.

Esterases

Plasma and tissue esterases mediate hydrolysis of esters like diacetylmorphine (heroin) and remifentanil. Diacetylmorphine is hydrolyzed to monoacetylmorphine and then to morphine which undergoes glucuronide conjugation and elimination [16].

Remifentanil is hydrolyzed by nonspecific plasma and tissue esterases to the principal metabolite remifentanil acid. This is far less potent than the parent compound and is renally eliminated. N-dealkylation constitutes a minor metabolic pathway for remifentanil [17].

Opioid Use in Children and Genetic Variability

Genetic polymorphisms have been well characterized in major opioid metabolic pathways, especially in CYP2D6 enzyme system (Table 17.1). More than 100 different alleles have been described in CYP2D6 [31]. Based on the enzyme expression, the population can be broadly classified under four phenotypic classes, ultrarapid, extensive, intermediate, and poor metabolizers (UM, EM, IM, and PM) [32]. Codeine, which is solely dependent on CYP2D6-mediated activation, is greatly affected by the phenotype. Many deaths or life-threatening respiratory depression have been reported with regular weight-based doses of oral codeine in children later found to be UM of *CYP2D6* [33, 34]. In 2009, a fatality after codeine administration was reported in a healthy 2-year-old boy given codeine 2 days after adenotonsillectomy due to functional duplication of the *CYP2D6* allele [33] resulting in high blood concentrations of morphine with standard codeine doses. Additional deaths and respiratory insufficiencies in postsurgical children with OSA [35, 36] highlight combined risks of OSA and CYP2D6 genetic variability. In 2013, obesity, codeine toxicity, and polypharmacology were implicated in the deaths of three obese children aged 4–10 years given standard codeine doses [37]. Multiple life-threatening respiratory depression and deaths have been reported in children after standard dose codeine administration, who were found to have high plasma morphine concentration [33, 34]. This led to further investigation and regulation of the use of codeine. Case reports of mortality in breast-fed infant after codeine administration in mother who was an UM have also raised concerns [38]. Hydrocodone and oxycodone, despite being prodrugs, have some innate analgesic activity. Response to oxycodone ranges from no analgesia in PMs to life-threatening respiratory depression in UMs. A recent pediatric postoperative oral oxycodone pharmacokinetic and pharmacogenetic study revealed that compared to PMs, IMs and EMs have higher oxymorphone concentration [30]. Oxycodone and hydrocodone are also subject to CYP3A4 metabolic pathways. So, they are affected to a lesser extent by CYP2D6 polymorphism than codeine and tramadol.

Reports of Codeine Fatalities

The other opioid influenced by the CYP2D6 polymorphism is tramadol [39]. There have been reports of mortality after standard weight-based dosing of tramadol [40]. The Food and

Table 17.1 Genetic variations that impact metabolism and clinical effects of commonly used opioids

Substrate	Gene	Functionally important allelic variant(s)	Effects associated with variant allele(s)
Codeine	*CYP2D6*	Multiple	Poor metabolizers have decreased analgesia; ultrarapid metabolizers may have toxicity and death [18]
	CYP3A4		
	UGT2B7		
Tramadol	*CYP2D6*	Multiple	Poor metabolizers have decreased analgesia; ultrarapid metabolizers may have toxicity [19]
Morphine	*UGT2B7*	−161 C > T and 802 C > T	Decreased morphine-6-glucuronide ratios and decreased morphine levels in adults; no effect in children [20]
	ABCB1	Multiple SNPs	Increased analgesic effect. Increased risk for postoperative respiratory depression in children [21]
	ABCC3	Multiple SNPs	Increased liver morphine metabolite transport and morphine-related adverse effects [22, 23]
	FAAH	Multiple SNPs	High risk for morphine-induced respiratory depression in children and PONV; suppressed hypercarbic response in pediatric postoperative setting [24]
	OCT1	Multiple SNPs	Impaired liver uptake of morphine and morphine-related PONV and respiratory depression [23, 25–27]
	COMT	472 G > A (rs4680)	Decreased morphine requirements [28]
	OPRM1	118 A > G (rs1799971)	Decreased opioid requirements and higher respiratory depression risk [29]
Fentanyl	*CYP3A4*		
	OPRM1	118 A > G (rs1799971)	Decreased fentanyl requirements with G allele† Decreased ED50 of IT fentanyl with G allele† No influence on potency and efficacy†
Remifentanil	*5-HTT*	rs25531	Better analgesic effect with low 5-HTT expression
Hydromorphone	*CYP2C9*		
	CYP3A4		
	CYP3A5		
Methadone	*UGT1A3*		
	CYP2B6	*6	Slow metabolizer phenotype
	CYP3A4		
	ABCB1		
	OPRM1		
Oxycodone	*CYP2D6*		Increased oxymorphone formation with increased CYP2D6 activity in children [30]
	CYP3A4		
	CYP3A5		
Hydrocodone	*CYP2D6*	Multiple	Poor metabolizers have decreased hydromorphone formation
	CYP3A4		

