Assessment and management of the predicted difficult airway in babies and children

Paul A Baker

Abstract

Although it is essential to take a history and examine every child prior to airway management, preoperative anticipation of a difficult airway is not totally reliable and therefore it is wise to be prepared for the unexpected difficult airway. Information about the airway can be gained from previous medical records, current history, physical examination and other tests. A natural consequence of airway assessment is development of an airway plan. Important anatomical and physiological features may be identified in an airway assessment which can then have a direct influence on the subsequent airway plan. Managing the predicted difficult airway is usually elective. This allows proper preparation of equipment, assistants, expertise and the environment required for the airway plan. This article will discuss paediatric airway assessment, outline those features that contribute to airway difficulty, and identify indications and risk factors associated with various airway techniques. Key objectives for an airway management plan are to maintain oxygenation and avoid trauma. This involves adopting techniques that avoid hypoxia and provide a high success rate with minimum attempts.

Keywords Airtraq®; C-Mac®; difficult airway; difficult intubation; fibreoptic bronchoscope; Glidescope®; paediatric; supraglottic airway devices; TrueView®; video laryngoscope

Royal College of Anaesthetists CPD Matrix: 1C02, 2A01, 2D02

Learning objectives

After reading this article, you should be able to:

- identify a child with a predicted difficult airway
- formulate a clear plan for the management of a child with a difficult airway
- know which equipment is available, and appropriate, for use in managing the difficult paediatric airway

Infant anatomy and physiology

There are a number of key differences between the anatomy and physiology of the paediatric and adult airway and respiratory system (Tables 1 and 2) that have major implications for airway management in children.

Prediction of the difficult paediatric airway

A history and examination help predict the difficult airway and planning for the unexpected difficult airway. Pre-existing respiratory risk factors, including asthma, wheezing, upper respiratory tract infection, snoring and passive smoking, are significantly associated with critical respiratory events and this trend is independent of the chosen airway device.[1] Paediatric airway difficulty is commonly caused by functional airway problems. This group includes children with laryngospasm, aspirated foreign bodies, tonsil hypertrophy, ineffective head positioning, bronchospasm and muscle or laryngeal rigidity secondary to opioids.[2]

The use of bedside screening tests that rely on fixed endpoints, such as the thyromental distance test, are problematic in the paediatric age group, where age ranges from newborn to teenager. Uncooperative behaviour and poor compliance with instructions can render the Mallampati test inaccurate and unreliable in small children.

Knowledge of normal airway anatomy and an understanding of congenital airway anomalies are essential aspects of safe paediatric airway management. For example, ear abnormality could suggest a defect in the embryonic development of the first branchial arch, giving rise to micrognathia and airway management difficulty. Predictors of a difficult airway include a high Mallampati score, limited mouth opening, dysmorphic features, micrognathia, retrognathia, inability to prognath, poor dentition and decreased neck mobility. Signs of airway compromise include tachypnoea, stridor, use of accessory muscles, weak or absent cry, and a history of sleep apnoea or difficulty with breathing during feeding.

Children with facial abnormalities will usually have undergone a range of investigations; results will impact both on the anaesthetic management as well as the plans for postoperative care. These will include imaging (CT and MRI) and nasopharyngoscopy. Sleep studies may highlight abnormal sleep patterns and obstructive sleep apnoea.

Congenital airway anomalies are relatively rare with a prevalence ranging between 1 in 10,000 and 1 in 50,000 live births. These conditions have varied aetiology including genetic, infectious, neoplastic and environmental causes (Tables 3 and 4). Congenital anomalies can affect any part of the airway and may compromise respiratory function at multiple levels. They are frequently associated with anomalies from other organ systems, including cardiovascular, gastrointestinal and central nervous systems. Maturity may also have an impact on the airway. Children with Treacher Collins syndrome, for example, become more difficult to intubate with age, whereas Pierre Robin syndrome improves with age. Relying on past history to anticipate airway difficulty can be unreliable in these patients.

The following definition is taken from the Canadian Airway Focus Group guidelines.

