A Framework For The Management Of The Pediatric Airway

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What is already known

- Critical airway events are common in pediatric anesthesia and are a significant cause of morbidity and mortality.
- Current algorithms are modifications of adult approaches which are often inappropriate because of differences in age-related anatomy, physiology and neurodevelopment.

What this article adds

- An overarching framework for the management of the pediatric airway has been developed to achieve acceptance across diverse pediatric clinicians, societies and groups.
- This universal and pragmatic approach will help to establish minimum standards for pediatric airway equipment, personnel and medications whenever pediatric airway management is required.
1. Introduction

Critical airway incidents in children are a frequent problem in pediatric anesthesia\(^1\) and remain a significant cause of morbidity and mortality\(^2\). Young children are at particular risk in the perioperative period\(^3\). Delayed management of airway obstruction can quickly lead to severe complications due to the short apnea tolerance in children. A simple, time critical, pediatric specific airway management approach combined with dedicated teaching, training and frequent practice will help to reduce airway related pediatric morbidity and mortality\(^4\). There is currently no pediatric specific universal framework available to guide practice. Current algorithms are modifications of adult approaches which are often inappropriate because of differences in age-related anatomy, physiology and neurodevelopment. A universal and pragmatic approach is required to achieve acceptance across diverse pediatric clinicians, societies and groups. Such a framework will also help to establish minimum standards for pediatric airway equipment, personnel and medications whenever pediatric airway management is required.

2. Background

Airway obstruction leads rapidly to profound hypoxemia, respiratory acidosis, bradycardia and ultimately cardiac arrest in children. This is because children have a decreased oxygen reserve and increased oxygen consumption as well as higher carbon dioxide production when compared with adults\(^5,6\). In general, neonates and infants at particularly high risk\(^7,8\) as are children with significant cardiopulmonary co-morbidities and those undergoing emergency procedures\(^9,10\). Transient perioperative hypoxemia usually does not result in immediate overt postoperative morbidity, however long-term consequences remain largely unknown. Prolonged hypoxemia and bradycardia increases the risk of cognitive and motor impairment in later life in pre-term neonates\(^11\).

Reducing the incidence of hypoxia and bradycardia using ‘optimal’ pre-oxygenation is difficult and on occasion impossible to perform in awake children (particularly infants) without causing distress. Even when successfully performed, preoxygenation may not result in a sufficiently long period of normoxia to allow the airway to be secured\(^12\). Intermittent ventilation and oxygenation including ‘rapid sequence inductions’ is commonly required. Techniques to continuously oxygenate during airway management (such as high flow humidified \(O_2\) via nasal cannula) should be considered in small children\(^13,14\). ‘Modified’ awake intubations with ORL/ENT support may be required in
appropriate situations\textsuperscript{15,16}.

Timely, goal-directed approaches are required to re-establish an open airway and oxygenate and ventilate. Numerous published difficult airway algorithms are available in various formats and languages to guide practice. These are mostly co-opted from adult algorithms which are modified for children; their relevance is controversial, particularly in younger children. Several pediatric anesthesia societies and groups have published expert opinion based algorithms that are often discordant. Non-anesthesiology specialties have also published their own recommendations making it difficult for individual practitioners to identify the optimal approach.

A simple, universal, intuitive and clear framework to manage the pediatric airway that is easily adaptable to diverse clinical situations and personnel may help guide clinical practice and reduce complications.

3. Principle approach to the pediatric airway

3.1 Prevention of pediatric airway difficulties

Routine (daily best practice) pediatric airway management in healthy (ASA-PS 1 or 2) patients is easy for the trained and experienced clinician. Careful pre-anesthetic evaluation and clinical assessment and recognition of possible signs and symptoms of airway obstruction including apnea, stridor, wheeze, cyanosis, dyspnea, suprasternal retractions and use of accessory respiratory muscles will reduce airway management related complications. Acute upper respiratory tract infections may contribute to perioperative respiratory adverse events.

A clear airway management plan including the knowledge of all possible complications and their management are essential before administering sedatives or inducing general anesthesia. This is best achieved through regular practice, continuing medical education and simulation team training including human factors in an airway crisis.