*IT, intrathecal; PONV, postoperative nausea and vomiting.
†Contrasting results.

Drug Administration (FDA) has restricted use of codeine and tramadol in all children less than 12 years of age [19]. They are also contraindicated in children between 12 and 18 years of age who have obstructive sleep apnea, obesity, other chronic lung diseases, and after adenotonsillectomy. FDA also recommends against the use of codeine and tramadol in breast-feeding mothers [19].

The Clinical Pharmacogenetics Implementation Consortium (CPIC) has recommended to avoid the use of codeine, tramadol, oxycodone, and hydrocodone in UMs and PMs. Codeine and tramadol can be used at regular doses in EMs.

Label doses can be used in IMs, and patients should be monitored for analgesic response. Alternatives should be considered in case of ineffective analgesia [41].

Polymorphisms in UGT2B7 enzyme resulting in variable morphine response have also been described [42]. Genetic polymorphisms have also been described in CYP3A4 and CYP2B6 enzyme systems [43]. These should be considered when using opioids for analgesia in children, given the relatively narrow margin of error, especially in the setting of OSA, adenotonsillectomy, and other airway surgeries.

Personalized analgesia with routine presurgical genotyping of multiple genetic variations affecting opioids and other analgesics to identify children at high risk for adverse effects is still many years away. Pharmacogenetics has the potential to guide anesthesia providers on perioperative opioid selection (e.g., CYP2D6) and dosing to improve safety.

Opioid Administration During Airway Surgery in Children

The administration of opiates to the pediatric patient undergoing an otorhinolaryngologic procedure is often a key component of a balanced anesthetic. However, in the patient with OSA, who experiences periods of intermittent hypoxia and hypercapnia, the response to opiates may be exaggerated. Thus, a standard analgesic dose used in an otherwise healthy aged match cohort may yield significant side effects such as respiratory depression in the patient with severe OSA [3]. The prevalence of OSA is 1–3% in children and is one of the main indications for adenotonsillectomy in children. The hallmark features of OSA and obstructive syndromes are recurrent bouts of hypoxia and hypercapnia. In developing animals, exposure to recurrent intermittent hypoxia, such as occurs with OSA, increases the number of μ-opioid receptors in the brainstem. This upregulation of μ-opioid receptors may in fact be adaptive; however the true biomechanical nature has yet to be elucidated [4, 44].

Brown et al. demonstrated that the severity of the nocturnal desaturation, in patients with severe OSA correlated with the sensitivity to exogenously administered opioids. The morphine dose needed to acquire a uniform endpoint was significantly lower in patients with OSA whose preoperative saturation nadir during sleep was lower [45, 46].

Patients with OSA are known to have increased sensitivity to intraoperative and postoperative opioids [4, 47, 48]. This increased sensitivity may be attributed to upregulation of mu-opioid receptors as a result of recurrent episodes of hypoxemia, leading to an increased risk of respiratory depression with opioid administration [49, 50]. As a result, reduced doses of opioids with careful titration are recommended in children with significant OSA. A review of tonsillectomy-related malpractice claims and jury verdict reports over a period of 28 years showed that malpractice claims associated with opioids had larger monetary verdicts. Sleep apnea was documented in 17 fatal and 15 nonfatal malpractice claims signifying need for better and safe management of children with OSA undergoing tonsillectomy [51]. Another Closed Claims Project on death or neurologic injury following tonsillectomy showed that more than half of the children had a diagnosis of OSA or met the criteria for "at risk of OSA" [52]. Obese children also have an increased risk of developing OSA and also are at risk of opioid overdose if dose calculations are made using total body weight.