A difficult airway can be defined as one where an experienced provider anticipates or encounters difficulty with any or all of face mask ventilation, direct or indirect (e.g., video)

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Anatomical features of the paediatric airway

	Infant	Practical implications
Head	Large in proportion to the rest of the body	Head positioning for intubation
Oral cavity	Grows in first year with mandible and teeth growth	Accounts for infant intubation difficulty
Face	Proportionally small in neonates due to absent paranasal sinuses	
Tongue shape	Neonatal tongue is flat with minimal lateral mobility	
Tongue size	Large relative to small oral cavity	Obstruct early, oral airway useful
Larynx appearance	Cephalad anterior, loosely embedded in surrounding structures	Easily moved with external manipulation
Larynx position	Neonates (C2/C3), Descends to C5 after 2 years.	
Larynx shape	Conical in neonates, cylindrical in older child	
Vocal cords	Shorter in neonate (50% of anterior glottis), 66% in older child	
Epiglottis	<4 months level C1–3. Long, floppy, narrow and omega shaped >6 months level C3–4 (cf adult C3–6) Hard and narrow in older patients Large and omega shaped	Straight-bladed laryngoscope useful
Narrowest part of airway	Cricoid ring in child cf. laryngeal inlet in adult glottis	Uncuffed tubes more commonly used
Hyoid bone	Prominent	Easily mistaken for thyroid cartilage
Cricothyroid membrane	Small (neonate 2.6 × 3.0 mm)	Difficult cricothyroidotomy Surgical cricothyroidotomy with tracheal tube contraindicated
Cricoid ring	Functionally narrowest part of neonatal airway Ellipsoid shape, mucosal layer susceptible to trauma	
Trachea length	5 cm in newborn, 8 cm at 1 year, 0–2 years 5.4 cm, 2–4 years 6.4 cm, 4–6 years 7.2 cm, 6–8 years 8.2 cm	Bronchial intubation more common
Carina	T2 in newborn and T4 at 1 year	

From birth to adolescence, tracheal length doubles, tracheal diameter trebles and tracheal cross-sectional area increases sixfold

Table 1

laryngoscopy, tracheal intubation, supraglottic device use, or surgical airway.[3]

Airway assessment should include every aspect of the airway. If more than one aspect of airway management is concerning, the risk increases and a suitable airway plan should be designed.[4] Appropriate equipment and assistance needs to be in place and the team need to be aware of the airway plan. A difficult intubation trolley should always be immediately available (Table 5). Lists of recommended equipment for the anticipated and unanticipated difficult intubation in children have been produced. Specific equipment lists can also be devised depending on local preference and requirements. Equipment choice is based on the principles of standardization (to avoid duplication and clutter), redundancy (to provide back-up), and a culture of safety to ensure safe functional equipment at all times.

Physiological features of the paediatric airway

High metabolic rate, 7–9 ml/kg/min	Rapid oxygen desaturation with apnoea or obstruction
Closing capacity relatively high	Rapid oxygen desaturation with apnoea or obstruction
Functional residual capacity (FRC) low	Rapid oxygen desaturation with apnoea or obstruction
Diaphragmatic breathers	Diaphragmatic splinting will compromise ventilation

Table 2

Preparation

An oral sedative can be useful in the anxious child provided there is no sign of imminent airway obstruction. In some circumstances, H_2-blocking drugs and metoclopramide should be considered to mitigate gastro-oesophageal reflux and aspiration. Anticholinergics are occasionally used to decrease secretions and the chance of laryngospasm.

Induction and maintenance of anaesthesia

The safest way to manage a difficult airway is with an awake child. This may not be practical in the uncooperative paediatric patient, but variants of this technique can be used in neonates and infants. Insertion of a supraglottic airway (SGA) is a safe technique for early establishment of an airway in an awake neonate. This technique avoids hypoxia during induction of anaesthesia and has been successfully used in patients with Pierre Robin syndrome and Treacher Collins syndrome. Following application of local anaesthetic, the SGA is inserted, and the neonate then receives a gas induction followed by tracheal intubation with an ultrathin, flexible bronchoscope and an appropriate size tracheal tube.[5] Older children may be able to cooperate for an awake fibreoptic intubation. The parents and child should be informed of the risks associated with the difficult airway, for example local trauma, airway swelling, bleeding, pain and possible failure of the airway management plan, which may lead to a tracheostomy in certain cases.