All equipment as well as resuscitation drugs should be prepared in appropriate sizes or dosages and in working condition. Equipment includes tracheal tubes and supraglottic airway devices, laryngoscope blades, stylets, forceps, facemasks, nasopharyngeal and oropharyngeal airways, self-
inflating ventilation bag permitting continuous positive airway pressure (CPAP) and positive end-expiratory pressure (PEEP), suction devices, reliable oxygen source and vascular access equipment. All tools to establish a safe pediatric airway and to manage possible complications must be ready for immediate use.

3.2 General approach to the pediatric airway

A pragmatic classification of pediatric airway problems into 3 categories determines the anesthetic approach. These categories are:

- Normal airway (the child without history, sign and symptoms for a difficult airway)
- Impaired normal airway
- Abnormal or difficult airway

The urgency of the clinical situation then dictates the necessary steps:

- Immediate intervention
- Mobilizing of best existing local expertise (which includes ORL/ENT specialists or general surgeons
- Careful planning and referral to a specialist pediatric center.

Children who present with an acutely impaired otherwise normal airway or known difficult airway should be treated by an experienced clinician in an appropriately staffed and equipped pediatric setting unless there is an immediate threat to life.

Figure 1 outlines the general approach to a child that requires anesthesia or sedation for surgery, interventional or diagnostic procedures. It considers the child’s airway, the facilities and expertise of the department and the urgency of the underlying clinical condition. While it is impossible and beyond the scope of this framework document to address all potential scenarios the general underlying principles of pediatric airway management are discussed below.
4. Framework for the approach to the pediatric airway

4.1. Principles

Pediatric airway management can be stressful for the inexperienced clinician and may lead to poor decision making\textsuperscript{20}. Good outcomes in critical situations require a structured approach that is:

- Simple, intuitive and forward only
- Easy to memorize and practice
- Open Box i.e Generally applicable and adaptable to all situations including local resources and expertise

A forward only, ‘step by step’, easy to memorize algorithm significantly reduces the cognitive load in a clinical crisis. It allows the clinician to focus on the essential steps without distraction. The ‘Open-Box’ approach allows the incorporation of local expertise and unique local experiences. A solution incorporating these principles will be easily adoptable across diverse pediatric specialists, specialties and societies.

4.2 Clear separation of airway problems

The ability to oxygenate and (facemask) ventilate saves lives and must be prioritized over tracheal intubation\textsuperscript{21}. Good basic airway management skills are essential. Fortunately, facemask ventilation is easy to perform in experienced hands in the child with a normal airway. A large cohort study reported successful oxygenation and ventilation in all patients using either a facemask or a laryngeal mask airway\textsuperscript{2}.

Pediatric tracheal intubation is generally easy in healthy (ASA-PS 1 or 2) children but can be more challenging in infants (particulalay syndromic patients)\textsuperscript{4,18,22}. There is no best equipment or technique for all tracheal intubations. Continuing education, training and use of simulation scenarios with direct/video laryngoscopic techniques reduces associated complications. Repeated tracheal intubation attempts may traumatisethe pediatric airway and can render a difficult tracheal intubation impossible or result in the inability to oxygenate and ventilate the patient. An alternative airway technique should be used early\textsuperscript{2,4}.

4.3 Recognize and treat airway obstruction
Airway obstruction is a common cause of anesthesia related perioperative hypoxemia and may occur at any time in the perioperative period. To manage such a situation successfully it is important to distinguish between anatomical (mechanical) and functional causes of airway obstructions which require different strategies of treatment.\textsuperscript{17,21,22}

**CALL FOR HELP:** *It is essential that help and suitable assistance is sought at an early stage.*

This must be clearly identified on a locally adapted algorithm including emergency contact details and/or easy to access technical alarm/call devices.

Anatomical/mechanical airway obstruction and functional airway obstruction can occur at the same time. An anatomical/mechanical airway obstruction is a physical obstruction of the airway and requires the intervention of the clinician using basic and advanced airway skills. Functional airway obstruction is generally treated with drugs as mechanical interventions are mostly ineffective. Structured teaching and training for managing functional airway obstruction is essential since this is responsible for the majority of perioperative respiratory complications\textsuperscript{3,24}.