This relative sensitivity to opiates not only has implications in the intraoperative period, but also in the postoperative period when smaller than normal dosages may lead to profound respiratory depression. Thus, in the postoperative period, extreme vigilance is paramount, especially in the pediatric patient with OSA. In children with OSA or other respiratory comorbidities (e.g., asthma) undergoing tonsillectomy or painful airway procedures, in the absence of facilities to do routine preoperative genotyping, it is safer to avoid codeine and tramadol and other opioids significantly metabolized via CYP2D6 pathway, given the literature evidence and the FDA's warnings

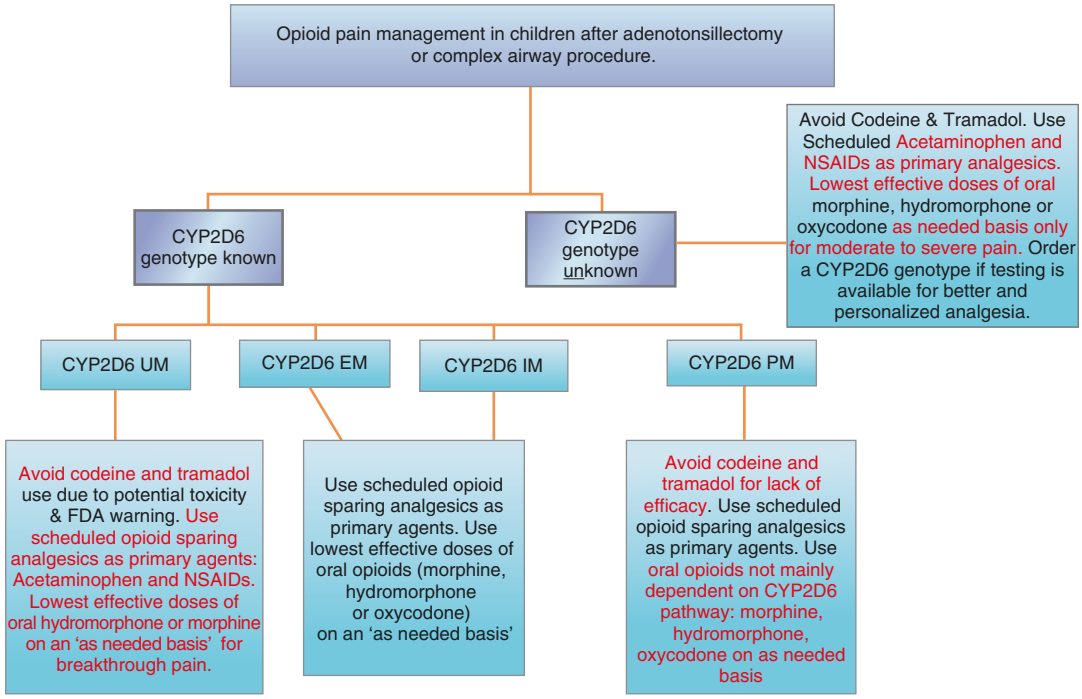

Fig. 17.1 CYP2D6 genotype-based decision algorithm to manage surgical pain following complex airway procedures and adenotonsillectomy. This algorithm, developed based on the FDA's warning on codeine following tonsillectomy and literature evidence, shows opioid-sparing approach is safer to manage surgical pain following complex airway procedures and adenotonsillectomy in children, especially if CYP2D6 metabolizing status is unknown. If CYP2D6 metabolizing status is known, in extreme genotypes (ultrarapid and poor metabolizers), opioid selection and dosing can be personalized as depicted in the algorithm

(Fig. 17.1). Opioid-sparing analgesics (acetaminophen and NSAIDs) are effective analgesics if administered on scheduled basis, and minimize the need for opioids (Fig. 17.1).

Treatment of Opioid Overdose

The immediate postoperative period for the pediatric patient who has undergone an otorhinolaryngologic procedure is often dynamic. During the recovery phase, the patient is not only returning to a state of homeostasis but often requires pharmacological intervention for pain. Children with OSA continue to demonstrate oxygen desaturations during sleep on the first night after adenotonsillectomy, with those who carry a diagnosis of severe OSA manifesting more severe oxygen desaturations [53, 54].

Thus, the administration of a potent opioid in this population may lead to worsening hypopnea and desaturation. In an emergent situation, in conjunction to supportive and resuscitative measures, naloxone may be administered. To note care must be taken when both providing positive-pressure ventilations and deciding to insert either an oral or nasal airway in the patient who has just underwent an otorhinolaryngologic procedure. One device may be superior to the other when deciding, based on the risk of bleeding and or disruption of the surgical repair.