Anatomical approach to congenital airway anomalies

Anatomical site	Condition	Anomalies	Difficulty
Nasal malformations	CHARGE syndrome	Coloboma Heart defect Atresia of the choanae Retarded growth Genitourinary abnormalities Ear defects	
	Choanal atresia	If bilateral can cause severe airway obstruction	May require positioning and an oropharyngeal airway
	Crouzon syndrome	Maxillary hypoplasia, small nasopharynx, proptosis, midface retrofusion and craniosynostosis	
	Apert syndrome	Choanal atresia, midface hypoplasia, saddle nose, high arched palate	
	Piriform aperture stenosis	Single central incisor, boney overgrowth of the maxilla	
	Pfeiffer syndrome	Midface hypoplasia, vertebral fusion, beaked nose, congenital tracheal stenosis	BMV, DTI
	Nasal dermoid cyst, gliomas, encephalocoeles		BMV, DL, DTI. Avoid nasal intubation
Neck and head anomalies	Hydrocephalus, encephalocele and mucopolysaccharidosis Cervical spine instability seen in Down's syndrome, mucopolysaccharidosis		BMV difficulty Access to DL BMV, DL, DTI
	Neck anomalies including Klippel Feil syndrome	Congenital fusion of at least two cervical vertebrae.	Progressive syndrome. May present difficulty later in life. DL, DTI
	Goldenhaar syndrome	Usually unilateral. Facial, mandibular and tongue anomalies	DL, BMV, DTI
	Congenital neck tumours including teratomas and cystic hygromas Conjoined twins	Lesions can develop in utero causing airway obstruction	May require an EXIT procedure Requires meticulous planning. Positioning
	Congenital microstomia (Freeman—Sheldon and Hallerman-Streiff and otopalatodigital syndromes)		DL and DTI difficult. May require flexible bronchoscopy
	Macroglossia, haemangioma and lymphangioma, lipid storage disease, neurofibromatosis and Beckwith-Wiedemann, Down's syndrome	Risk of airway obstruction, particularly immediately after induction of anaesthesia. If macroglossia, macrocephaly, cervical and mandibular anomalies co-exist, consider preparation for a surgical airway	BMV, DL, DTI
Mandibular hypoplasia			

BMV, bag mask ventilation; DTI, difficult tracheal intubation; DL, difficult laryngoscopy.

Table 3

Inhalational induction is well tolerated by most children. Special circumstances require modifications from the supine position. An inhalation induction for a child with a symptomatic mediastinal mass includes careful positioning to optimize breathing. This could involve a sitting position and a prolonged induction time. A carefully titrated intravenous (IV) induction using propofol and/or remifentanil with the aim of maintaining spontaneous ventilation may be also suitable, but great care should be taken to maintain spontaneous ventilation and avoid airway obstruction and awareness.

Neuromuscular blocking drugs (NMBDs) can be beneficial for patients with functional airway obstruction, such as laryngospasm, and muscle rigidity secondary to opioids.[2] Mask ventilation and tracheal intubation conditions may improve with

Some conditions associated with difficulties in airway management

	Syndrome/Condition	Airway features	Effect of increasing age
Congenital			
Craniofacial branchial arch mal-development	Pierre Robin syndrome	Cleft palate, micrognathia, glossoptosis	May improve with age
	Treacher Collins syndrome	Micrognathia, aplastic zygoma, choanal atresia, microstomia, cleft palate SGA placement under local anaesthetic and flexible bronchoscopy and intubation is an option for tracheal intubation	May be more difficult with increasing age
	Goldenhaar's syndrome	Hemifacial hypoplasia, cervical spine anomalies. mandibular hypoplasia	May be more difficult with increasing age
Lysosomal enzyme defects	Mucopolysaccharidoses Seven hereditary conditions including Hunter's, Hurler's and Morquio's syndromes. Overall incidence of difficult intubation 25%, and in Hurler's syndrome 54% 20—30% mortality secondary to failed intubation	Group of disorders with progressive tissue thickening due to deposition of lysosomes in cells of the upper airway, e.g. Hurler's syndrome Those with OSA are at increased risk of airway obstruction	Progressive disease with worsening airway problems
Congenital swellings	Cystic hygroma	Can affect tongue, pharynx and neck, may cause gross distortion of the anatomy	Increase in size and number of cysts if no surgical intervention
Cervical spine anomalies	Trisomy 21 Incidence of airway difficulties 4.6%	Atlanto-occipital instability, subglottic narrowing, macroglossia, small mouth. Prone to OSA. Bradycardia and hypotension during Sevoflurane anaesthesia is common (57%), independent of CHD	
	Klippel—Feil syndrome	Failure of cervical vertebrae segmentation during fetal development. Includes at least two cervical vertebrae. Commonest fusion is of C2,3 Short neck, restricted mobility of the upper spine.	The syndrome is progressive, with disc degeneration and cervical stenosis. Difficulty may not arise until later in life.
Acquired			
Burns	Thermal/chemical/post radiation		Airway swelling can occur early. Evidence of airway burn is an indication for early intubation
Infection	Epiglottitis, croup, bacterial tracheitis, diphtheria, retropharyngeal abscess Neonatal	TMJ fusion	

(*continued on next page*)

Table 4 (*continued*)