### 4.3.1 Anatomical/mechanical airway obstructions

Anatomical and mechanical airway obstructions occur frequently after induction of anesthesia in the unconscious patient and are usually easy to resolve. *(Table 1)*

**Anatomical/mechanical airway obstructions:** Must be recognized and treated by the clinician.

A combination of head-tilt, chin-lift and/or jaw-thrust while maintaining an open mouth are simple treatments employed in daily practice. Alternatively, an appropriately sized oro- or nasopharyngeal airway will relieve most upper anatomical airway obstructions. Forceful bag-mask ventilation may result in gastric distension (commonly not recognized by inexperienced practitioners) which can impede ventilation/oxygenation and requires prompt decompression using an oro-gastric tube. Effective bag-mask ventilation can be monitored using waveform capnography.
4.3.2 Functional airway obstruction

Functional airway obstruction can occur in the upper and lower airway.

Functional upper airway obstruction is common and usually caused by insufficient depth of anesthesia (closure of pharynx), laryngospasm or opioid-induced glottic closure. Functional lower airway obstruction is induced by bronchospasm in children with recent respiratory tract infections, bronchial hyperreactivity or thoracic wall rigidity as a consequence of rapid and/or high dose opioid administration. While minimal laryngospasm and loss of pharyngeal tone may initially be treated using continuous positive airway pressure (good routine basic airway management);

Severe Functional Airway Obstructions are treated with drugs.

Hypnotics such as propofol may be used early in otherwise healthy, non-compromised children to overcome these acute functional airway problems such as insufficient depth of anesthesia and severe laryngospasm. Careful hemodynamic monitoring is essential as severe hypotension may ensue. Muscle relaxants can be used early as an effective alternative to effectively overcome functional airway obstruction in children with a normal airway with the exception of bronchospasm. Care must be excercised in patients with known distal airway obstruction. Intravenous epinephrine starting with low doses (1 mcg/kg) is highly effective to treat severe bronchospasm (‘silent chest’). Appropriately diluted intravenous epinephrine should be readily available at all times.

The early use of hypnotics and relaxants to overcome functional airway obstruction instead of attempts to awaken the child is based on the rational that the apnea tolerance in young children is too small to safely overcome a ‘cannot oxygenate- cannot ventilate’ situation. In addition, muscle relaxants should be used in the ‘cannot oxygenate/ cannot ventilate’ situation before any attempts of surgical airway such as emergency cricothyroidotomy, needle insertion or tracheostomy are to be considered as endorsed in adults. Muscle relaxants overcome most functional airway obstruction permitting facemask / laryngeal mask ventilation and improve tracheal intubation conditions.

Patients with an expected or suspected difficult airway must be treated by practitioners
experienced in difficult pediatric airway management and adequate help sought before starting a procedure. (Figure 1)

4.4 Universal approach

A universally accepted and implemented framework for the difficult pediatric airway requires the recognition and use of local expertise, resources and facilities. The following simple, ‘Open-Box’ algorithms can be adapted according to local expertise and facilities.

The algorithms are separated into

- Oxygenation and ventilation
- Tracheal intubation

While this suggested framework specifically applies to the normal pediatric airway, the main underlying principles can also be considered for the expected abnormal and acutely impaired but otherwise normal pediatric airway.

The rare but frequently discussed need for front of neck airway (FONA) in children can be attempted as a last resort in a ‘cannot oxygenate - cannot intubate’ situation. FONA is likely to be futile in a child in an emergency. It is not possible to sufficiently practice or gain experience for this situation to be useful and relied upon in an emergency due to age and size range from neonates to adolescents. Emergency FONA has been attempted in approximately 2% of anticipated and unexpected difficult airways of the PeDI registry with considerable subsequent morbidity and mortality. This is in stark contrast to the ability to almost always overcome difficult or impossible facemask ventilation in this large cohort of difficult pediatric airways by the recognition and treatment of anatomical airway obstructions such as the use of supraglottic devices or functional airway obstructions through muscle paralysis.