The pharmacokinetics of naloxone makes it extremely effective for the immediate reversal of a mu-opioid agonist. As a competitive antagonist, it may be given intravenously, with an onset of action between 30 s and 1 min. However, it may also be administered via intraosseous, neuraxial, or endotracheal routes. The resuscitative

dose of 0.1 mg/kg IV/IO/ET (<5 or 20 kg) or 2 mg IV/IO/ET (5y or >20 kg) may be decreased substantially in the context of the patient in respiratory distress and not in-extremis (1–15 μg/kg) [55]. Care must be taken to observe the patient carefully after the initial administration for resurgence of hypoventilation. The dose can thus be repeated, with caution being observed, and if necessary an infusion being initiated at 0.16 mg/kg/h. As a competitive antagonist, naloxone may cause systemic hypertension, dysrhythmias, and non-cardiogenic pulmonary edema with overzealous use [56]. In the context of administration, the resulting side effects may occur even after a single administration. In an analysis of 195 pediatric patients that received a single dose of naloxone, Prough et al. found that there was an incidence of 0.5% of pulmonary edema [57]. Although no consensus has been reached as to how long a patient should be observed after administration of naloxone, clinical judgment and unique patient comorbidities must be taken into account. It is ideal to closely monitor patients for at least 2–3 h after administration to make sure of a full recovery from opioid-induced respiratory depression and meanwhile, treat them with supportive measures.

Conclusion

Children with OSA undergoing tonsillectomy and other painful airway procedures are at high risk of postoperative respiratory depression with opioids. Given the FDA's warning against codeine and tramadol in children and available literature evidences, it is safer to avoid codeine and tramadol following tonsillectomy and major airway procedures in children. Though preoperative *CYP2D6* genotyping could facilitate appropriate opioid selection, it is not widely available and covered by third-party payers. To realize the dream of pharmacogenomic-based personalized analgesia decision support, we need more robust studies, independent validations, larger study populations, and better statistical approaches [58, 59].

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18 ENT Surgery and Anesthesia Neurotoxicity in Children

Susan Lei and Lena S. Sun

Case Illustration

A 2-year-old otherwise healthy boy with obstructive sleep apnea (OSA) documented by a recent sleep study is scheduled for a tonsillectomy and adenoidectomy. Parents have been extremely concerned for weeks about this surgery, a procedure which their child needs to treat his OSA. As the day of surgery approaches, the parents wanted to know more about anesthesia, particularly the potential neurotoxic effects of the anesthetic drugs that have been reported in the news and online. How can we best explain anesthesia to the parents as anesthesiologists and discuss what we know about anesthesia and neurodevelopment in their young son?

Questions to Be Addressed

What information and counseling related to anesthesia care can the otolaryngologist provide at the office visit to prepare them for the day of surgery? We will discuss these areas specifically in this chapter.

Background

Over the past decade, animal studies using rodent models and nonhuman primates have provided compelling evidence that exposure to general anesthesia in young animals is associated with long-term neurocognitive, learning, and behavior deficits. In the United States, an estimated two million children under the age of 5 years undergo surgical procedures and diagnostic imaging studies each year [1, 2]. Therefore, the potential neurotoxic effects from exposure of commonly used anesthetic agents in infants and young children during surgical procedures and diagnostic studies remain a significant matter of serious concern to parents, caretakers, and providers.

The US Government Food and Drug Administration (FDA) recently issued a change in labeling regarding the safe use of anesthetic and sedative agents: http://www.fda.gov/Drugs/DrugSafety/ucm532356.htm.

Review of the Current Preclinical Data

Animal studies have shown that anesthetic and sedative drugs can cause neuronal damage to the developing brain leading to lasting behavioral and cognitive deficits. The mechanisms of neurotoxicity from exposure to anesthetic agents in preclinical studies have suggested the role of

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neuronal apoptosis, neuro-inflammation and dysregulation of other growth and survival pathways, and other downstream developmental processes, such as synaptogenesis, neurogenesis, and dendritic branching disruption. Essentially all anesthetic agents and sedatives used today have been implicated in many reports demonstrating widespread neurodegeneration and long-term developmental impairment. These preclinical studies were conducted in vitro and in vivo on cultured cells, primary neurons, rodents, and nonhuman primates, with exposure of anesthetic agents that act via *N*-methyl-D-aspartate (NMDA)- or γ-aminobutyric acid (GABA)-mediated signal transmission during vulnerable period of neurodevelopment.