	Syndrome/Condition	Airway features	Effect of increasing age
Tumour	Papillomatosis	Recurrent respiratory papillomatosis (RPP) is the most common benign neoplasm of the larynx in children. It is an infectious disease contracted during birth from human papilloma virus (HPV 6 and 11) infected mothers. RRP is the second most common cause of hoarseness in childhood after vocal cord nodules	The disease tends to recur and spread after removal. Treatment is with CO_2 laser microlaryngoscopy. Complete airway obstruction can occur on induction of anaesthesia and appropriate equipment and expertise is required
	Mediastinal masses	Anterior mediastinal masses are associated with airway obstruction and haemodynamic instability. The patient may be difficult to ventilate and anaesthesia should be avoided, if possible Patient posture is important: sitting, reverse Trendelenburg, or even prone position may relieve airway obstruction. Gas induction using sevoflurane and oxygen—helium mixture (20:80%) may be prolonged and is conducted in the best breathing position for the patient Spontaneous ventilation is maintained, muscle relaxants are avoided, rigid bronchoscopy is considered and femoral—femoral bypass is planned	Some mediastinal masses grow rapidly with short cell doubling times. Without treatment, airway obstruction is progressive
	Laryngeal cysts can present with airway obstruction, including saccular cysts, vallecular cysts, thyroglossal cysts, ductal cysts and laryngoceles.	Airway management may be complicated by airway obstruction, difficult BMV, and DTI. Planning in advance for a surgical airway may be required	
Post surgery/trauma	Post cervical fixation or post maxillofacial surgery		
Joint problems	Still's disease	TMJ ankylosis, cervical spine instability	Condition can deteriorate with time. Stiff TMJ and cervical spine cause difficult intubation
Tracheal abnormalities	Subglottic stenosis (can be congenital or acquired)		

CHD, congenital heart disease; TMJ, temporomandibular joint.

Table 4

Recommended equipment for management of difficult intubation (in addition to equipment available in the anaesthetic induction area)

Equipment	Advantage	Tips and tricks of use
Endoscopy mask for FOI cf. VBM	Allows oxygenation and ventilation during intubation	Get the best fit with a large soft cushion
Swivel connectors cf. VBM	Used with LMA or facemask	Made with various sized holes for FOI
Tube introducers, gum elastic bougies	Wide range available	Choose one that fits the tube snugly
Flexible bronchoscope and light source	See Table 6	Needs to be sterilized prior to use
		Choose one that fits the tube snugly
Intubating laryngeal mask		Available in size 3, 4 and 5 only
AirQ® intubating laryngeal mask	Wide range from neonatal up	Available from 0.5 to 4.5
Pro-Seal LMA		
Alternative laryngoscope blades, e.g. Miller, McCoy	Useful to have a selection	
Polio handle		Polio handle useful if the neck is fixed, or the child is in a plaster jacket so access is difficult
Alternative laryngoscopes cf. Airtraq, Glidescope or other video laryngoscope	Lots of different equipment on the market for paediatric use	Need to practise with equipment available in your hospital
		Easily portable
Cook exchange catheter		Care with choosing size. Use one with a snug fit
Guidewires for FOI for use via the suction channel or for retrograde intubation		Use long wires of various diameters, check wire will pass through the FOS suction channel
Cricothyroid equipment: cannula, e.g. 14G/16G Ravussin, Portex Mini Trac 4 mm internal diameter tube		Practice on manikin Check you have the equipment to ventilate with these

FBI, flexible bronchoscope intubation; FB, flexible bronchoscope; LMA, laryngeal mask airway; VBM Medizintechnik (Sulz, Germany).

Table 5

NMBDs. Conversely, patients with distal airway obstruction, including tracheomalacia, mucopolysaccharidosis and mediastinal masses, should not be paralyzed. Extrinsic airway compression is exacerbated, diaphragmatic movement is eliminated, large airway compression increases and expiratory flow rates decrease when paralyzed.

Sugammadex rapidly reverses the action of rocuronium providing a faster onset—offset profile than that seen with succinylcholine during a rapid sequence induction. If the patient remains impossible to intubate, despite a limited number of optimal attempts, and the patient is still adequately oxygenated, the appropriate action is to wake the patient up and reverse neuromuscular blockade using sugammadex. If it is impossible to intubate and ventilate (CICV) the patient, an emergency surgical airway is required. Oxygenation of the patient remains the priority in this situation and the administration of sugammadex should not delay this urgent requirement. One should also be mindful that reversal of neuromuscular blockade could make ventilation, intubation, or a surgical airway more difficult, and a delay in the management of oxygenation could have a detrimental effect. The administration of sugammadex may fail to adequately restore spontaneous ventilation in a timely manner during a CICV situation. The reversal of other administered drugs such as intravenous induction agents, opioids and volatile agents should also be considered.