There is rarely a need for FONA in the otherwise healthy child without history and findings for a difficult airway. It may occur following airway trauma, swelling or anaphylaxis in the otherwise healthy child or rapid respiratory deterioration in a child with a known difficult airway.

Preventing the need for emergency FONA by identifying high risk patients (pre-existing concerns about the ability to oxygenate/ventilate) is essential for optimal pediatric airway management.
Early anticipation of a difficult pediatric airway allows organisation and preparation of best and appropriate ORL/ENT or surgical support. The most experienced anesthetic and surgical (ideally ORL/ENT) help should be available before induction of anesthesia except in the situation of immediate threat to life. Options available are needle or surgical cricoidotomy. Rigid bronchoscopy may also be successful in specific circumstances if facilities and expertise are immediately available. There is insufficient evidence and clinical experience to support any specific device or technique over another\textsuperscript{33-35}.

If a tracheostomy is considered as a final option after complicated and failed intubation attempts and before airway trauma makes mask ventilation impossible an emergency FONA should be declared in the paralyzed patient. An unplanned (emergency) FONA should only be considered as an option in a desperate scenario rather than a recognized effective treatment of failed airway management in children. However, elective FONA contingency planning in children with a known difficult airway may be considered before the start of a procedure.

4.4.1. Oxygenation and ventilation (Figure 2)

Saliva, blood, regurgitation or supraglottic foreign bodies can also lead to mechanical obstruction and necessitate suction and removal under direct vision using either direct laryngoscopy or videolaryngoscopy (\textbf{PLAN A}). A tracheal tube can be inserted if the larynx is visualised. Rarely, an unexpected subglottic or tracheal obstruction needs to be bypassed with a small tracheal tube or a Frova bougie and ventilation achieved using the Ventrain\textsuperscript{R} device\textsuperscript{36}. Careful lung recruitment manoeuvres are required to prevent atelectasis and to restore optimal oxygenation and ventilation following prolonged tracheal intubation attempts.

If no anatomical or mechanical obstruction is apparent during direct laryngoscopy and the trachea cannot be intubated, a supraglottic airway device or a nasopharyngeal tube should be used to overcome any potentially unrecognized anatomical upper airway problems\textsuperscript{21}. (\textbf{Plan B}) A supraglottic airway device (SAD) may be inserted before direct laryngoscopy, however, this may be unsuccessful in the presence of an intra-oral mechanical obstruction or limited mouth opening.

4.4.2. Tracheal intubation (Figure 3)
Tracheal intubation in children is usually easy in experienced hands but may be more difficult in infants and neonates. There is no consensus as to which technique or device is best suited for various clinical situations. There is continuing development of new devices, techniques and technologies requiring frequent updates to recommendations by various groups involved in pediatric airway management.

It is, therefore, impossible to develop and dictate a detailed algorithm that will be accepted by clinicians involved in pediatric airway management.

Therefore, an ‘open box algorithm’ based on local expertise and available resources is the most practical.

It is essential to recognise that oxygenation and ventilation as suggested above saves lives and prevents avoidable harm. Simple, effective mask ventilation and placement of supraglottic airway devices can be learned by all specialists involved in pediatric airway management.

Multiple tracheal intubation attempts lead to preventable harm and must be avoided\(^2,4\).

An initial tracheal intubation plan should be the daily local routine, taught and practised. This can be in the form of direct laryngoscopy or videolaryngoscopy\(^37,38\). Failure to successfully intubate should necessitate a call for assistance. Consider using a supraglottic airway device (SAD) for the procedure if tracheal intubation fails.

The anesthetic should be continued and oxygenation and ventilation maintained while **Plan A is implemented**. This should be an alternative laryngoscopy technique (videolaryngoscopy), that is locally agreed upon and regularly practised. Failure to secure tracheal intubation via this method should necessitate reconsidering the indication for tracheal intubation, potential use of a supraglottic airway or if necessary abandoning the procedure.

If local expertise and resources are available, flexible endoscopic (fibrebronchoscope) intubation (nasal, oral or via supraglottic airway device) represents **Plan B**.
4.4.3. Pediatric Airway Equipment

Safe management of the pediatric airway requires a minimum availability of suitable equipment according to national standards or recommendations. The equipment must also meet a minimum standard of performance and quality. Principles of standardisation, redundancy and safety cultures need to apply. Make and manufacturer are less relevant, but the equipment must be suitable for children and acceptable to the clinician in charge\textsuperscript{39-41}.