While animal studies have consistently reported brain injury and behavioral changes when exposed to anesthetic and sedative agents during critical periods of brain development, translating these findings to humans and clinical medicine has been challenging to do. The rate of brain maturation varies across species. The human brain is much more complex and undergoes a much longer period of development than rodents and nonhuman primates; therefore there may be more extended periods of vulnerability depending on the brain region and possibly a greater capacity for neuroplasticity and recovery from any insult [3]. In addition, the dose and duration of anesthetic exposure in animal studies often exceed what are found clinically further complicating translation to relevant equivalents in humans. Animal studies, particularly in rodents, have also been criticized since they are often conducted without specific monitoring of physiologic parameters such as hypoxia and hypercarbia, which can significantly affect neurologic outcomes. Results from nonhuman primate studies may be considered to be more easily translated to humans. The neurodevelopmental stages more closely resemble humans, and these animals possess higher-order cognitive function as in children. Moreover, the experimental conditions always provide close physiological monitoring. However, most preclinical studies examine exposure to anesthesia in the absence of surgery; thus it is a major limitation since anesthesia exposure in infants and children is most often in the context of surgery. In spite of the many limitations of the preclinical studies, the findings do support the idea that anesthetic-induced neurotoxicity occurs during a vulnerable window during brain development and neurotoxicity is dose-dependent, as well as an increased risk from multiple exposure to anesthetic agents.

Review of Data from Clinical Studies

Replicating animal studies in children using the same methodologies is impossible, but clinicians and researchers have responded to the growing concern surrounding the potential neurotoxic effects of anesthetic and sedative drugs and begun to explore the clinical relevance of anesthetic neurotoxicity by conducting observational epidemiologic studies. The early observational studies have almost entirely been retrospective in nature with its inherent limitations and varying degrees of confounding and reporting bias. Some of the studies used population-wide results of academic achievement testing and teacher evaluation, while others utilized birth cohort registries and used diagnostic codes for learning disabilities or behavioral disorders such as attention deficit hyperactivity disorder (ADHD), as outcome measures. The comparison was usually made between those children undergoing surgery as the exposed group with those who had no surgery as the unexposed group. In some of the studies, neuropsychological testing results were used to assess IQ scores and other specific cognitive function. To date, an association between anesthesia exposure early in life and the development of adverse neurodevelopmental outcomes has been inconsistent, and very much dependent on the outcome measures examined [4].

Several recent clinical studies have provided or will provide more data regarding the clinical effects of anesthesia exposure on neurodevelopment in children, specifically, GAS, PANDA, and MASK studies.

The General Anesthesia compared to Spinal Anesthesia (GAS) study is an ongoing international, multicenter, prospective randomized

controlled equivalence trial with premature and full-term infants undergoing inguinal hernia surgery randomized to two different anesthetic techniques with one group receiving the volatile anesthetic agent sevoflurane and the other group receiving a regional anesthetic. The study was conducted at 28 study sites, including hospitals in the USA, Australia, Italy, UK, Canada, Netherlands, and New Zealand, and was randomized to either sevoflurane-based general anesthesia or awake spinal anesthesia [5]. Infants with previous exposure to general anesthesia or have any risk factors for adverse neurodevelopmental outcomes were excluded. The study aims to determine whether regional and general anesthesia resulted in equivalent neurodevelopmental outcomes. The primary outcome was IQ at age 5. Secondary outcomes include assessment of neurodevelopmental outcome at age 2 using Bayley scale III and the frequency and characteristics of postoperative apnea. Reports of the interim analysis at age 2 years did not show any difference in the composite cognitive score between the two groups of children who received regional anesthesia versus general anesthesia. However, age 2 years may still be too early to detect any cognitive deficits or behavioral changes as the brain is still developing. It is well known that Bayley performed at age 2 years is a poor predictor of neurodevelopmental outcome later in life. Therefore, while the interim results of the GAS study are reassuring, they are not the primary outcome of the study nor are they necessarily predictive of long-term cognitive functions. The median duration of sevoflurane anesthesia exposure was only just under 1 h (54 min), so the effects of a longer duration of anesthesia still need to be investigated. The GAS study thus provides evidence that general anesthesia in infancy does not cause any major injury, particularly with the exposure of sevoflurane-based anesthesia for short durations.