A child may become apnoeic with either an intravenous or gas induction. Never assume that a child's airway will remain patent, as the muscles of the tongue and pharynx relax on induction. The airway may become obstructed early, making it difficult to increase the depth of anaesthesia. For this reason some favour a total intravenous anaesthesia (TIVA) technique with propofol and remifentanil or alfentanil to ensure adequate depth of anaesthesia throughout. It may be necessary to use an airway adjunct, e.g. a Guedel oropharyngeal airway, in order to maintain anaesthesia, and this may be necessary prior to gaining IV access.

Once anaesthetized, airway management is dictated by physiological factors in the child and the surgical requirements. In many circumstances tracheal tube placement is not required and the airway can be managed with a SGA. Repeated intubation attempts are traumatic and associated with significant morbidity, and should be avoided. Two large multicentre studies from Europe and North America have shown that children who receive more than two attempts at tracheal intubation or supraglottic airway insertion suffer significantly more severe respiratory critical events.[1,6] If difficulties arise, senior help should be sought early. The practical way in which the anaesthetist plans to manage the paediatric difficult airway depends on his or her set of skills and experience.

Bag mask ventilation

This is a corner stone of airway management and a position of safety when other techniques fail. Difficult ventilation is primarily caused by airway narrowing. Laryngomalacia, which is an

example of a collapsible upper airway in a child, can benefit from continuous positive airway pressure (CPAP), which stents the airway and increases functional residual capacity. Inhalation induction can be challenging in the child with a difficult airway, particularly in children with a history of obstructive sleep apnoea caused by tonsil hypertrophy or micrognathia. Optimum bag mask ventilation (BMV) may be required. This includes manoeuvres such as head positioning, chin lift, jaw thrust and oropharyngeal airways. An assistant may be required to inflate the lungs. Of the airway manoeuvres, jaw thrust is the most effective. Predicted difficult ventilation during induction for an infant can be avoided by awake placement of a SGA under local anaesthetic.

Difficult laryngoscopy

Although the incidence of difficult laryngoscopy is lower in children than in adults (1.37 vs 9%), the incidence of difficult laryngoscopy in infants is significantly higher than in older children (4.7 vs 0.7%). Other risk factors for difficult laryngoscopy include children undergoing cardiac and oromaxillofacial surgery, ASA physical status III and IV, Mallampati III and IV and children with a low BMI.[7] The incidence of difficult laryngoscopy is doubled in children undergoing cardiac anaesthesia due to the relatively high incidence of concomitant congenital syndromes such as CHARGE and DiGeorge.

Prolonged intubation attempts in the difficult airway are associated with awareness and hypoxia. Techniques such as TIVA and nasal oxygen can be used to minimize these complications.[8] Optimum intubation attempts are associated with laryngoscope selection, positioning and the use of intubating introducers. Laryngoscope blades vary in length and shape. The ideal blade depends on the size and anatomy of the patient and the expertise of the practitioner. For example, a straight blade paraglossal approach with a bougie can be successful for infants with Pierre Robin syndrome. Neonates with proportionally large heads may improve with a pad behind their shoulders, where older children do not need head positioning, and teenagers improve with a pillow behind their head.

It is now clear that multiple tracheal intubation attempts are associated with increased morbidity. It has also been shown that three direct laryngoscopy attempts before resorting to an indirect attempt is a risk factor for increased morbidity, along with a child's weight of <10 kg and a relatively short thyromental distance.[6]

Success rates for various intubation techniques are age dependent, with significantly lower success recorded for all methods in children less than 10 kg. Data taken from the Paediatric Difficult Intubation (PeDI) registry suggests that tracheal intubation with a flexible bronchoscope through a SGA is associated with the highest success rate in those <10 kg.

Paediatric tracheal tubes

There are a number of important issues concerning tracheal tubes (TT) in paediatrics which should be considered, e.g. the outer diameter of TTs (note that the TT is measured by its internal diameter (ID)), the cuff design and cuff placement and cuff pressures. Cuffed TTs do not increase the risk of post extubation stridor compared with uncuffed TTs, they reliably seal the airway at cuff pressures of ≤ 20 cm H_2O and reduce the need for TT exchanges.