Individual departments need to decide on the best options based on their needs and affordability. It is essential that pediatric airway equipment is well maintained and that staff are trained regularly.

A separate difficult/emergency airway trolley should be available where children’s airways are managed. This should be adapted to locally accepted difficult airway algorithms. A one-stop ‘airway trolley’ may be the best option for some departments, with equipment separated according to age/weight. Other departments who have a dedicated ‘difficult airway’ trolley for elective procedures may choose an additional simplified ‘airway rescue’ trolley equipped according to departmental rescue algorithms. Simplicity is the key to success and overstocking must be avoided at all costs. An example of a difficult/emergency trolley setup is offered in the supplementary material and can be arranged according to the locally adapted airway algorithm and available facilities.

5. Summary

The overarching goal of an universal, consensus approach to the pediatric airway is the prevention of perioperative hypoxia in children. Prevention of intubation related complications through regular practice, teaching and training with dedicated pediatric staffing and equipment is a priority. The first crucial step after encountering difficulties is to prevent, recognize and treat ANATOMICAL/MECHANICAL and FUNCTIONAL airway obstructions with skill and drugs, respectively.

A locally accepted algorithm based on simple and common principles using local expertise with existing suitable equipment should be established. Such an approach to the pediatric airway may find acceptance across specialist pediatric specialties and pediatric anesthesia societies and groups.
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6. References


Figure legends:

**Figure 1:** Flow chart for approaching the pediatric airway in a child undergoing sedation or anesthesia for surgery, interventional or diagnostic procedures [adopted from 19].

**Figure 2:** Pediatric Oxygenation and Ventilation. Adapt according to local expertise and facilities. If appropriate, consider abandoning the attempted procedure (see Figure 1).

**Figure 3:** Pediatric Tracheal Intubation Approach. Adapt according to local expertise and facilities. If appropriate, consider abandoning the attempted procedure (see Figure 1). A failure to intubate should not result in an attempt at an emergency Front Of Neck Airway (eFONA) if oxygenation and ventilation is possible.
Table 1: Airway obstruction during anesthesia can generally be divided into an anatomical (mechanical) or functional obstruction. This distinction is important because treatments generally differ: Airway maneuvers and adjuncts for the treatment of anatomical/mechanical airway obstructions. Pharmacological interventions for functional airway obstructions.

<table>
<thead>
<tr>
<th>Causes</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate head position</td>
<td>Repositioning, re-opening</td>
</tr>
<tr>
<td>Large adenoids/ tonsils/ obesity/pharyngeal</td>
<td>Oropharyngeal/ nasopharyngeal</td>
</tr>
<tr>
<td>Difficult face mask technique</td>
<td>Two hand/ two person technique</td>
</tr>
<tr>
<td>Blood, foreign body, secretions¹</td>
<td>Suction, removal</td>
</tr>
<tr>
<td>Alveolar collaps (closing capacity)</td>
<td>Alveolar recruitment maneuvers</td>
</tr>
<tr>
<td>Gastric hyperinflation / distension</td>
<td>Decompression by an oro-gastric tube</td>
</tr>
</tbody>
</table>

Functional Airway Obstructions

<table>
<thead>
<tr>
<th>Causes</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate depth of anesthesia</td>
<td>Deepen anesthesia</td>
</tr>
<tr>
<td>Laryngospasm²</td>
<td>Propofol, muscle relaxation</td>
</tr>
<tr>
<td>Opioid induced muscle rigidity and/or vocal cord closure</td>
<td>Muscle relaxation</td>
</tr>
<tr>
<td>Bronchospasm³</td>
<td>Epinephrine, bronchodilators (sevoflurane)</td>
</tr>
</tbody>
</table>

¹Pre-existing copious secretions (upper respiratory tract infection) may benefit from a pre-induction anti-sialogue
²Minimal laryngospasm can initially be treated with jaw thrust and positive airway pressure
³Use epinephrine (titrate) in the peri-arrest situation