The Pediatric Anesthesia NeuroDevelopment Assessment (PANDA) study is a multicenter, ambi-directional, observational study examining the effect of a single brief anesthetic on performance in a sibling cohort discordant for exposure to general anesthesia for inguinal hernia repair [6]. The exposure is retrospective but assessment is prospective. Sibling pairs within 36 months in age are assessed for neurocognitive and behavior outcomes prospectively and the data from the documented anesthesia records of the exposed sibling are reviewed retrospectively. The exposed siblings were less than age 3, a period of peak synaptogenesis activity in various regions of the human brain and healthy, at the time of the surgery and anesthesia exposure. The study examines whether the exposure was associated with impaired neurocognitive development and abnormal behavior in later childhood. The sibling pairs were evaluated using the PANDA neuropsychological battery, a questionnaire developed by a team of experts in neuropsychology and neurodevelopment, at age 8–15 years, which was chosen because results from that age group would be reliable and valid and enough time would have passed by for impairments and deficits to emerge. The primary outcome is global cognitive function (IQ), and the secondary outcomes include domain-specific neurocognitive function and behaviors. The results from the PANDA study showed a statistically insignificant mean difference of 0.2 IQ points between exposed and unexposed siblings. This degree of difference is deemed clinically undetectable especially when compared to mean IQ losses of up to 6 points in population studies of lead exposure in children [7]. The secondary outcomes also showed no statistically significant differences in mean scores of memory, attention, visuospatial function, executive function, language, motor and processing speed, or behavior between sibling pairs. The PANDA study utilized sibling-matched comparison groups to control for confounding factors such as genetics, familial environment, parental education, and socioeconomic influences of neurodevelopment. However, the study has several limitations. First, there is no data on neurocognitive risks of repeated or prolonged exposure or risk in premature infants. Second, some of the anesthesia records from many years ago that were retrospectively reviewed were handwritten so data may not be complete or accurate.

The Mayo Anesthesia Safety in Kids (MASK) study, similar to the PANDA study, is an

ambi-directional observational study with a retrospective arm that involves analysis of anesthesia records and school records and a prospective testing arm that requires children to undergo the Operant Test Battery, a neurodevelopment test [8, 9]. The study compares children exposed to anesthesia before age 3 to a reference sample of propensity-matched unexposed children to determine whether anesthetic exposure was associated with neurodevelopmental abnormalities. The study uses a population-based birth cohort born to mothers residing in Olmsted County, Minnesota. From data gathered from birth and medical records, the birth cohort was divided into three propensity-stratified groups consisting of no anesthesia exposure, single exposure before 3 years of age, and multiple exposures before age 3.

The Mayo group recently examined an Olmsted County birth cohort from 1996 to 2000 and reported that there was an increased risk for learning disability and ADHD associated with multiple exposure but not single exposure, with the anesthetic agents mainly consisted of sevoflurane. These results essentially validated the investigators' previous study using a birth cohort from Olmsted County from 1976 to 1982, where the anesthetic agents used were primarily halothane, ketamine, and nitrous oxide. Therefore, the results from both the older cohort and the more recent cohort had the same findings and showed that an increased risk of learning disabilities with multiple anesthetic exposures but not with a single anesthetic exposure occurred in spite of the differences in the anesthetic medications and intraoperative monitoring used in the 1970s, 1980s, and 1990s.

The ambi-directional MASK study includes children born between 1994 and 2007 who still reside in the area to undergo prospective testing with the Operant Test Battery, which was also used to study anesthetic-related neurotoxicity in nonhuman primates and offers a direct comparison of the effects of anesthetic exposure in children and nonhuman primates performing identical behavioral tasks. The domains tested include cognition, memory, language, executive function, motor and visual spatial tasks, attention, and processing speed. The goal is recruit 1000 subjects to find a phenotype for anesthetic neurotoxicity.

The available data thus far from the interim results of the GAS study and those from the ambi-directional observational PANDA study suggest that a single brief anesthetic exposure does not appear to be associated with any neurodevelopmental deficits and behavioral changes but the case is much less clear with repeated exposures and exposures of long duration.