Supraglottic airways

Laryngeal mask airway (LMA) failure rate in children was 0.86% and is lower than adults (1.1%).[9] Independent risk factors associated with failure include ear, nose and throat surgery, non-outpatient admission status, prolonged surgical duration, congenital/acquired airway abnormality and patient transport.[10]

Supraglottic airway devices are effective as primary airway devices during elective anaesthesia in children with normal airways and as a rescue ventilation device during failed tracheal intubation. SGAs can also reliably provide a clear airway in some children with known difficult airways, but universal application of SGAs for any child with a difficult airway has not been proven. The use of a SGA as a conduit for tracheal intubation in children is now recommended in airway management guidelines and has been described as either a blind intubation technique through the Air-Q™ (Cookgas LLC; Saint Louis, MO, USA), or as a conduit for flexible bronchoscopy.[11,12] SGAs remain contraindicated in children at increased risk of pulmonary aspiration although a modified rapid sequence induction technique following awake insertion of the Air-Q™ has been described.[13] Other contraindications for SGAs include children with distal airway collapse (mediastinal masses), raised distal airway pressure including asthma and victims of drowning, children with a partially collapsible lower airway, such as tracheomalacia and children with very limited mouth opening. Specific SGAs have been designed for paediatric use.[14] The Ambu Aura-I and the i-gel both function as airway devices and conduits for tracheal intubation.

Video laryngoscopes

Video laryngoscopes integrate video technology with laryngoscopy providing real-time images during intubation from the tip of the blade and displaying them on monitors. Compared to direct laryngoscopy, videolaryngoscopes usually provide a better view of the larynx due to the wide optical angle of view. Intubation times can be longer than direct laryngoscopy, secondary to difficulty manipulating the TT through the vocal cords and also occasional impingement of the TT on the cricoid ring. If this occurs, slightly withdraw the blade of the videolaryngoscope to provide a flatter approach to the glottis, and advance the tracheal tube with a clockwise rotation.[15] Use of a bougie or stylet may assist tube delivery, and TT design and manipulation can help tracheal intubation. Particularly difficult tracheal intubations can be successful by combining videolaryngoscopy and flexible bronchoscopy techniques.

Examples of paediatric videolaryngoscopes include the GlideScope® videolaryngoscope® (Verathon Inc. Bothwell, WA, USA), Airtraq® (Prodol, Vizcaya, Spain), C-Mac® (Karl Storz Endoscopy; Tuttlingen, Germany) and TrueView® (Truphatek, Netanya, Israel).

Glidescope®

This video laryngoscope provides laryngoscopic views at least equal to if not better than conventional laryngoscopy, both in adults and children. It consists of a video monitor attached to a reusable video baton. A disposable blade is in turn attached to the video baton. The single-use blades come in five sizes (0, 1, 2, 3, and 4). Sizes 0 to 3 cover the paediatric population. The

blade has an angulated tip, thus reducing the degree of angulation needed on the blade handle. It is advised that the tracheal tube is mounted onto a stylet to improve tracheal intubation success. Care must be taken to avoid oral trauma with the intubating stylet. A reasonable amount of mouth opening is required for the use of the Glidescope®. In children with small mouths, it may sometimes pose a challenge to manipulate both the baton and the tracheal tube within a limited space.

C-Mac®

C-Mac® is available in paediatric sizes (Miller 0 and 1, Macintosh 2 and 3 and a paediatric D-blade which is a hyper-angulated Macintosh style blade). A camera at the tip of the laryngoscope blade provides an 80° angle of vision. The blades can be sterilized and fitted to a reusable handle. The image is projected on to a portable video-monitor or a hand-held screen. Intubation can be enhanced with a bougie or stylet. The D-blade has a channel that can be used to hold an oxygen catheter.

TrueView® infant EVO_2

TrueView® infant EVO_2 is recommended for children 1–10 kg. It is based on a prism optical rod with an optical lens and an angulated blade tip that provides a wide magnified laryngeal view of 46° anterior refracted angle. The blade is narrow with a very low profile, incorporating an oxygen port (flow 2–5 L/min) to reduce hypoxia and prevent fogging. The laryngoscope comes with a stylet (OptiShape™) to provide control and rigidity to the independently advancing tracheal tube.

Airtraq®

This device comes in two paediatric sizes, 0 (infant) taking a TT of ID 2.5–3.5 and 1 (paediatric) taking a tracheal tube size of ID 3.5–5.5 cuffed or uncuffed. There are also two further sizes, 2 (small) and 3 (regular). The advantage of the Airtraq® is that the TT is loaded onto the device itself, thereby not overcrowding an already small space. The device can be attached to a screen for teaching purposes or can be viewed through an eyepiece by the person intubating. The device has an integral light source. Once the child's trachea has been intubated, ventilation can commence even prior to disengagement of the tracheal tube from the device. A device for nasal intubations is also available, but exists in only one size.

Optical stylets for paediatric airway management include the Storz Brambrink and the medium size Bonfils (Karl Storz Endoscopy; Tuttlingen, Germany), and the paediatric Shikani Optical Stylet (S.O.S.)™ (Clarus Medical; Minneapolis, MN, USA). These devices rely on space within the oral cavity in order to advance the optical stylet to the larynx. This can be achieved by manually lifting the mandible and clearing the tongue away from the posterior pharyngeal wall, or using a laryngoscope to achieve the same result. Optical stylets can be useful to intubate the difficult airway with limited upper airway space and/or partially occluding oral lesions.

Cook exchange catheter (CEC): the CEC is a small hollow catheter that can remain in place in the airway, allowing the administration of oxygen via continuous flow during airway exchange manoeuvers. The CEC is useful for changing the TT, and is also used during flexible bronchoscopy with a wire technique. Rapifit connectors are provided for oxygen insufflation through the CEC by either a re-breathing bag or a jet ventilator. Extreme caution is required when using oxygen down the CEC because of the high risk of barotrauma, and therefore it is not recommended to use oxygen down these catheters. Nasal oxygen is a preferred technique.

Retrograde intubation: A percutaneous needle is placed into the trachea via the cricothyroid membrane. A wire is advanced superiorly into the pharynx. It is then used to railroad either a small TT or a bronchoscope via the suction port to aid visualization of the larynx and so feed a TT over the wire (an exchange catheter may be useful) and into the trachea. An airway exchange catheter may be required for larger patients where the gap between the inside of the tracheal tube and the wire is excessive. Retrograde intubation is rarely required, but has been shown to be of particular use in patients with occlusive upper airway lesions, mucopolysaccharidoses, severe burns, base of tongue lesions and airway debris including blood, pus and sputum.

The flexible bronchoscope

Skill with a flexible bronchoscope is essential to manage paediatric patients with difficult airways (Table 6). Results from the Paediatric Difficult Intubation (PeDI) registry confirm superior tracheal intubation first pass success with the flexible bronchoscope compared to direct laryngoscopy, particularly in those <10 kg. Children with limited mouth opening, distorted anatomy, requiring intubation through the nose or conduits, confirmation of tracheal intubation and examination of the upper and lower airway are all indications for a flexible bronchoscope. Flexible bronchoscopes are available in a range of sizes and are designed for different applications. For example, ultra-thin or neonatal bronchoscopes (2.2 mm diameter) allow a size ID 3.0 mm TT, but lack a working channel. Flexible bronchoscopes should be accompanied by ancillary equipment to avoid hypoxia and facilitate intubation, including light sources, bronchoscopy swivel connectors, endoscopy masks, intubating airways, wires, and equipment to apply local anaesthetic to the patient's airway.[16] Inexperienced users of the flexible bronchoscope may find the nasal route easier for intubation.

The following techniques with the flexible bronchoscope incorporate a method to maintain gas exchange (oxygen and volatile).

- Flexible bronchoscopy via an endoscopy mask and an endoscopic oral airway or a split nasal airway.

Paediatric flexible bronchoscopes

Scope External diameter	Tracheal tube Internal diameter	Suction channel	Features	Ease of use
2.2 mm	2.5 mm	–	Delicate	Very pliable, easily misplaced
2.5 mm	3.0 mm	✓	More robust	✓
3.8 mm	4.5 mm	✓	Better optics	✓

Table 6

- Flexible bronchoscopy via a SGA (cLMA™, Air-Q™, ProSeal™) using a swivel connector and an Aintree intubation catheter.
- Flexible bronchoscopy via an ILMA™ and a swivel connector (note the ILMA™ is only suitable for children >30 kg). The ILMA™ is available in sizes 3, 4 and 5, allowing the passage of a size 6 mm internal diameter Euromedical tracheal tube; it is of particular use in older children with cervical pathology, and limited neck mobility.
- Paediatric flexible bronchoscopy with an adult size bronchoscope, via a swivel connector, a cLMA™, and a 145 cm 0.038 inch wire (Newton cerebral wire, Cook Critical Care; Bloomington, USA).
- Combined flexible bronchoscope and video-laryngoscope technique is providing superior success rates (GlideScope alone 68% compared with 81% for Glidescope in combination with a flexible bronchoscope).[17]
- **EXIT procedure:** The EX utero Intrapartum Treatment (EXIT) procedure is performed by a multidisciplinary team during Caesarean section. It is indicated when the neonate's airway is at significant risk of severe obstruction immediately after birth. The technique allows the fetus to be partially delivered and the airway to be controlled while placental perfusion is maintained. Indications include lung or mediastinal tumours, severe micrognathia, congenital high airway obstruction syndromes (CHAOS), EXIT to extra-corporeal membrane oxygenation (ECMO) for certain congenital cardiac conditions and congenital cystic adenomatoid malformation (CCAM).