Anesthesia for Infants and Young Children

Studies in young animals have shown that almost all commonly used anesthetic and sedative drugs can be harmful to the developing brain. These commonly used anesthetic and sedative drugs are not used exclusively in the operating rooms and anesthetizing sites by anesthesiologists only. Drugs such as propofol, midazolam, and ketamine are also used frequently in the intensive care units (ICU) by pediatric intensivists to sedate critically ill intubated children, in the emergency room by physicians to perform bedside procedures, in endoscopy suites and offices to perform esophagogastroduodenoscopy and colonoscopy procedures, and in dental offices to perform procedures. It is important to note that doses used in the ICU settings are commonly high and exposure times may be even longer than the operating rooms.

An important question that clinicians and parents frequently ask is: at what age is anesthesia safe for the child? The age at which the developing brain is most vulnerable to the deleterious neurotoxic effects of conventional anesthetic drugs is unknown, debatable, and controversial. Human brain development starts in the embryonic period and continues into the adolescent period. Based on rodent studies, the most susceptible period is believed to be the period of maximal synaptogenesis, which is 2 days before birth to 2 weeks affect birth in rodents. During this vulnerable period, exposure to anesthetic agents has led to cellular evidence of neurotoxicity as

well as functional deficits [10, 11]. Perhaps because of the assumption that peak synaptogenesis in most human brain regions are complete by age 3 years, most large observational studies have age younger than 3 years as the presumptive vulnerable period. Thus, the most recent FDA labeling change has also used this as the age of "cutoff," though there is *no* evidence to support such an approach.

The minimum dose of anesthetic and sedative drugs that can potentially lead to neurotoxic effects is also largely unknown. All published data on human studies to date have involved volatile agents with or without additional use of one or more intravenous sedative agents. None of these studies have any information regarding specific drugs administered or the exact doses of drugs used. Therefore, it can only be inferred that a lower dose is used with a single episode of exposure and that multiple exposures would be associated with higher doses from the aggregate of multiple doses.

Brief, single exposures are not associated with detectable neurodevelopmental effects, but the precise nature of "brief" has not been defined. Therefore, the consideration should be to provide anesthesia for children under 3 years old for only necessary diagnostic imaging studies. In the case of whether to proceed with elective surgical procedures, the risks and benefits in each case must be carefully weighed. Finally, whenever possible, procedures should be scheduled concurrently to minimize the number of exposures to anesthesia, and the procedures should be performed by the most skilled surgeons to decrease the duration of the exposure.

What Should the Otolaryngologist Know

There is a high volume of pediatric otolaryngologic procedures performed annually, and those who require surgical intervention or diagnostic workup will require general anesthesia especially in young children. In December 2016, the FDA issued the warning that "repeated or lengthy use of general anesthetic and sedation drugs during surgeries or procedures in children younger than 3 years or in pregnant women during their third trimester may affect the development of children's brains" [12]. The FDA recommends that healthcare providers discuss with pregnant patients and parents of young children the benefits, risks, and appropriate timing of surgery requiring anesthesia that will take longer than 3 h. This warning was issued based almost entirely on evidence from preclinical studies. The objective of the labeling change was to raise awareness and to ensure that the information needed about the risks and benefits of anesthesia in young children is widely available to clinicians and parents. However, the association between anesthetic drugs and its potential neurotoxic effects and the degree of risk remains unclear. In response to the FDA warning, the American Society of Anesthesiologists, the Society for Pediatric Anesthesia, and the Executive Committee of the American Academy of Pediatrics Section on Anesthesiology and Pain Medicine issued a statement. In their statements, they emphasized that the FDA warning was based on animal studies that need to be further verified in human clinical studies. While the potential risk of negative cognitive or behavioral effects of anesthetic agents remains uncertain, they cautioned clinicians and parents the need to weigh the possible risk of delaying needed surgical or diagnostic procedures against the unknown potential neurotoxicity effects. Nevertheless, when parents present to the doctor's office for initial consultation on a possible ENT procedure, concerns about anesthesia and the FDA warning about its potential neurotoxic effects will most likely need to be addressed.

There were no recommendations for an alternative anesthetic strategy from the FDA when they issued the warning, and while clinicians are looking into alternative drugs such as dexmedetomidine and opioids, the research has been limited and will most likely not represent a feasible option alone when compared to conventional general anesthetic agents for ENT procedures.