Tracheostomy: In the difficult airway scenario a tracheostomy may be required to provide a long-term safe airway or may be useful to facilitate major surgery such as craniofacial, maxillofacial or cervical surgery. Paediatric tracheostomy can be technically difficult especially in the very young. Tracheostomy in children does have associated morbidity and mortality and this must be discussed with the family. Overall, complications occur in up to 30% of paediatric patients related to tracheostomies. Complications include failure of placement, trauma, bleeding, pneumothorax, pneumomediastinum, subcutaneous emphysema, accidental decannulation, and displacement or blockage of the tracheal tube. In addition to these, later complications include tracheal stenosis, difficulty with decannulation, granulation formation, subglottic stenosis and long-term speech damage. Direct tracheostomy-related mortality is somewhere between 0.5% and 2.5%. Anaesthesia for a tracheostomy can be achieved with tracheal intubation or if this is anticipated to be difficult, a tracheostomy can be done using a SGA, nasopharyngeal airway or a facemask.

Paediatric CICO: Management of CICO in children has received recent attention. A management protocol and algorithm proposed by Weiss and Engelhardt suggests surgical cricothyroidotomy for all ages, cannula cricothyroidotomy for patients over eight years and surgical tracheostomy and rigid bronchoscopy if expertise and equipment is available.[18] Little clinical evidence exists to support these recommendations. There are only seven cases of paediatric emergency transtracheal cannula ventilation reported since 1950. The Association of Paediatric Anaesthetists of Great Britain and Ireland in conjunction with the Difficult Airway Society released three consensus documents, one of which considered CICO in a paralysed child aged 1–8 years.[19] This algorithm recommends surgical tracheostomy or rigid bronchoscopy if ear nose and throat surgeons are available. If this fails, surgical cricothyroidotomy with low pressure ventilation through an endotracheal or tracheostomy tube is recommended. Cricothyroidotomy for infants and neonates is contraindicated because of the high risk of severe laryngeal trauma. In this age group an emergency surgical tracheotomy can be performed with a longitudinal midline incision and insertion of a small size 3.0 tracheal tube to allow ventilation with an anaesthetic circuit or self-inflating bag. An animal study used piglets to compared needle cricothyroidotomy and surgical tracheotomy following a training session with anaesthetists. The success rate was highest for surgical tracheotomy.[20] Complications were highest for needle techniques. Training should be available on manikins in case an eFONA procedure is required. On the rare occasion where this situation arises, it is important that an airway ENT surgeon is notified early.

Extubation

Extubation is a time of increased risk of laryngeal spasm, coughing and stridor. Patients, in whom the airway has been difficult to manage, should be extubated awake in a controlled setting. There should be a clear plan for the immediate post-extubation period and expertise must be available to reintubate at any moment. Extubation guidelines for adult anaesthesia have been published.[21] It is important to avoid disturbing the child during extubation as this will minimize coughing and the risk of laryngospasm and airway complications. Intravenous lidocaine has been shown to decrease the risk of breath holding and laryngospasm at extubation with a dose of 1–2 mg/kg given just prior to extubation. Similarly, lignocaine spray at intubation may decrease adverse events during extubation, including laryngospasm and stridor. Laryngospasm is a common adverse event in paediatric anaesthesia with associated morbidity and mortality. It should be avoided if possible by careful extubation practice. Treatment includes 100% oxygen with continuous positive airway pressure (CPAP), eliminating the stimulus and deepening anaesthesia with propofol or volatile agents, and suxamethonium for persistent laryngospasm.

Stridor can be treated with 'CASH' (CPAP, adrenaline, steroids and helium). Continuous positive airway pressure (CPAP), adrenaline (nebulized adrenaline, 400 μg/kg; maximum 5 mg [5 ml of 1:1000] with electrocardiograph monitoring), steroids (Dexamethasone at 0.6 mg/kg IV. can be given to decrease swelling of the airway), and helium blended with oxygen 30–50% FiO_2. Occasionally, it will be necessary to maintain tracheal intubation if extubation is anticipated to be impossible, and the child will need to be transferred to a paediatric intensive care unit for stabilization prior to extubation.

Treatment with oxygen for the unconscious patient during transport from the operating room to the post-anaesthetic care unit (PACU) is recommended to avoid hypoxia.[22] Adding a pulse oximeter plus oxygen during transport has been shown to eliminate hypoxia on arrival in PACU.[23] Also, improved monitoring

in PACU using capnography is another mechanism to detect hypoventilation and potential hypoxic events.[24]

Conclusion

All of the techniques described in this article require practice. Familiarize yourself with the different techniques required for each potential scenario. First, practice on manikins in the simulation scenario; second, on the 'normal' airway; and, third, on the difficult airway. Training is paramount, and is surpassed only by preparation for the difficult airway. The three Ps of the paediatric difficult airway are planning, preparation and practice. ◆

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