ENT procedures such as myringotomy tubes, tonsillectomies, frenulectomies, and bronchoscopies are performed everyday on chil-

dren. The need to seek expert advice is usually first noticed by the parents or caretaker, and they often present to the doctor's office seeking for a treatment to relieve or attenuate the symptoms. While the majority of these children tend to be otherwise healthy, the need for treatment with a procedure or surgery becomes evident when evaluating the severity of presenting symptoms and with most ENT procedures performed on young children, there is a need for general anesthesia. Children coming for myringotomy tubes often have chronic otitis media with recurrent fevers and possible hearing loss as a result. Children coming for tonsillectomies and adenoidectomies usually present with obstructive sleep apnea, chronic rhinitis, and multiple night arousals who are at risk for prolonged periods of hypoxia during sleep, which alone can affect neurodevelopment when the brain is subjected to repeated insults of hypoxic ischemic injury, development of pulmonary hypertension resulting in premature death from the complications of pulmonary hypertension, and daytime sleepiness and poor performance in school and academic achievement examinations. Children who come for laryngoscopies and bronchoscopies may be otherwise healthy presenting with stridor alone, but these patients typically are chronically ill children who are premature at birth and required mechanical ventilation for the first few days to few months of life. They can present with subglottic stenosis, laryngomalacia, tracheomalacia, laryngeal webbing or cleft or tracheal granulomas as a result of prolonged intubation, or traumatic intubations due to prematurity. These patients have most likely been exposed to anesthetic and sedative agents early in life multiple times or for prolonged periods of time while in the neonatal intensive care unit. In addition, constant threats to their life from hypoxia and prematurity during critical periods of neurodevelopment and growth will make them susceptible to cognitive and behavioral deficits that may be unrelated to anesthetic neurotoxic effects, and for these patients, they will need the bronchoscopy procedure and treatment to alleviate their respiratory symptoms.

There are also otolaryngology procedures that take much longer to perform even in the most skilled hands such as tympanomastoidectomy, laryngotracheal reconstruction (LTR), and choanal atresia repair. However, tympanomastoidectomies are usually performed in older children, while LTR procedures are usually performed in prematurity children who have other comorbidities, and choanal atresia repair is not a procedure that can be delayed without significant health risks to the child. Further workup for surgical planning that involves radiologic imaging such as MRI or CT scan should be combined with other surgical procedures when possible and recruit the help of a child life specialist to keep the child calm and preoccupied. If premedication is required, consider intranasal dexmedetomidine for its safer profile.

Most of the common ENT procedures performed on children younger than 3 years old such as myringotomy tubes, tonsillectomy and adenoidectomy, laryngoscopy, and bronchoscopy are fairly short procedures under 2 h. However, most of these procedures are often repeated on multiple occasions for recurrent symptoms, which lead to multiple exposures to anesthetic agents for short durations [13]. Nevertheless, as described above, the critical importance for these procedures, in and of itself, for appropriate development in hearing, language development, and good health probably cannot be overstated. Thus, it is not appropriate to postpone these procedures due to the potential effects of anesthesia exposure on neurobehavioral development.

The ENT physician should remain up to date with the most recent literature and recommendations on issues relating to anesthesia in young children and appreciate the importance of combining procedures and diagnostic imaging under the same anesthetic event. This would allow for the ENT physician to provide a thoughtful response to families when information on the topic is asked. Careful consideration and discussion about possible changes or alterations made to treatment protocols within members of the field may also help reduce the anesthetic exposure in young children. While time-consuming, open discussion at the initial consultation visit is helpful and will provide the needed reassurance to the families when anesthetic risks are discussed by the otolaryngologist before scheduling the procedure since the pediat-

ric anesthesiologist will not meet the family until the day of the surgery. Many clinicians have now incorporated this discussion into their office visit and written informed consent.

Information for Parents Regarding the Risks of Anesthesia in Young Children

While clinical research is ongoing and more results are emerging, it is safe to say that in general, young children typically do not undergo surgery or diagnostic testing unless it was vital to their health and development. Postponing the surgery or imaging studies may be detrimental to their health and development with unnecessary consequences; therefore delaying may not be an option for young children. As was recommended in the most recent FDA statement: "Parents should talk to their doctors if they have any questions or concerns about general anesthesia and sedation drugs." In December 2016, the FDA had issued a warning regarding the potential risks of negative effects on the developing brain from administration of anesthetics and sedative drugs; there is very limited clinical evidence to support this claim; thus there is great need for clinical research. This warning was modified in April 2017 to specifically state that "surgeries or procedures in children younger than 3 years should not be delayed or avoided when medically necessary. Consideration should be given to delaying potentially elective surgery in young children where medically appropriate" [14].

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